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Discussion of “Earth Concrete. Stabilization Revisited”

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Abstract

Using metrics is an informative approach to compare the effectiveness of cement use in material systems, but does not necessarily consider all factors needed to determine which system is most sustainable. To make a fair comparison, it is necessary to consider the functions cement performs in each system. In this discussion, suggestions are given for how to assess the use of cement as a binding agent in stabilised earth construction. Consideration of structural requirements and durability, life cycle analysis and moisture buffering shows that the effectiveness of cement use depends on more than just embodied carbon and dry compressive strength.

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1 Introduction

The cement industry recognises that there is an urgent need to reduce the environmental impacts, particularly greenhouse gas (GHG) emissions, associated with cement production and use in order to meet our 2050 GHG reduction targets [1]. As part of this ongoing effort, there is debate over the most effective way to use cement in structural materials [2, 3]. In earthen construction, this debate is manifest in the question of whether it is most advantageous to stabilise or not to stabilise earth, with cement as the most common stabiliser [4, 5]. The recent article by van Damme and Houben [6] provides an overview of earth construction and makes a useful contribution to this debate, by framing the discussion in terms of cement use and its effective use as a material resource. However, this contribution - and the critical conclusion it draws about the effectiveness of stabilised earth - is limited by a lack of sufficient consideration for the broader factors needed to make a fair comparison between stabilised earth, unstabilised earth and concrete blocks. In this discussion, three important points will be elaborated that were not fully addressed in the original article: the importance of wet strength and structural requirements in the relevant construction context; broader life cycle considerations, and non-structural functions of these materials.

2 Comparison of materials using the metric of dry compressive strength per unit of binder

In order to compare the environmental impact of different materials, it is helpful to choose an appropriate measure by which to normalise the embodied impact [7]. For structural materials, it is often appropriate to normalise this to a mechanical property. The binder intensity index (Equation 1) is one example of how this can be done.

$$bi = \frac{b}{p}$$

Equation 1: bi = binder performance index, b = total consumption of binder materials (kgm^{-3}*), p = mechanical performance requirement [8].*

To make valid comparisons, the context of how these materials are used in a structure, and in an individual element, must be considered [9, 10]. Compressive strength could be considered the most convenient mechanical property to use in the binder intensity index, although other mechanical criteria are often required in structural design such as flexural and shear strength [11].

In order to compare between cement-stabilised soil and concrete, metrics normalised by compressive strength measured in the dry state do not give a full and fair comparison. In cement-stabilised soils, the cement is typically added for durability and moisture resistance. More specifically, the purpose is to attain sufficient strength in the wet condition and maintain the stability of the structure when fully or nearly saturated. If it were simply a matter of dry strength, then a carefully specified non-stabilised soil would normally be the obvious choice. But as the authors state, unstabilised blocks do not withstand inundation and saturation upon moisture absorption. Unstabilised earth buildings collapse during floods. To demonstrate, by plotting the effect of increasing cement content on saturated compressive strength, then for unstabilised soil, the saturated strength is zero and hence the CO_2 per MPa becomes infinite (Figure 1). As the authors state, with proper design, detailing and maintenance, an unstabilised earth building may never be exposed to immersion, and hence will never be put in this position. However, it remains that in many instances this is not a risk that many builders, building control officers, homeowners or insurers are willing to take. It is more difficult to convince a homeowner or warrantee agency to build with a material that does not pass a saturated strength test, which a concrete block does pass, as this gives the impression of a poorer quality material. Backed up by the socio-psychological perceptions of earth structures that the authors observe, the end result is that stabilisation is purposefully chosen for many contemporary earthen structures. Therefore, whilst stabilisation is not enforced for earthen construction in building codes, sufficient compressive strength in the saturated state is highly desirable in many instances. This should be explicitly considered when evaluating embodied impact per unit of compressive strength.

