Design and Development of a Large-Scale Compressed Earth Block Building System for Developed Countries

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ABSTRACT

Building designers must approach energy, economic, and environmental considerations in a holistic manner including resource consumption during construction, energy use during occupancy, and the environmental impact due to procuring, manufacturing, and disposal of materials. The Texas Tech Mechanical Engineering Department, Civil Engineering Department, and College of Architecture have been working with EarthCo Building Systems to develop a comprehensive building system for efficient construction using compressed earth blocks (CEBs). The main components of the system are a power plant, hydraulic system, pressure plate assembly, extrusion chamber, shear mechanism, and controller that are used for extrusion of the blocks as well as accompanying lifting device and trailer. By scaling up the production and placement of CEB blocks, manual labor and production time can be minimized, and CEB technology can be made competitive with traditional building technologies.

Keywords: compressed earth block, wall system, buildings

1 INTRODUCTION

This compressed earth block (CEB) project seeks to create a new paradigm for delivery of construction services. The objective is to dramatically decrease energy consumption at lower construction cost compared with conventional buildings through incorporating compressed earth block technology into standard building practices. Moreover, the aims are to foster sustainable growth by mitigating the negative impacts of growth through reducing the embedded energy and material resources for building construction and minimizing ecological impact of building systems.

According to the Department of Energy in 2005, 40% of the total energy consumption in the United States was used for residential and commercial buildings, representing a cost of $370 billion. Twenty-three percent of the energy use in buildings was used for heating; 18% was used for lighting; 13% was used for cooling; and 7% was used for water heating [1]. In addition to the 40% of US primary energy consumption in the building sector, a complete picture of building energy use must also account for the embedded energy used in harvesting, mining, processing, manufacturing, and shipping associated with creating the built environment.

Currently, the US imports 13.5 million barrels of oil per day at $85 per barrel [2]. The national dependence upon limited, foreign oil and gas resources needs to be reduced, and part of the solution is to move toward more energy-efficient buildings. In addition to economic costs, there is a growing national sensitivity to environmental issues associated with buildings. For a typical 2,000 square foot home, 4 tons of waste are generated [1].

2 NEED FOR INNOVATIVE BUILDING MATERIALS

2.1 Issues with Current Building Materials

Wood-framed housing accounts for ninety percent of all new home construction in America [3]. Thus, buyers of new homes have little choice but to buy wood-framed houses. Because of higher costs of construction, only the wealthy or owner-builders can build custom homes that use superior construction materials.

While wood frame construction is the currently preferred choice of buyers and builders alike, it has several major drawbacks that will only become more pronounced over time. Although wood is a renewable resource, it does have negative impact on the environment. Finished lumber requires large amounts of embodied energy to harvest, manufacture, and transport to the job site. With sharply rising energy costs, the cost of lumber will continue to rise, eating into the bottom line of homebuilders and forcing housing costs ever skyward. During occupancy as well, rising energy costs motivate home owners to find ways to save. Wood-framed housing makes an energy inefficient building to heat and cool that requires a significant investment in insulation to reduce energy bills to affordable levels. Disadvantages of timber use include destruction of habitats, resulting in reduced biodiversity, use of harmful resins and glues, such as formaldehyde, in fiberboard and plywood, and end of life disposal in landfills [1, 4].

2.2 Motivation for Investigating Compressed Earth Block as a Building Material

In contrast to timber, earth has many potential advantages as a building material. Earth is the most abundant building material and should also have the best life cycle assessment (LCA) of any building material known to man. It has the potential to be the ultimate recyclable material: When additive stabilizers are not used, at the end of a building's life, the material in the wall can be productively returned to the ground from which it originally came.

Walls have been built out of earth for thousands of years. The oldest continuously occupied houses on the earth are made of earthen construction that date back over 5,000 years—they have survived floods, droughts, earthquakes, and the wars of man. Earth can be formed into walls using dried mud bricks, dried poured earth, rammed earth, and compressed earth blocks. With rammed earth, forms are first built similar to cast-in-place concrete forms, and earth is then added in shallow layers and rammed. While compressed-earth-block homes rely on a material (namely adobe) that has been proven over hundreds or thousands of years, they build upon that technology by producing building materials that are capable of withstanding compressive pressures comparable to concrete [5, 6].

