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## Standard Guide for Design of Earthen Wall Building Systems<sup>1</sup>

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### 1. Scope

1.1 This standard provides guidance for earthen building systems, also called earthen construction, and addresses both technical requirements and considerations for sustainable development. Earthen building systems include adobe, rammed earth, cob, cast earth, and other earthen building technologies used as structural and non-structural wall systems.

NOTE 1—Other earthen building systems not specifically described in these guidelines, as well as domed, vaulted, and arched earthen structures as are common in many areas, can also make use of these guidelines when consistent with successful local building traditions or engineering judgment.

1.1.1 There are many decisions in the design and construction of a building that can contribute to the maintenance of ecosystem components and functions for future generations. One such decision is the selection of products for use in the building. This guide addresses sustainability issues related to the use of earthen wall building systems.

1.1.2 The considerations for sustainable development relative to earthen wall building systems are categorized as follows: materials (product feedstock), manufacturing process, operational performance (product installed), and indoor environmental quality (IEQ).

1.1.3 The technical requirements for earthen building systems are categorized as follows: design criteria, structural and non-structural systems, and structural and non-structural components.

1.2 Provisions of this guide do not apply to materials and products used in architectural cast stone (see Specification C1364).

1.3 The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

<sup>1</sup> This guide is under the jurisdiction of ASTM Committee E60 on Sustainability and is the direct responsibility of Subcommittee E60.01 on Buildings and Construction. Current edition approved Sept. 1, 2016/Dec. 1, 2023. Published September 2016/December 2023. Originally approved in 2005. Last previous edition approved in 2010/2016 as E2392/E2392M – 10 (2016)<sup>1</sup>; DOI: 10.1520/E2392\_E2392M-10R16; 10.1520/E2392\_E2392M-23.

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

- C1364 Specification for Architectural Cast Stone
- D2487 Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
- E631 Terminology of Building Constructions
- E2114 Terminology for Sustainability

### 2.2 ASCE Standards:<sup>3</sup>

- ANSI/ASCE 7 Minimum Design Loads for Buildings and Other Structures

### 2.3 New Zealand Standards:<sup>4</sup>

- NZS 4297:1998 Engineering Design of Earth Buildings, 1998
- NZS 4298:1998 Materials and Workmanship for Earth Buildings, 1998
- NZS 4299:1998 New Zealand Standard, Earth Buildings not requiring Specific Design, 1998 (including amendment #1, December 1999)

## 3. Terminology

### 3.1 Definitions:

3.1.1 For terms related to building construction, refer to Terminology E631.

3.1.2 For terms related to sustainability relative to the performance of buildings, refer to Terminology E2114. Some of these terms are reprinted here for ease of use.

3.1.3 *alternative agricultural products, n*—bio-based industrial products (non-food, non-feed) manufactured from agricultural materials and animal by-products.

3.1.4 *biodegradable, adj*—capable of decomposing under natural conditions into elements found in nature.

3.1.5 *biodiversity, n*—the variability among living organisms from all sources including: terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems.

3.1.4 *ecosystem, n*—a community of biological organisms and their physical environment, functioning together as an interdependent unit within a defined area.

#### 3.1.4.1 Discussion—

For the purposes of this definition, humans, animals, plants, and microorganisms are individually all considered biological organisms.

3.1.5 *embodied energy, n*—the energy used through the life cycle of a material or product to extract, refine, process, fabricate, transport, install, commission, utilize, maintain, remove, and ultimately recycle or dispose of the substances comprising the item.

#### 3.1.5.1 Discussion—

The total energy which a product may be said to “contain” including all energy used in, inter alia, growing, extracting, transporting and manufacturing. The embodied energy of a structure or system includes the embodied energy of its components plus the energy used in construction.

3.1.6 *indoor environmental quality, IEQ, n*—the condition or state of the indoor environment.

#### 3.1.6.1 Discussion—

Aspects of IEQ include but are not limited to characteristics of the thermal, air, luminous and acoustic environment. Primary areas of concern in considering the IEQ usually relate to the health, comfort and productivity of the occupants within the indoor environment, but may also relate to potential damage to property, such as sensitive equipment or artifacts.

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard’s Document Summary page on the ASTM website.

<sup>3</sup> Available from American Society of Civil Engineers (ASCE), 1801 Alexander Bell Dr., Reston, VA 20191, <http://www.asce.org>.

