WHAT STANDARDS RUSH EARTHEN INTO THE MODERN WORLD?

James C. Moore

PhD, NeoTerra LLC, Weslaco, Texas, USA
jim@neoterrabuilders.com

M. John Jordan

MBA/MOT, Paverde LLC, Albuquerque, New Mexico, USA
john.jordan@paverde.com

None.

Until now.

Earthen is a broad category that holds under its umbrella everything from Adobe to stacked bags to rammed earth. More recently, Compressed Stabilized Earth Blocks (CSEB) have appeared and show promise for industrial adoption. However, the debate regarding standards has battled between independent builders who want to be left alone and regulators who do not want to be blamed for approved structures that failed on their watch, thus, this promising carbon-efficient building material has made almost no progress into the construction ecosystem. CSEB have been relegated to two spheres of work: locations where labor is plentiful and extremely low cost (third world) and places where people can afford to do what they wish and have a mindset towards next generation eco-friendly materials (aka rich do-gooders). Neither of these populations draw forth large scale change, but they do allow us to look at what has been possible and ask, "what can we fix to make the larger middle market addressable?" One: cost. Two: standardization. This paper addresses the latter.

Which standards matter?

Materials in a dwelling are used due to their ability to resist various forces and situations:

- Resistance to gravity (collapse)
- Resistance to wind
- Resistance to water (rain and flood)
- Resistance to temperature (cold and hot)

- Resistance to sound
- Resistance to infestation (insects, mold, fungus)

Standards allow makers to have confidence that any particular material will perform in an expected and predictable way when a particular material is chosen. There is no material that is perfect in all resistances, so materials are layered to achieve the needed resistances (e.g. the roof has a skin to resist water, a truss to resist wind and weight, insulation to resist thermal loss). Each component in the layer has some contribution to the needed overall resistances. CSEB deliver a combination of resistances that offer the potential to utilize far fewer materials in a wall system. Therefore, our focus will expand to cover thermal and moisture properties in addition to compressive strength. Finally, and this may be controversial, the size/shape of CSEB also requires a standard. Block shape controls the building process and wall system properties. Any standard lacking a block shape component will complicate the adoption of an CSEB standard, so it is included here. This proposed CSEB standard focuses on wall system construction for residential and light commercial structures, but other uses are touched on where pertinent.

Background

CSEB have been widely described with their main benefits being strength, sound resistance, thermal stability, insect resistance, fire resistance, availability, and low carbon footprint. It is no surprise that many manufacturers have been inspired by this broad spectrum of benefits and created devices ranging from the simplest CINVA ram to the advanced machines made by EarthTek and AECT. Even Elon Musk's The Boring Company made a show of it, utilizing waste materials from boring tunnels in the earth to make blocks. Yet, by any measure, CSEB have been a market failure. Their use hit a peak soon after block machines hit the market and has waned since. In New Mexico, CSEB may be used without Professional Engineer approval provided they follow the NM CID earthen construction code.

This (adobe) standard strongly limits the use of CSEB far below their capacity in construction and, further, does not reach beyond New Mexico. This proposal addresses the key properties and sets the stage for CSEB to enter the marketplace of standard construction materials.

Which Properties? We propose the following properties for standardization:

- Block Standard Code (category, size, shape)
- Compressive Strength (minimum)
- Thermal Diffusivity (average)
- Thermal Conductivity (R-value) (average)
- Water diffusivity (minimum and maximum)
- Water Absorption (average)

Figure 1. Boring block.

Figure 2. CINVA.

Figure 3. EarthTek Press.

We propose the following ancillary properties be measured and provided for use by designers:

- Acoustic Transmissivity (db ~ f(Hz))
- Compressive modulus of elasticity

This proposed standard is manufacture-technique agnostic, but it *is* design-use specific. This standard supports construction of wall systems that have tight controls on physical and material property tolerances as would be used in modern, rapid-construction, and robotic-construction techniques. It also addresses less stringent, but reliable, techniques found in common practice.