Compressed earth blocks are defined as earthen bricks created by means of compression in hand-operated or hydraulic machines. Commercially available machines* make blocks up to approximately 10 x 14 x 4 inches which are stacked to form a wall, and stabilizers such as Portland cement, lime, gypsum, and other chemical stabilizers can be used along with the soil in the bricks. However, stabilization can also be achieved physically without chemical additives by using compaction and granular stabilization [9]. Currently CEB's are commonly used in rural areas of third-world countries to construct buildings at very low cost. In developed countries, because of the labor-intensive work required for manufacturing and placing the blocks, houses built with CEB or rammed earth have been limited to high-end, custom homes.

The Department of Energy's Building Envelope Technology Roadmap lists objectives for 2020 [10]. According to the report, building envelopes need to be energy positive ("minimizing energy use; providing heating, cooling, and electricity; and storing or returning excess energy to the grid"), adaptable, affordable, durable, environmental ("harmless to the natural environment, resource-efficient, and appropriately balanced between embodied energy and durability"), healthy and comfortable, and intelligent. Compressed earth block structures can directly address five of these seven goals.

In the 1920s the U.S. government and several state colleges started research in compressed earth. These included the Agricultural Experiment Station of University of California, Davis, and in 1926 the USDA published a booklet *Rammed Earth Walls for Buildings*. Ralph Patty at the South Dakota Experiment Station and George F. Middleton at the Commonwealth Experimental Building Station in New South Wales, Australia did field trials on rammed earth wall construction in the 1930s and 1940s. Since the 1950s most work has centered on soil stabilization as applied to road engineering [9].

Buildings constructed of compressed earth blocks exhibit numerous benefits when compared with wood frame construction [9]:

- Compressed earth is a versatile building material, and earth is readily available locally.
- Earth is a fire resistant material with a 4-hour rating.
- Earth can be used to produce load-bearing structurally sound walls.
- Earth construction—having a large thermal mass—produces a consistent internal temperature. Specifically it evens out diurnal variations and traps internally generated heat.
- Built environments using earth are quiet, having low sound transmission. Additionally they have good air quality.
- Earthen structures are durable and resistant to weathering. When treated with sealant, earthen walls are water resistant. They resist habitation and damage from insects, such as ants and termites.
- Additional structural elements can be incorporated into earthen walls to provide earthquake protection.
- Economic benefits include low costs of maintenance, low costs of heating and cooling the interior, and construction costs using existing compressed earth block technology that are comparable to wood-framed buildings.
- Stabilization can be achieved using several methods: compaction/densification, granular stabilization, or chemical stabilization.

3 WORK IN-PROGRESS TO "MODERNIZE" CEB PRODUCTION

Texas Tech University has been working with EarthCo Building Systems to develop a comprehensive building system to enable efficient and low-cost manufacture and placement of compressed earth blocks (CEBs). This project has been carried out by faculty, graduate students, and undergraduate student design teams. In contrast to the existing "small block" machines for producing compressed earth blocks, Texas Tech University in conjunction with EarthCo Building Systems has developed a prototype machine for producing very large-scale compressed earth blocks ("megablocks"). The system that has been developed is similar in technological maturity to current

* The largest CEB equipment maker is Advanced Earthen Construction with annual sales of $2.5-5 million [7, 8].

CEB construction technologies except that the blocks produced are much larger than those currently produced by any other CEB machine worldwide. The blocks produced can be as large as 24 x 24 x 120 inches. The system is designed to produce blocks that do not require additives for stabilization thereby leaving the soil in a state that can be returned to nature at the end of life cycle for the structure. Even larger size blocks are also possible using the same technology for specialized, non-residential applications such as military or transportation structures.

The main components of the system shown in Figure 1 [11] include a power plant and hydraulic pump, hydraulic cylinders, pressure plate assembly, extrusion chamber, shear mechanism, and controller. The blocks are created in a 24 by 24 inch chamber that is used to extrude the blocks in a semi-continuous process. The block is produced in lengths up to 10 feet and is cut to length by a shearing mechanism. In addition to a square cross-section, the extrusion process can be used for producing blocks of any constant cross-section. The other specialized equipment needed for use of large-scale CEB production are equipment for lifting and placing the blocks as well as equipment for transporting the extruder and soils [11].

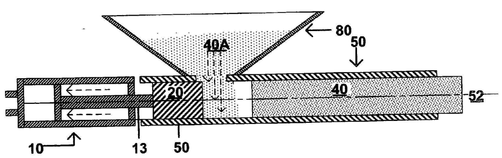

Figure 1: Schematic of compressed earth block extruder [11].

By using this CEB manufacturing and placement technology, a massive earthen wall of 24 in. or greater thickness can be constructed in less time and at less cost compared with typical wood frame construction. The resulting wall structure can be many times stronger than typical wood frame construction. The designed production and placement capacity of approximately 110 tons per hour is enough to complete both the exterior and interior wall system for a 6,000 ft^2 house in one work day at an estimated cost of \$3 per square foot to the builder. By contrast, framing with Canadian lumber costs approximately \$14.50 a square foot. For a 1200 square foot house, the savings are \$13,800.

