POURED EARTH FORMWORK: LIMITING TRANSPORTATION BY USING FABRIC AND TEMPORARY STAGING AS PERMANENT STRUCTURE

Catherine Page Harris

Associate Prof., Landscape Architecture and Art & Ecology
University of New Mexico, Albuquerque, NM, USA
cphunm@unm.edu

Charlie O’Geen

B.S.Arch, M.Arch, Lecturer, Architecture & Urban Planning
University of Michigan, Ann Arbor, MI, USA
cjogeen@gmail.com

Abstract

The use of offsite materials in building can be lessened by using fabric formwork for poured earth (previously explored primarily for concrete [West, 2017]) and by using temporary staging that is incorporated into the permanent structure. Fabric formwork tolerates shrink and swell, limits cracking at form-ties, and provides options for curved forms. The authors developed a standard methodology for staging (O’Geen and Harris, 2022): hanging a fabric bag from a temporary (light-framed wood) infrastructure, and repeating form-tie spacing. The temporary infrastructure is rotated and reused to become permanent roof rafters, minimizing the material removed from the project site. Research includes rectangular mockups to test materials and formwork at a one-half cubic foot volume and a larger curved partial scale mock-up at a five cubic foot volume.

Thesis

Geotextile fabric formwork can be used in earthen building to provide a lighter formwork to hold earthen material. This lighter formwork can be supported by structures built from materials that stay on site, like roof members. Together, this formwork method allows earthen materials to be used without extensive “double wall building” as in the case of panelized formwork, and thus cuts down on material use and material transportation to the site.

Context

In 2017 Gauzin-Müller and Fuchs published a review of contemporary poured earth projects in France, describing stabilized poured earth walls in panelized concrete-style formwork and one infill pre-cast poured earth panel project with an internal basket frame that settled into the material halfway through the pour. Their poured earth research requires the addition of 4% Portland cement by

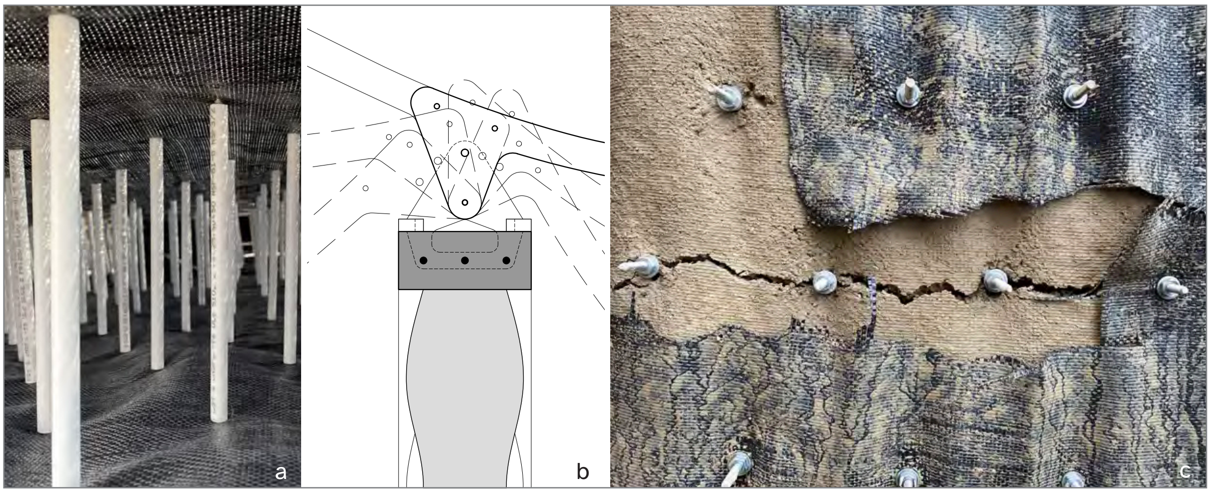

Figure 1. (a) Detail of form times in fabric. (b) Diagram of rotation. (c) Crack on previous study.

weight to pour earthen material into panelized (non-breathable) formwork for both interior and exterior walls. The infill panels used un-stabilized poured earth that was allowed to dry in forms in a studio and shrink to a stable size; the panels were then built into framed walls. Gauzin-Müller and Fuchs work with the support and research of amáco, CraTerre, NSEAG, and the French government to use site soils in construction to mitigate the transportation of excavated materials off site, and to take advantage of the poetics of earth (Gauzin-Müller and Fuchs 2017).