Material Requirements

The definition of a compressed stabilized earth block, for the purpose of this proposed standard is as follows:

A prismatic load-bearing block, manufactured by compressing precursors composed of sharp sand, silt, sharp aggregate, non-expansive clay, and either lime or Portland cement stabilizer in the minimum quantity (not less than 6 wt %) to ensure stabilization. The block shall have no more than 0.5 % (by weight) organic material with aggregate materials sized no larger than 3/8” minus. Blocks may include non-expansive inorganic fillers provided the block meets the minimum material properties specifications.

Block Standard Code

The intent of this standard is to be as permissive as possible while encouraging wide adoption. The CSEB standard, like ASTM Standard C140, will include designed use as a criterion which will control the constraints on block shape. Design uses include

- Precision Structural Wall Construction (PS)

- Mortar/Fill Structural Wall Construction (MS)
- Landscape Retaining Wall (L)
- Ornamental (O)

The remainder of this paper will focus primarily on Precision Structural Walls, with Mortar-bonded walls identified by exception.

PS-(1, 2, 3)

The goal of precision blocks is to control stacked block gaps to a small variance for the range of wall systems constructed with CSEB thus making rapid construction and bonding agent minimization possible. Faces must be parallel, and heights must be constant within tolerances. PS-x blocks must be parallel on vertical (stacking) faces +/- 0.02 inches (.5 mm) and have height variation of +/- 0.01 (.25 mm) inches from the specified height. Block variations are described below.

Name	Definition	Tolerance
PS-1	Height Fixed 2 sides variable	+/- .25 mm per mfr.
PS-2	Height + side fixed 1 side variable	+/- .25 mm per mfr.
PS-3	3 sides fixed	+/- .25 mm

This treatment does not directly address unique proprietary shapes, however, the parallelism requirement may be proposed in terms of block gap spacing tolerances to apply to any block shape made.

MS

Mortar/Fill Structural Wall blocks have identical material property requirements as PS-x blocks but with more forgiving size tolerances which can be easily managed with mortar or other 3/8” typical bonding agent. MS blocks shall have a height tolerance of +/- 1/8” (3mm) and width gap tolerance of +/- 1/8” (3mm). Gap tolerances allow for irregular widths but limit the gap size the mortar must fill.

L

Landscape blocks are not certified for structural use but guaranteed to be manufactured by compressing CSEB base materials and are distributed in a cured state per deployment requirements.

L-blocks shall comply with the height tolerances of PS blocks, making them suitable for dry stacking.

O

Ornamental blocks are not certified for structural use but are guaranteed to be manufactured by compressing CSEB base materials and are distributed in a cured state per deployment requirements.

Standardized Material Properties

Like most earthen construction materials, CSEB are capable of fulfilling a dwelling's structural, thermal, moisture, and acoustic needs. CSEB offer properties that are well-suited for hot climates, especially if there are typically large daily variations in temperature. While CSEB offer architects many nice-to-have features such as acoustic performance, texture, crack resistance, and low allergy response, structural standards address issues of safety and energy efficiency.

Compressive Strength

Like ASTM C140 for CMU, we propose PS and MS blocks support full block compression testing operated in the identical manner as C140 with an average failure load of 800 psi (3 blocks) and a minimum failure load of 720 psi (single block) in uni-axial compression. This is an easily achievable strength that allows building designers maximum flexibility in design.

Thermal Diffusivity

The goal of thermal management of a dwelling is to minimize the lifetime energy cost of maintaining a comfortable interior temperature. This is accomplished with the balance of the material costs to insulate the dwelling and differential decrease in energy costs over the lifetime of the dwelling that the insulation provides. This cost is calculated over the range of likely daily and seasonal climates at the building location.

In climates where temperatures vary widely from the daily average, the material's resistance to the change in the outside temperature can be leveraged to minimize or eliminate the need for traditional (R-value) insulation. R-values (thermal resistivity, the inverse of conductivity) work under the assumption that the inside of the dwelling "sees" the outside temperature instantly and the R-value controls the rate in which the heat enters the dwelling. This approach is appropriate when the outside temperature is constantly above or below room temperature. When the outside temperature swings above and below room temperature (75°F, 25°C) on a roughly daily basis, the wall material can absorb those swings and cause the net energy requirement of the building envelope to approach zero.