<sup>4</sup> Available from Standards New Zealand, Ministry of Business, Innovation & Employment, 15 Stout Street, Wellington 6011, <http://www.standards.govt.nz>.

3.1.7 *renewable resource*, *n*—a resource that is grown, naturally replenished, or cleansed, at a rate which exceeds depletion of the usable supply of that resource.

3.1.7.1 *Discussion*—

A renewable resource can be exhausted if improperly managed. However, a renewable resource can last indefinitely with proper stewardship. Examples include: trees in forests, grasses in grasslands, and fertile soil.

3.1.8 *sustainability*, *n*—the maintenance of ecosystem components and functions for future generations.

3.1.9 *sustainable development*, *n*—development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

~~3.1.12 *toxicity*, *n*—the property of a material, or combination of materials, to adversely affect organisms.~~

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *adobe*, *n*—(1) (*building product*), unfired masonry units made of soil, water, and sometimes straw or other admixtures; (2) (*product feedstock*), the soil/straw/admixtures mix that is used to make *adobe* (1), (here also called *earthen building mixtures* or *earthen material*;

(3) (*building product*), the earth plaster used for covering walls or ceilings, or both;

(4) (*structure*), the building that is built of *adobe* (1), (3); and

(5) (*building design*), an architectural style of earthen construction (see also 3.2.9).

3.2.1.1 *Discussion*—

The word itself comes from an Arabic word *atob*, which means muck or sticky glob or *atubah* “the brick.” In many other countries, the word “adobe” is meaningless, and it is more accurate to say “earthen-brick.” “Adobe architecture” also has different meanings in different places.

3.2.2 *asphalt emulsion*, *n*—a thick liquid made by combining by-products of crude oil distillation with water and proprietary surfactants.

3.2.3 *cast earth*, *n*—a construction system utilizing a slurry containing soil plus a chemical binder such as portland cement or calcined gypsum and water, which is sprayed against or poured into forms similar to those used for cast-in-place concrete; also called *poured earth*.

3.2.3.1 *Discussion*—

In the sprayed system, modern shotcrete equipment is adapted to spray the wet earth mixture, which is usually stabilized earth.

3.2.4 *clay*, *n*—inorganic soil with particle sizes less than 0.002 mm [0.00008 in.] having the characteristics of high to very high dry strength and medium to high plasticity.

3.2.4.1 *Discussion*—

This size definition for clay, along with those for silt, sand and gravel, is according to Practice D2487. Other standards in the world have slightly different size limitations.

3.2.5 *cob*, *n*—a construction system utilizing moist earthen material stacked without formwork and lightly tamped into place to form monolithic walls.

3.2.5.1 *Discussion*—

Reinforcing is often provided with organic fibrous materials such as straw.

3.2.6 *earth*, *n*—granular material derived from rock, usually with air voids and often with organic content (humus) (also called *soil*).

3.2.7 *earth, stabilized*, *n*—earthen building mixtures to which admixtures are added during the manufacturing process to help limit water absorption, stabilize volume, increase strength, and increase durability (see also *stabilization*).

3.2.8 *earth, unstabilized*, *n*—earthen building mixtures that do not contain admixtures intended to help limit water absorption, stabilize volume, increase strength, and increase durability (see also *stabilization*).

3.2.9 *earthen construction, n*—construction in which walls and partitions are comprised primarily of earth.

3.2.9.1 *Discussion*—

Roofs and other framing may be wholly or partly of wood or other materials. Common earthen construction systems go by many names, which sometimes connote minor variations. Some of those names are:

*adobe, or mud brick, earthen brick, banco, butabu, brique de terre*  
*cast earth, or poured earth, earthcrete, sprayed earth*  
*cob, or zabur, puddled mud, puddled earth*  
*extruded earth block*  
*pressed brick, or compressed earth brick/block (CEB)*  
*rammed earth, or pisé, tapial*  
*sod, or turf, fale and divet*  
*tire houses, also earth bags, earth tubes*  
*wattle and daub, or quincha, jacal, barjareque, nyumba yo mata*

3.2.10 *energy efficient, adj*—refers to a product that requires less energy to manufacture or uses less energy when operating in comparison with a benchmark for energy use, or both.

3.2.10.1 *Discussion*—

For example, the product may meet a recognized benchmark, such as the EPA’s Energy Star Program standards.

3.2.11 *gravel, n*—inorganic soil with particle sizes greater than 4.75 mm [0.187 in.].