Conventional rammed earth formwork is identical to the panelized concrete-style formwork described above. After the concrete footing or slab is poured, two "form walls" are constructed making the inside perimeter of the desired walls (Grometer 2015). The material is then compacted in layers (usually pneumatically) and incorporates a Portland cement stabilizer. The thickness of the walls ranges from 18-24", so the forming components are often heavy steel panels that must be transported by flatbed truck to and from the work site. Because the formwork comes in standard rectilinear sizes, the form results in efficient, modular constructs (Grometer 2015).

Alan Chandler and Rowland Keable have built and tested a series of experiments combining flexible fabric formwork and rammed earth. Chandler's fabric-forming work in concrete was published with Remo Pedreschi in the book *Fabric Formwork* two years prior to the publishing of the rammed earth tests. "Fabric earth Wall One '' is made of rammed earth and is parallel to "Wall One," using an identical construction system but cast in concrete (Chandler and Pedreschi 2007). In both constructs, the fabric is attached to vertical pieces of timber which are square and set on a slight angle vertically. This system was able to control the ramming impact and pressure "without fault" (Chandler and Keable 2009). "Fabric earth Wall Two'' is a parallel test of the "quilt point" method pioneered by Kenzo Unno in concrete (West 2017). In this case, the rammed earth inside the floating form-ties fills the bag equally from top to bottom. Chandler and Keable's research in fabric-formed rammed earth convincingly repeats methods previously used in concrete, but the tamping of the earth in the formwork is only slightly different formally from previous tests in concrete.

Figure 2. System timelapse showing the roof rafters as temporary support before final rotation.

Methodology

In this research, the fabric-formed poured earth walls create an infill panel, which is then surrounded by supporting posts and bond beams to create a module for building – this is "outsiding the infill." This method uses a geotextile bag to hang the earthen material while it dries. It then frames that panel with conventional supports poured in concrete, with roof connections. The authors created a half scale mockup of this system in Spring 2022, with a volume of five cubic feet (see Figure 4). Note: this research was performed using poured earth in an optimal mix of clay and aggregates as previously determined by the authors (O'Geen and Harris, 2022).

The first step in creating the formwork is sewing the geotextile bag. The research investigated curvature for the wall, so the bag consisted of a front face of 39" and a back face of 41" widths respectively. The front and back faces were connected with sewn panels to create a width of 5", with slip pockets for two battens to constrain the material and create a key in the edge of the pour. The bottom edge of the bag was left open with a 6" margin at the bottom to attach to the base of the pour. The top edge of the bag was hemmed to create a slot for two ⅜" curved rebar rods. The bag was measured prior to sewing with a diagonal grid at 5" on center on the 39" width side and then an expanded grid out from a centerline on the 41" width side. These markings were then drilled through and an assembly of a threaded rod, a PEX sheath, and nut and washers at each end was inserted to create a grid of form-ties (see Figure 1a).

The authors also poured half-cubic-foot volume tests in both panelized and fabric forms (see Figure 3). The material for the panelized formwork in melamine weighed a total of 11 lbs 8 oz, not including the base material. The fabric formwork material, including the upright 2x4s (4 lbs 8 oz), the fabric bag (2 oz), the bungee cords (6 oz), and the rebar top edge control rods (1 lb), weighed a total of 6 lbs. The fabric system is roughly half the weight of the panelized system; at this scale.