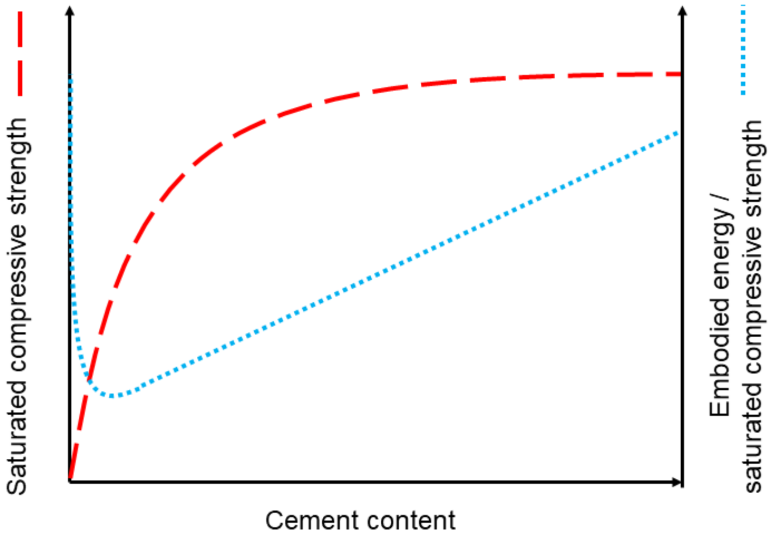

Figure 1: The binder intensity index of an unstabilised soil becomes infinite when embodied energy is normalised to saturated compressive strength.

Material performance should be evaluated within the appropriate structural and construction context. The plots of binder intensity index against compressive strength presented by Damineli et al. [8] evaluate different concretes, covering a range of strengths from around 5 – 150 MPa. As the authors state, earth construction is generally used for low-rise construction, often outside of dense urban areas. In this context, there is often little need or benefit for materials to have compressive strength greater than around 5-10 MPa. Not all units of strength are as valuable as each other; an extra unit of strength above the level required is not nearly as valuable as the units of strength that come before it. Hence, it is not fair to compare low and high strength materials, used in different contexts, and simply normalise per unit of strength. This especially holds true for earthen structures; these generally require a minimum wall thickness as given in standards (for exterior walls: 325 mm in Germany [12], 200 mm in Australia [13]) to avoid elastic buckling, and moreover due to practical constraints (especially for rammed earth) (Figure 2). Therefore, above a certain level, higher strengths do not translate into a reduction of wall thickness, and hence do not result in a reduction of material mass.

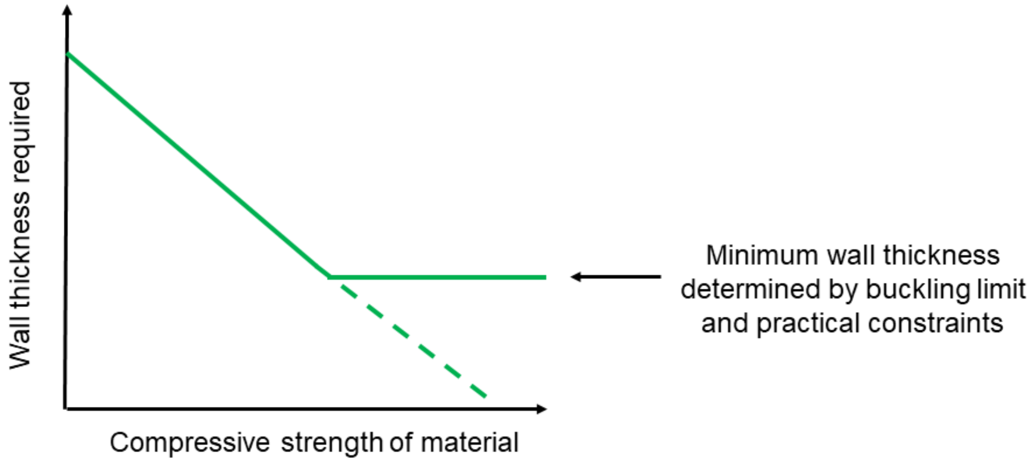

Figure 2: Earthen construction materials are limited to a minimum wall thickness.