3.2.12 *horizon, n*—distinctive layer of in situ soil having uniform qualities of color, texture, organic material, and obliteration of original rock material.

3.2.12.1 *Discussion*—

In *World Reference Base for Soil Resources*, by the Food and Agriculture Organization of the United Nations, seven master horizons are recognized – H, O, A, E, B, C, and R.

3.2.13 *loam, n*—soil with a high percentage of organic material, particles are predominately silt size but range from clay size to sand size.

3.2.13.1 *Discussion*—

Loams are usually good agricultural soils due to their nutritional organic content and their ability to hold water. Loams should be avoided in earthen construction, as the organic content is subject to biological decay and volume change. Note that the word “loam” derives from the German “lehm.” In Europe, “loam” and “lehm” usually have an opposite meaning; that is, they connote earth with a very low organic content, ideal for building but not for agriculture.

3.2.14 *material (product feedstock), n*—refers to the substances that are required for the manufacture or fabrication, or both, of a building product.

3.2.14.1 *Discussion*—

Material resources include raw materials and recycled content materials.

3.2.15 *moisture wicking*—the capillary uptake of water from foundation soil or precipitation.

3.2.15.1 *Discussion*—

Moisture wicking can result in saturation of adobe with an accompanying decrease in strength and durability.

3.2.15 *operational performance, n*—refers to the functionality of a product during its service life.

3.2.15.1 *Discussion*—

Specific measures of operational performance will vary depending upon the product. Aspects of operational performance include: structural strength, durability, energy efficiency, and water efficiency.

3.2.16 *poured earth, n*—see *cast earth*.

3.2.17 *pressed block, n*—a block (or brick, or the construction system using those blocks) that consists of earthen materials formed in a block mold by the mechanical compaction of lightly moistened earth into a dense mass (also called *compressed earth block, CEB*).

3.2.18 *rammed earth, n*—a construction system that consists of walls made from moist, sandy soil, or chemically stabilized soil, which is tamped into forms (mechanically stabilized).

3.2.19 *sand, n*—inorganic soil with particle sizes ranging from ~~0.75 to 4.75 mm [0.03 to 0.19 in.]~~ 0.75 mm to 4.75 mm [0.03 in. to 0.19 in.].

3.2.20 *silt, n*—inorganic soil with particle sizes ranging from ~~0.002 to 0.75 mm [0.00008 to 0.03 in.]~~ 0.002 mm to 0.75 mm [0.00008 in. to 0.03 in.] having the characteristics of low dry strength, low plasticity, and little dilatancy.

3.2.21 *soil, n*—see *earth*,

3.2.22 *stabilization, n*—modification of soils to limit water absorption, stabilize volume, increase strength, and increase durability, or some combination of these.

3.2.22.1 *Discussion*—

For the purposes of this guide, reference to “stabilization” or “stabilized” means chemical stabilization or chemically stabilized. Chemical stabilization is achieved by the intermixture of cement, lime, gypsum, asphalt emulsion, or other materials with the soil before emplacement, and curing as appropriate for the stabilizer and chemical reaction. Mechanical stabilization is achieved by compacting or compressing a plastic earth mixture, or containing earth in permanent forms such as bags.

3.2.23 *straw, n*—an agricultural waste product that is the dry stems of cereal grains, or sometimes native grasses, after the seed heads have been removed.

3.2.25 ~~*straw-clay, n*—a construction system that consists of clay slip mixed with straw, of which straw makes up a high percentage by volume.~~

3.2.25.1 *Discussion*—

~~Other fibers such as wood shavings or paper are sometimes used. This system is well suited for manufacturing blocks and in situ insulating wall panels.~~

## 4. Summary of Guide

4.1 This guide identifies the principles of sustainability associated with earthen building systems. Additionally, it outlines technical issues associated with earthen building systems, identifying those that are similar to construction that is commonly used in the marketplace.

4.2 This guide is intended for use in framing decisions for individual projects.

4.3 This guide is intended for use in development of standards and building codes for earthen building systems.

## 5. Significance and Use

5.1 *Historical Overview*—Earthen building systems have been used throughout the world for thousands of years. Adobe construction dates back to the walls of Jericho which ~~was~~ were built around 8300 B.C. Many extant earthen structures have been functioning for hundreds of years. However, with the development of newer building materials, earthen building systems have fallen into disfavor in parts of the world where they were once commonly used. At the same time, earthen construction is experiencing a revival in the industrialized world, driven by a number of factors.

