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STRUCTURAL ANALYSIS OF THE ECOEARTH SANDWICH SYSTEM

ENRIQUE VILLACIS TAPIA[1], PATRICIO CEVALLOS[2], and CYNTHIA AYARZA[3]

[1]*School of Architecture, Design and Arts, Pontifical Catholic University of Ecuador, Quito, Ecuador*
[2]*Alternative Technology, Quito, Ecuador*
[3]*Ensusitio, Quito, Ecuador*

The eco earth sandwich is a construction system with a CMU foundation, braced vertically with treated wood poles and horizontally with steel rods and rammed earth. A reinforced concrete crowning beam confines a steel panel envelope, developed as an alternative wall using local resources, materials, and workforce. The Con Lo Que Hay 14 (CLQH 14) workshop, which translates to "With What is Available, edition 14 workshop," developed the eco earth sandwich for a small suburban community center in the Ecuadorian Andes, based on vernacular contained earth criteria. The model is a one-story structure in which the resistance of its conforming elements will be evaluated in a theoretical approach. Earthquake resistance: Compression and tensile stresses and cutting effects produced at the foot of the wall will be evaluated. Verifying its effectiveness as a one-story self-standing structure and the possibility of becoming bearing walls. Future studies are planned with laboratory structural stress load tests.

Keywords: Alternative earth wall, Recycled wall-filling, Local materials, Rammed earth, Sheet metal contained earth enclosure, Incased wall.

1 INTRODUCTION

Due to the current energy crisis and the effects of the construction industry on global resource consumption and waste generation, the search for alternative structural systems with replicable, reuse, and self-construction options is a field that must be addressed in the educational and professional aspects of construction professionals. (Villacis *et al.* 2020).

As a means to address economic and social crises by proposing accessible construction systems coherent with the context, the eco earth sandwich system was developed by the Con Lo Que Hay 14 (CLQH 14) workshop, which translates to "With what is Available, edition 14 workshop". Students, professionals, and the community worked together to evaluate the community`s actual needs. Working sustainably, using local resources, materials, and workforce.

All constructions must be structurally responsible to ensure proper safety and protection. As a first step in the structural analysis of the eco earth sandwich, the construction system will be detailed, and its structural coherence will be evaluated. This research is a starting point in the structural analysis of the eco earth sandwich system self-standing enclosure.

2 METHODOLOGY

This research evaluates mathematically the eco-earth sandwich system on the characteristics of earthquake resistance: compression and tensile stresses, as well as cutting effects produced at the foot of the wall. Following the Ecuadorian code NEC-SE-VIVIENDA (MIDUVI 2014), which works with the Design Manual for Woods of the Andean Group (JUNTA DEL ACUERDO DE CARTAGENA 1984), specifications of its one-story structure effectiveness will be verified.

3 THE ECO EARTH SANDWICH SYSTEM

With what is available 14 (CLQH 14 2019) workshop, a hands-on practical workshop for sophomore university students in Ecuador, developed the eco earth sandwich system in a suburban community center in the Ecuadorian Andes, utilizing local resources and workforce to lower construction cost and reduces the environmental impact. (ENSUSITIO 2019). The task to be addressed was an independent enclosure to an existing porticode structure by embracing the openings between pillars with an independent structure. Traditional alternatives, such as CMU Block, brick, and wood, were considered, but the proposed challenge was to build the closure with recyclable material on site. See Figure 1.

Figure 1. The initial independent structure is on the left, and the eco earth sandwich enclosure is on the right.

The available materials were earth, corrugated steel roofing sheets, CMU blocks and eucalyptus wood. The soil contained a moderately sandy grain size and, therefore, had an excellent capacity to compact and remain stable. The metal corrugated sheet material used for roofing can manage tensile forces. This led us to visit vernacular construction systems that used earth in a compressed form with a container or containment and how the materials could be combined.

The research through vernacular sources referenced walls or earth cores protected with stone used by the Incas with the example of earth walls protected-contained by stone seen in Machu Picchu, and the vernacular construction system of Rammed earth and stone foundations made with stone and earth, and two layers of "*molón*" stone and earth as mortar and interior filling, this system known as a Strip Foundation used in the Ecuadorian Highlands (Zeas and Flores 1982).

The Geophysical Institute of the National Polytechnic University of Ecuador (IG 2023) and the International Seismological Center (ISC 2022) have recorded earthquakes with a magnitude above seven since the first recordings. Through time, withstanding earthquakes with magnitude above seven have proven they both have seismic resistance. In Machu Picchu, the exterior element protects and contains the soil, while in the rammed earth process, the exterior mold element can be removed while the wall is being raised due to its width, making it self-supportive.