In fact, within the relevant range of strength (i.e. 5 - 10 MPa), stabilized earth blocks actually perform the same or better than concretes in both the binder and carbon intensity indices (Figure 3). As the authors also state, stabilized earth blocks are currently the most widespread earth construction technique. So whilst the authors’ criticism of cement stabilisation as inefficient may hold true for some techniques (particularly stabilised adobe), the overall conclusion that “*stabilization of crude earth with OPC is, in general, not an environmentally advisable technology*”, does not reflect the evidence when using stabilised earth materials in the construction contexts they are designed for.

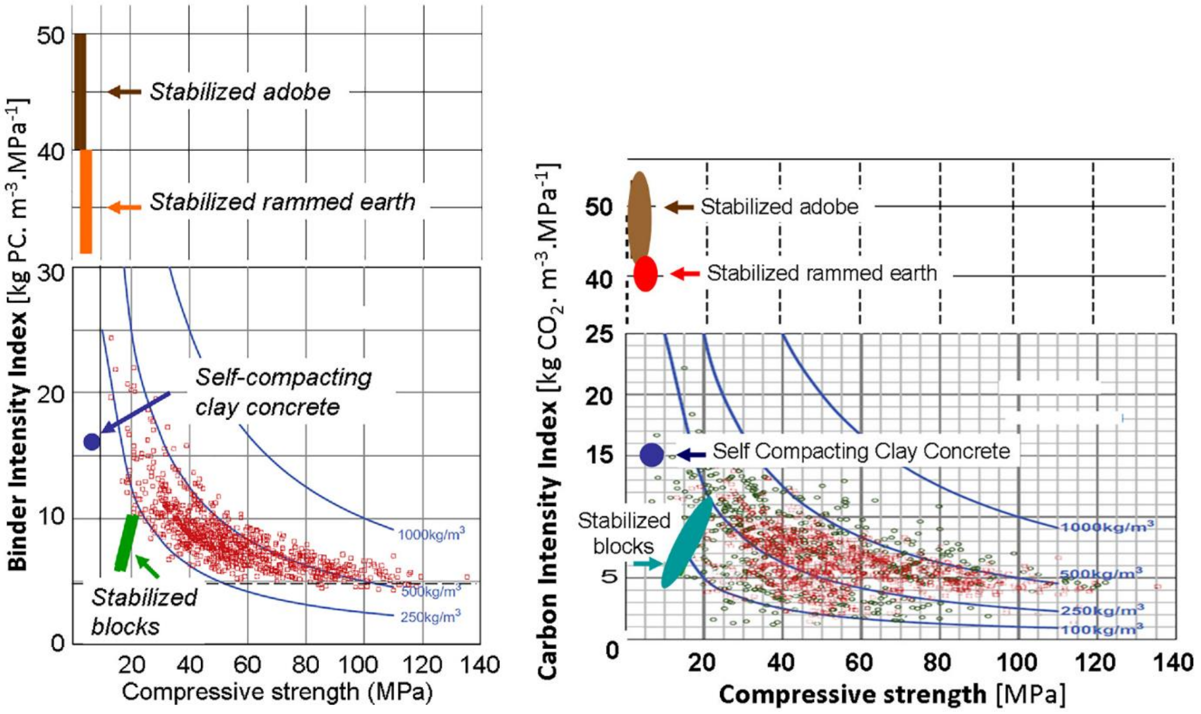

Figure 3: To compare concrete with stabilised earth materials within their construction context, the valid range of comparison is within the range of 5 – 10 MPa. Reproduced from [6].

3 Comparison of materials using other sustainability indicators

It is arguably right that assessing the sustainability of cementitious materials should concentrate primarily on the embodied carbon of the binder phase. However, for a full and fair comparison, analysis must also consider other sustainability indicators, as well as the non-binder components of cementitious materials. These factors were only briefly mentioned in the authors’ concluding remarks and deserve greater examination.