5.2 *Sustainability*—As world population continues to rise and people continue to address basic shelter requirements, it becomes increasingly necessary to promote construction techniques with less life cycle impact on the earth. Earthen building systems are one type of technique that may have a favorable life cycle impact.

5.3 *Building Code Impact*—Earthen building systems have historically not been engineered, but as of the late ~~20th~~ 20<sup>th</sup> Century it is for the first time in history possible to reliably apply rational structural design methods to earthen construction. A large number of earthen building codes, guidelines, and standards have appeared around the world over the past few decades, based upon a

considerable amount of research and field observations regarding the seismic, thermal, and moisture durability performance of earthen structures. Some of those standards are:

Australian Earth Building Handbook  
 California Historical Building Code  
 Chinese Building Standards  
 Ecuadorian Earthen Building Standards  
 German Earthen Building Standards  
 Indian Earthen Building Standards  
 International Building Code / provisions for adobe construction  
 New Mexico Earthen Building Materials Code  
 New Zealand Earthen Building Standards  
 Peruvian Earthen Building Standards

This guide draws from those documents and the global experience to date in providing guidance on earthen construction to engineers, building officials, and regulatory agencies.

5.4 *Audience*—There are two primary and sometimes overlapping markets for earthen construction and for this guide:

5.4.1 *Areas with Historical or Indigenous Earthen Building Traditions*—In places where earthen architecture is embedded in the culture, or there is little practical or economical access to other building systems, this guide can set a framework for increasing life safety and building durability.

5.4.2 *Areas with a Nascent or Reviving Interest in Earthen Architecture*—In places where earth is sometimes chosen over other options as the primary structural material, this guide provides a framework for codification and engineering design.

## 6. Considerations for Sustainable Development and Durability

6.1 *Materials (Product Feedstock)*—Materials of earthen building systems include clay soil and inorganic or organic tempering materials. Silt, sand, and gravel are commonly used inorganic tempers and straw, hair, and chaff are commonly used organic tempers. Soils may be stabilized, using such materials as cement, asphalt emulsion, calcined gypsum or cactus juice, or may be unstabilized. Systems may be finished with plaster or left unfinished.

6.1.1 *Soil*—Soils for earthen building systems are a mixture of a binder (clay), and temper soils of silt, sand, and gravel. These mixtures may be naturally occurring local soils or engineered by mixing different soils. Sources for the soils include on-site horizons, by-products of sand and gravel quarrying, and alluvial deposits. Some clays are highly expansive (montmorillonites) or moderately expansive (illites) when wetted, and thus problematic for earthen construction. Ideally, a non-expansive kaolinite clay should be used. The intermixture of small amounts of lime, bitumen, or cement will negate the expansive properties of swelling clays, but by the same chemical mechanism negate the binding and other beneficial properties of the clay. Stabilizing binders should thus generally be used only when there is no other viable strategy for meeting the project requirements. Care should be taken to avoid adverse ~~affects~~effects on the capacity for food production when considering the use of loams and other soils that are suitable for agricultural purposes.

6.1.2 *Straw*—Straw, being dry and having no seed heads is more durable in earthen building systems than hay which contains seed heads. Straw is an agricultural waste product that is typically not used for productive end use; therefore, it is considered an alternative agricultural product and a renewable resource when used in earthen building systems.

6.1.3 *Plaster*—“Plaster” is a material applied to the exposed surfaces of earthen building systems to improve durability and modify appearance.

6.1.3.1 *Earth (or ~~clay~~) Clay) Plaster*—Earth plaster is a mixture of clay, silt, sand, and water. Fibrous tempering materials are typically added.

6.1.3.2 *Cement Plaster*—Cement plaster is a mixture of cement, sand and water; the mixture may also include pozzolans, lime, pigments, glass fibers, and proprietary admixtures. Cement plaster, which is considerably less vapor-permeable than earthen plaster, can trap moisture, resulting in saturation and deterioration of unstabilized earth wall systems. For this reason, the use of cement plaster over unstabilized earth is strongly discouraged.

6.1.3.3 *Lime Plaster*—Lime plaster is a mixture of hydrated lime and sand that is much more compatible with unstabilized earth than cement plaster in terms of vapor permeability, coefficient of temperature change, and stiffness. Lime plaster has a long and