The eco earth sandwich has a strip foundation beam conformed by concrete masonry units (CMU) laid with an earth-cement-mortar ratio of 6:3:1. The wall is assembled by placing steel panels against the two faces of the CMU base. The wall is filled by placing rammed earth (rammed a maximum of 7 times) between the two steel panels. The earth must be raised evenly throughout the system and dampen every 20 cm: in the crowning beam use a 3:1 ratio mortar. See Figure 2.

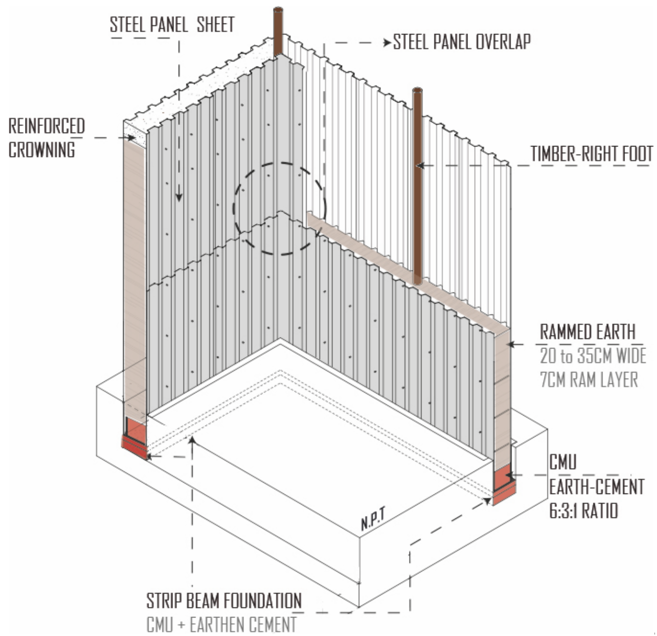

Figure 2. Eco earth sandwich system components.

It is braced vertically with a G-shaped wall and eucalyptus post during construction, horizontally with steel rods and rammed earth, and with a steel panel envelope, all confined by a reinforced concrete crowning system.

4 STRUCTURAL ANALYSIS

For the enclosing walls, it is required that they be stable to traction and compression forces; the metal sheet covers the traction forces. The metal sheet used is the AR-5000 from NOVACERO with the specifications shown in Table 1.

Table 1. The characteristics of the AR-5000 metal sheet are the following (NOVACERO 2022).

TECNICAL SPEC AR-5000	
Utility Width (mm)	1090
Wave Height(mm)	70
Thickness (mm)	0.35
Distance between suports(m)	1.2
Weight (kg/m2)	2.89

To withstand compression forces, rammed earth was used; together with these two materials, the aim is to have an enclosure that in a combined way reacts favorably to the two requests. See Figure 3.

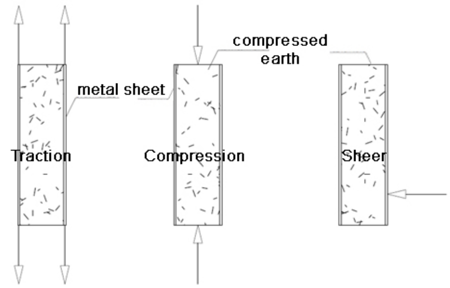

Figure 3. Traction, compression, and shear deformation.

To obtain the interaction between the two materials, the confinement of the earth was improved using steel pins every 60 cm in both directions that join the two sides of the steel sheet, as shown in Figure 4. In this way, the wall and its two elements, soil– and steel, work in solidarity. The anchors control the shear effects produced at the foot of the wall to the foundation, the soil compaction quality, and the metal sheet corrugation. The soil should be clayey sand with a sand content close to 65% and a maximum compaction humidity of 10%.

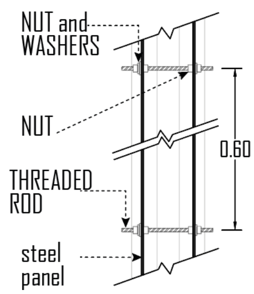

Figure 4. A steel pin threaded rod every 60cm joins the two metal sheets.

Possible deformations (bending, due to lateral forces, are controlled by the corrugated sheet, which, although designed to work as a roof element, in this case it is placed vertically as containing wall for the core of 20 cm compacted earth. Taking advantage of the 7 cm corrugation gives it greater lateral resistance. In the presence of perpendicular forces to the metal sheets, they are supported by the earth core, and in this way, the bending and bending shear that occurs at the foot of the wall is controlled. See Figure 5.