The standard treatment of a heat resistance requirement is the Fourier heat equation: $q = A/R(T_o - T_i)$ where A and R are the wall system surface area and R-value respectively. This approach has the benefit of being both conservative and simple. However, it omits a significant benefit offered by materials that can store heat. For that benefit, time has to be included in the analysis in the form of the Heat Diffusion Equation:

$$\partial T/dt = \alpha \partial^2 T/dt^2$$

where α is thermal diffusivity ($k/\rho \cdot Cp$) describes how the input of a temperature condition on a material moves through that material with time. By measuring α, which can be deduced from the through thickness timed wall response to a step temperature input on one (or both) sides of the wall, the net energy requirement for the wall system can be calculated based on regional temperature data. This feature of a massive wall system only works when the wall response is slower than the change in temperature. A common criterion for this is a Fourier number (Fo) less than 0.2 which is defined as

$Fo = \alpha \cdot t / L^2$ where α is thermal diffusivity, t is time, and L is the wall thickness. A 12-inch-thick wall has response time of 25 hours with a thermal diffusivity of 2x10-7 m^2/s (typical of CSEB). Therefore, this time-based mechanism is active and should be used in energy cost estimates.

PS and MS wall systems should include thermal diffusivity as a standard required property for treatment of energy efficiency.

Thermal Conductivity (R-value)

R-value shall be reported per ASTM C 177 or C 518.

Water Diffusivity

In warmer climates, CSEB can cool themselves via *transpirational cooling*, a process in which condensed moisture is absorbed into the outer surface of the wall and evaporates during the day. This phenomenon converts solar energy gain into evaporated water rather than increased surface temperature. The block property that limits how much water can be absorbed (and hence evaporated) is Water Absorption Rate. This value shall be measured with ASTM C1585.

Note, while similar to the water absorption test required for CMU certification, this test is measuring a rate of moisture absorption, not the amount of absorption. Water absorption tests are used to measure porosity and commensurate susceptibility to freeze-thaw related cracking in concrete. High porosity materials have been shown to resist freeze-thaw effects and thus the water absorption test is not required for CSEB.

Desired but not Required

Acoustic Transmissivity

The acoustic properties wall section may be provided using ASTM E413. Sound pressure level drop (db) over the frequency range of 50 Hz to 20,000 Hz should be provided for standard wall thicknesses offered by the block manufacturer. As wall size will affect lower frequency transmissivity, the wall section size used in testing shall be published with the results.

Compressive Elastic Modulus

Elastic modulus provides designers and engineers the ability to calculate the building response to dynamic loads. This is vital for understanding the material behavior in an earthquake, hurricane, or tornado. The test should be conducted on three samples, applying 5 load/unload cycles to half of rated compressive strength followed by loading to failure.

CSEB Deployment

As this standard is concerned with the product quality, not the manufacturing details, we recommend the following as the normal approach:

It is the responsibility of the manufacturer to ensure the proper cure time and conditions are met. Complete CSEB shall be submitted for standards testing when they have reached greater than 95% of their cure. CSEB shall not be offered for sale or transport prior to reaching 95% of cure. Each manufacturer is responsible for validating their processes for ensuring that only cured blocks are distributed for use. Any significant change to manufacturing processes requires submission of samples for testing and updating of process documentation. Manufacturers must state and document their cure process for all categories of certified CSEB.

The implementation of CSEB standards will ensure safe and beneficial CSEB usage, leading to wider adoption of this very dependable earthen material product.

James C. Moore *attained a BSME from UT Austin and MS and Ph.D. from The Ohio State University in Columbus OH. He has worked in materials modeling and simulation, including a startup in simulation based design. He designed wireless sensors for a tunnel boring machine under Niagara Falls (and other cool stuff), and now wants to see the best homebuilding material in the world find its way into homes.*

M. John Jordan*, MBA/MOT, BS is President of Paverde LLC and Vice-President of NeoTerra LLC. He has been working on CSEB technology for over 12 years, developing continuous CSEB manufacturing operations processes and improving the quality of CSEB through research and testing. M. John Jordan has been a board member of TEG for over 5 years supporting all types of earthen construction; ECI member. CSEB research multi-year grant winner of over $400K.*