The global warming potential of cement based building materials is mainly due to the environmental impact of Portland cement production [14]. Reducing the use of clinker is therefore the key driver for reducing the overall greenhouse gas emissions related to cement and concrete industry [15] including the amount of cement required for cement stabilisation of soils [16]. As discussed in the original article, the embodied CO_2 of a cement stabilised earth block is not guaranteed to be lower than a cement stabilised sand/aggregate block. However, other environmental impact categories are also relevant beyond energy and carbon, in particular land use [17]. Among non-binder components, sand is not abundant at a local level around the world, and like other natural resources its criticality is a function of supply risk, environmental implications and vulnerability to supply restriction [18]. In some countries, such as India, the high demand for suitable sand frequently leads to environmentally damaging extraction, such as from rivers (Figure 4) [19]. In such situations, non-expansive soil, which is widely available in many regions, would be a better option for an aggregate in terms of direct environmental degradation. For dense, high volume materials with low cradle-to-gate impacts (such as aggregates), transport contributes a higher proportion of embodied energy than for other materials [20]. Given that transportation distances in many rapidly growing countries (such as India) are large [21], local sourcing of aggregate materials is an important contribution to minimising the overall embodied impacts.

Figure 4: Indiscriminate sand mining on the Chalakudy river, Kerala state, India. Image attributed to Challiyil Eswaramangalath Vipin [CC BY-SA 2.0 (https://creativecommons.org/licenses/by-sa/2.0)]

Although the environmental impacts of the materials involved is the main variable being assessed, the eco-profile of human labour still needs to be considered in the life cycle assessment [22]. This is especially the case when purely mechanical stabilisation is used (instead of chemical stabilisation) to improve compressive strength; construction techniques such as rammed earth are often highly labour-intensive. On the other hand, there are potential benefits to adopting labour-intensive construction technologies in countries with high levels of unemployment, and materials are expensive. However, assessing the benefits of labour involvement is difficult to grasp. Considering the amount of labour-hours without including the quality of the work can be misleading. Integrating the labour into an economic assessment of the project to quantify where money goes and to whom [23] can be a solution to distinguish concrete block and compressed earth block construction.

4 Material functions other than strength

So far, this discussion has focussed mainly on the mechanical and environmental credentials of cement-stabilised and unstabilised soil materials. Although load-bearing capacity is the primary function of structural materials, it is important to consider other material functions too.

As stated in the original article, two of the well-documented non-structural properties of earthen structures are their moisture buffering ability, and high thermal mass [24, 25]. Cement stabilisation does reduce the moisture buffering value (MBV) of earthen materials [26], but cement-stabilised blocks still outperform concrete blocks [27]. In addition to the presence of a binder, hygric properties are strongly influenced by the properties of the aggregate material, in particular, particle grading and clay content [28]. A main motivation of research into low impact materials is to prevent harmful climate change; however, considering that new buildings will likely be used for over 50 years, it is instructive to consider how materials could help us adapt to a changed climate. There are possible broader benefits of earth-based materials in improving occupant comfort, such as preventing the need for, or reducing the reliance on, mechanical systems to regulate temperature and humidity. The recent warehouse built by the Pritzker prize-winning architects Herzog and De Meuron for Ricola (also displayed in the original article) is a recent illustration of this effect for a large commercial building [29]. Large prefabricated rammed earth walls (stabilised with a mixture of lime and volcanic tuff) contribute to hygro-thermal regulation in maintaining a constant humidity for plant storage in the building [30]. As a consequence, the appropriate comparison of this wall in an LCA approach would be the prefabricated rammed earth solution compared to a concrete wall and a mechanical ventilation system.

Although comparative metrics are a very instructive way of evaluating some aspects of material performance, there are other aspects which are not captured by these, and hence assessment of multifunctional elements has to be conducted carefully [31].

5 Concluding remarks

Around the world, there is great local diversity in resource availability, construction demand, building typology and climate. Following from this, the cementitious materials that will replace our current Portland cement based materials will themselves be diverse and varied, there will not be a single like-for-like panacea. Although in many situations earth materials will continue to be used without the need for stabilisers, there will continue to be situations in which cement-stabilised earth materials are the best or accepted solution. In Western Australia, for example, cement stabilisation has also undoubtedly supported the wider acceptance of rammed earth building methods. To find the solution with least environmental impact, strength based metrics are an informative tool to help us compare material systems, but this must be balanced with consideration of the structural context in which they are used, and also the wider aspects including resource criticality, durability and internal comfort.

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