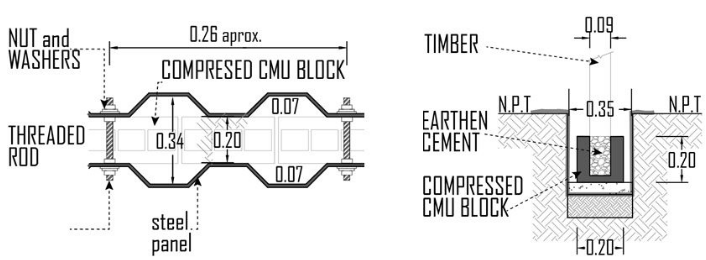

Figure 5. Community and students during the construction process.

The metal sheet dissipates the tensile forces while the compressed earth works efficiently in compression. In the case of the shear forces produced by earthquake or wind effects, the combination of the metal plate and the compacted earth work together to counteract the effects produced by the shear stress.

4.1 Wall Conformation

For the construction of the wall, it had to be considered that the walls did not support any additional load beyond their own weight, and a height of 3.60 m was estimated:

Self-weight estimate, Eq. (1).

$$\text{Width} * \text{Height} * \text{Length} * \text{Weight/m3} \tag{1}$$

Compacted soil 0.20 m * 3.60 m * 1.00 m * 1500 kg/m³ = 1080.00 kg
Steel sheets 2.00 U * 3.60 m * 1.00 m * 3.33 kg/m² = 23.98 kg
Estimated self-weight: 1104.00 kg

For the design of the continuous foundation required by the wall, the unit load would be Eq. (2):

$$q = \frac{\textbf{self-weight}\ \text{kg}}{\text{width cm} * \text{length cm}} = \text{kg/cm}^2 \tag{2}$$

$$q = \frac{1104.00\ \text{kg}}{20\ \text{cm} * 100\ \text{cm}} = 0.55\ \text{kg/cm}^2$$

The unit load by its own weight is very low, and its foundation will be with concrete blocks and earth–cement with bearing capacities estimated at 25 kg / cm².

To avoid deformations and ensure that the whole assembly functions jointly, bolts are placed face to face on the steel sheets; the bolts will have a separation of 60 cm in the vertical direction and 26 cm in the horizontal direction. The bolts shall be made of A36 or A40 steel with a 4200,00 kg/cm² tensile strength.

5 RESULTS

During the construction process, the verticality and flexibility of the steel sheets made it unstable and challenging to maneuver. To give additional vertical support, a minimum 2-wave overlap between sheets was necessary, as well as treated timber posts placed within the 20 cm interior of every 1.5m, working as right-foot as specified in the Design manual for woods of the Andean Group.

The connections in straight angles of the walls had to be reevaluated to contain the compressed earth properly and allow the 2-wave overlap between metal sheets. Considering the wall as a continuous structure, similar to a rammed earth self-supporting wall as per NEC-SE-VIVIENDA, generating a G-shaped wall also added stability to overturn.

The Eco-earth sandwich system has to work with all its elements jointly for the system to function correctly.

The self-weight of the system is 1104 kg, which results in a unit load of 0.55 kg/cm², and the bearing capacity of the CMU/earth-cement bearing load is 25 kg / cm²; the system can be supported by the foundations proposed.

6 CONCLUSIONS

The eco earth sandwich system wall is self-standing as a one-story enclosure with a height of 3.6m. It may receive a roof load when evenly distributed through the reinforced concrete crowning system. Further load tests are necessary to verify the effectiveness of a one-story self-supporting structure and the possibility of becoming bearing walls.

The timber elements work as left feet, following the Design Manual for Woods of the Andean Group. These control the bulking of the steel panel due to the compressed earth and maintain the steel panel's vertical position during the compressing process of the earth filling.

The eco-earth sandwich is a complete system where L, U, and G-shaped walls are necessary for a stable structure. Similar to the situation with the rammed earth self-supporting wall

The wall has served the purpose of enclosing the existing structures and has worked as a self-standing system, stable for its enclosure functions.

The structure has been self-standing for the past four years without any modification and in an active seismic area without being affected. The versatility of the components is open to variation depending on the context in which it is applied, testing different containing and filling materials according to what is available on each particular site. Understanding how each element structurally works independently is essential to combining them into an alternative innovative structure properly.

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