Case Studies in Construction Materials 1 (2014) 60–68

Contents lists available at ScienceDirect

Case Studies in Construction Materials

journal homepage: www.elsevier.com/locate/cscm

Case Study

Characterizing material properties of cement-stabilized rammed earth to construct sustainable insulated walls

Rishi Gupta *

Civil and Environmental Engineering Program, Department of Mechanical Engineering, University of Victoria, Victoria, BC V8W 2Y2, Canada

ARTICLE INFO

Article history:
Received 6 January 2014
Received in revised form 29 March 2014
Accepted 7 April 2014
Available online 24 April 2014

Keywords:
Rammed earth
Insulated concrete walls
Mechanical and structural properties of rammed earth
Sustainable construction

ABSTRACT

Use of local materials can reduce the hauling of construction materials over long distances, thus reducing the greenhouse gas emissions associated with transporting such materials. Use of locally available soils (earth) for construction of walls has been used in many parts of the world. Owing to the thermal mass of these walls and the potential to have insulation embedded in the wall section has brought this construction material/technology at the forefront in recent years. However, the mechanical properties of the rammed earth and the parameters required for design of steel reinforced walls are not fully understood. In this paper, the author presents a case study where full-scale walls were constructed using rammed earth to understand the effect of two different types of shear detailing on the structural performance of the walls. The mechanical properties of the material essential for design such as compressive strength of the material including effect of coring on the strength, pull out strength of different rebar diameters, flexural performance and out-of-plane bending on walls was studied. These results are presented in this case study.

1. Research significance

Production and transportation of many engineering construction materials requires high amounts of energy and has high levels of GHG (greenhouse gas) emissions associated with it. This can have a detrimental impact on the environment especially with the recent realization of the severity of climate change and global warming. Concrete is one of the most widely used construction materials and has CO_2 emissions associated not just with the manufacturing process of cement, but also transport of ingredients over long distances. One of the solutions to reduce the environmental impact of concrete is to use more environmentally friendly ingredients and reduce the amount of transportation required in shipping these ingredients and/or the finished material. One of the building materials, Rammed Earth (RE) also known as "Pisé de terre" or simply "Pisé" (Anderson, 2000) is the material that Ecosol Design & Construction (ED&C) Ltd and the builder members of the North American Rammed Earth Builders Association (NAREBA) have been using for construction in North Western Washington State, USA; and Southern Alberta and British Columbia, Canada. The material typically used consists of locally available sand, soil, or gravel and is stabilized using nominal quantities of cement. The author was approached was approached by the Cement Association of Canada (CAC) to undertake a research project to study mechanical properties of RE. In the recent years, RE walls construction has

* Tel.: +1 250 721 7033.
E-mail address: guptar@uvic.ca

http://dx.doi.org/10.1016/j.cscm.2014.04.002

become popular. However, the structural performance of such composite walls when bent out-of-plane was not understood. This was the motivation behind performing material and structural tests on RE. This article outlines the background, methods, and procedures used to construct and study the behavior of insulated RE specimens.

2. Background

Construction using Rammed Earth (RE) that includes use of locally available soils stabilized with binders such as lime dates back many centuries. RE structures including walls have been built in numerous countries since the 1800s (Earth Materials Guidelines, 1996). Research indicates that the USA and Australia have been the pioneers in using this sustainable material in building construction (Nelson, 1976). RE structures utilize locally available materials with lower embodied energy and wasted materials than traditional method (Earth Materials Guidelines, 1996). The soil used for RE building is a widely available resource with little or no side effects associated with harvesting for use in construction. The soils used are typically subsoil, leaving topsoil readily available for agricultural uses. Often soil of reasonable quality can be found close to the location of construction, thus reducing the cost and energy for transportation. Significant cost savings can be achieved when earth (aggregates or soil) is used for construction since the material is generally inexpensive and readily available. If the amount of cement used in RE is carefully controlled, more cost savings can be achieved. Today more than 30 percent of the world's population uses earth as a building material (Anderson, 2000). In addition, RE provides good thermal mass, with inherent good heat retention in buildings and cost-savings.

Once the ingredients for RE have been selected, compression or ramming of the material can be done manually using a tamper (made of a heavy flat bottom plate connected to a long vertical handle). However, RE construction without mechanical tools can be very time consuming and labor intensive. Buildings constructed using RE reduce the need for lumber because the formwork is normally removed and reused. The forms are usually made of form-ply and end panels reinforced and secured by a system of whalers, strongbacks and integrated scaffolding. The face formwork is secured to end panels. The spacing between the end panels is determined by the wall length. The spacing between the face form-ply, which forms the faces of the wall, is determined by the wall thickness. In RE construction, one face of the wall is usually formed to the full height of the finished wall. The other face, the face of the wall at which material will be delivered, is formed up to the final height in successive 20″ to 60″ (500–1500 mm) sections. The wall length and other forming details govern the length of these panels. This step by step process allows for the placement of soil in 8″ (200 mm) lifts. It also facilitates the placement of horizontal reinforcing, additional vertical reinforcing, insulation panels, and miscellaneous electrical, plumbing and mechanical elements as well as blocks outs for architectural cavities and mechanical services. Each loose lift of soil is rammed with pneumatic tampers or hand tampers after delivery into the forms.

In a project initiated at the British Columbia Institute of Technology (BCIT), RE specimens were constructed by using very low w/c ratios and about 10% cement by mass. The specimens were constructed to simulate field conditions by field experts in this industry. Specimens were constructed to evaluate compressive strength, pull-out strength, flexural strength, and out-of-plane bending of RE.

3. Method and test set-up

The rammed earth specimens were constructed by using two locally sourced soils that were blended in a 1:1 ratio. Based on the information provided by the supplier, the fineness modulus of the soil was 3.59. The clay content was approximately 6.55% by weight. During construction of the specimens, forms with secured scaffolds were set-up. The mix contained aggregate with a maximum aggregate size of 5/8″ (14 mm) and was mixed with 10% cement by mass (batched by volume). The amount of water required in the batch was determined based on the mixer operator's experience and hence the exact amount of water to cement ratio in each batch could not be determined. Post construction, the specimens were moist cured by misting frequently for a minimum of 28 days. The details about preparation of specimen and construction is described in the subsequent sections.

3.1. Production of RE specimens

As soon as the first trial mix was prepared using a rotary drum mixer, a test cylinder was made to make sure the mix met expectations in terms of cohesiveness and workability. Fig. 1 shows the first trial specimen constructed in its fresh state. The general principle followed by the field representatives for ramming was to use a lift of 8″ (200 mm) and then compact the material to a height of approximately 6″ (150 mm).

3.2. Cylinders

Cylinders of 6″ (150 mm) diameter and 12″ (300 mm) in height were cast using 200 mm diameter PVC pipes. Cylinders were made using lifts of 6–8″ (150–200 mm), which were compacted down to about 4″ (100 mm). A rectangular block of RE was also constructed from which cylinders were cored by third-party contractors to compare the effect of coring on the compressive strength of RE. Before testing, all cylinders were weighed and dimensions measured to determine the density of RE. They were later capped using sulphur compound according to CSA 4.2.4.2 requirements. Specimens were tested using a