3.1 Extruder

The compressed earth block extruder produces large CEB megablocks composed of a mixture of clay and sand. The earth enters the compression chamber through a hopper. The equipment for extruding the compressed earth blocks consists of a chamber in which the force for compaction is resisted by friction between the earth and the sides of the extrusion chamber. The compressive force is generated by a hydraulic system consisting of motor, pumps, and multiple hydraulic cylinders. The cylinders apply force against a compaction plate which applies a 1,500 psi pressure against the 24 by 24 inch face of loose earth. The earth is compressed from 8 inches of loose earth to a 4 inch thick lift and achieves a 50% reduction in volume and 97-98% maximum density. With each successive cycle of the machine, the four-inch lifts are fused together into a continuous CEB megablock. Figure 2 shows the fused block produced with a small-scale proof-of-concept machine. The block advances down the length of the extrusion chamber, and upon exit, can be cut into a desired length up to 10 feet long.

Figure 2: Continuous extrusion of compressed earth from small proof-of-concept machine.

The machine is designed to produce a megablock every six minutes, and the block length is controlled through a shearing mechanism. Each megablock weighs approximately six thousand pounds which the shearing chamber lifts and severs.

3.2 Lifting Device

The CEB extruder is designed to produce compressed earth blocks weighing up to six thousand pounds. Therefore, a lifting device capable of supporting the large weight is required. Additionally, the lifting device must be compatible with the material properties of the compressed earth blocks, which are similar concrete; that is, the compressive strength is much higher than the tensile strength. Therefore, the lighting device cannot lift the compressed earth block from one point in the middle of the block. Rather, the support of the block needs to be evenly distributed over a large area to prevent damage as the blocks are transported around a jobsite. The lifting device is designed to be attached to a variety of construction equipment that could be available at particular jobsites. The lifting device can be attached to a backhoe loader or a crane. The use of backhoes which have maximum lifting heights and capacities prescribe constraints on the size and weight of the lifting device in addition to requirements for safety, durability, and maintainability. The CEB lifting device is illustrated in Figure 3.

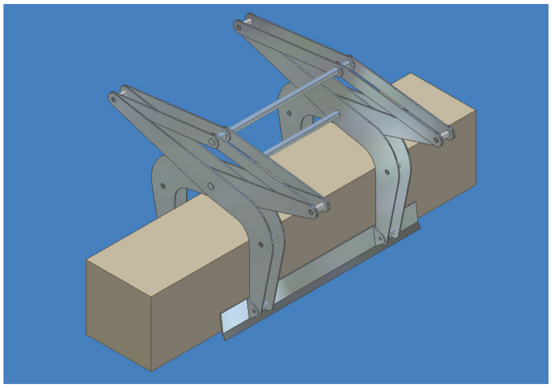

Figure 3: Isometric view of CEB lifter.

4 INTEGRATION WITH BUSINESS PLAN AND SYNERGISTIC ACTIVITIES

The equipment developed for large-scale production of compressed earth blocks fits with the business plan of EarthCo Building Systems[†]. Crews will provide the service of constructing CEB walls for home builders—for either development of neighborhoods or individual houses. The cost of CEB walls to the home builder will be comparable to timber frame construction and offer energy and environmental benefits: energy savings (high R factor) and much greater resistance to fire, storms, and insects.

In addition to the equipment development, the project at Texas Tech University incorporates interdisciplinary work on block characterization and development of soil recipes, thermal analysis of building performance, and design and research on sustainable architectural design using the compressed earth block system.

5 CONCLUSIONS

By scaling up the production and placement of CEB blocks, the manual labor and time previously associated with building CEB structures can be minimized, and CEB technology can be made competitive with traditional building technologies for residential and commercial construction in both developed and developing countries. CEB technology can reduce the cost of construction compared with wood-framed residential construction or steel-framed commercial buildings, save natural resources in construction, reduce construction by-products and disposal, and reduce energy consumption during occupancy. Advantages of CEBs include use of locally-available materials, reduced transport of materials, and uniform building component sizes.

[†] See additional paper by Larry Williamson presented at this conference.

6 ACKNOWLEDGMENTS

This work has been funded by EarthCo Building Systems, with thanks to Larry Williamson and Gary Hames. The authors would also like to acknowledge the contributions of the many student teams and students that have participated in the project.

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