For the half scale test, the authors developed a roof form in Rhino software and created roof rafters from the basic curves of the form. The rafters were cut in ¾" plywood with a CNC router run by RhinoCam. The rafters were designed with a connection system over the wall that allowed the two pieces to rotate freely until locked in place with bolts (see Figure 1b). Thus, the roof rafters could be rotated down to create "legs" to support the fabric formwork bag, then to support the casting of the posts and bond beam, and finally rotated up to support the roof itself. A curved piece of plywood was cut to

Figure 3. (a-b) Difference of cast section at bottom / top (c) comparison fabric and panel forms.

register the five rafter support pieces and ratchet straps were hung over a block, through-bolted into the connection system. The ratchet straps supported the bag of earthen material while it dried (see Figures 2b, 2c).

The earthen material weighed 640 lbs. for the total pour of 5 cubic feet of material. The material dried for 16 days before the form was removed. The compression of the material at the bottom of the form created a much smoother block at the bottom than the top. The authors note that the bag, which had been released at a rate of ½” per day for the first 5 days, could have been released more quickly initially to allow for shrinkage at the top.

Three factors determined the curvature of the bag: the sewn proportions (shorter on the front face, longer on the back), two control rods threaded through each side of the top of the bag, and a frame at the bottom, to which the free bottom edge was pinned down. The bottom frame was cut by CNC router to the same curvature as the top registration pieces for the roof rafter assemblies.

The roof rafter assemblies were extended to reach the base of the pour with a sandwich of cut-outs from the CNC routed sheets of plywood and wooden battens that connect the whole frame as a triangle to the base (see Figure 2a).

Results

Using the roof rafters as temporary support bracing to fill the bag was successful. By attaching the rafters to a central plate that was later embedded into the concrete bond beam (see Figure 2c), the rafters could triangulate to the ground (or in the case of this experiment, a pallet). Because the permanent roofing assembly was used as temporary bracing, less material was transported to and from the site. Further, due to the shrinkage of the material, the geotextile bag could be slipped off vertically, and thus reused, after releasing the threaded rod and wood pressure plates.

A few components of the system could be improved. Refinement of integrated bracing is necessary.

Figure 4. (a) Detail of concrete and earth. (b) Front elevation. (c) Overall view of half scale study.

During the experiment, diagonal braces were at first omitted causing the cast to deflect over an inch in elevation. Braces were later installed prior to the casting of the concrete frame around the panel and succeeded in keeping the embedded plates in the correct location.

The geotextile fabric and floating form-ties, together with bungee cords and ratchet straps, collaborate with the shrinkage of the poured earth. Further experiments will refine the mechanism that allows the fabric to move with the material without applying too much force as it dries. In the authors' first large-scale mockup, a large horizontal crack was formed as the form-ties lifted the top of the cast (see Figure 1c). The gravitational force on the hydrostatic pressure of the material causes the bottom of the cast to bulge more than the top. The small block section from a ½ cubic foot volume test shows the material distending 4 ⅛" to 5 ⅛" from top to bottom (see Figures 3a, 3b). Form-tie spacing may control this compression at the bottom.

Currently, the most complex part of the process is "outsiding the infill," the wrapping of the concrete frame around the infill panel. For a concrete-framed building with a brick infill system the frame can be perfectly made, and the unit-based brick system can be brought to it. With fabric-formed unstabilized poured earth, the initial cast is imprecise because the material moves as it dries. Therefore, there must be a customized formwork to shape the concrete, connecting it around the subtle changes in the earth. Further research is required to control the vertical edges to make this process less time consuming.

Discussion

Conventional rammed earth formwork is often reused from one job to another, becoming an asset for the rammed earth contractor, but requiring trucks to bring the wall forms to the site and remove it. According to Barrett and Wiedmann, transportation of material to a residential building site is about 5% of the total GHG emissions created in building (Barret and Wiedmann 2007). The formwork system of using the frame of the building to provide support for a light textile form for the earthen materials cuts the materials that come to the site in half in terms of weight. As they are re-used on site, there is no transportation of those materials away from the site. This method can cut the transportation percentage to roughly 1.25% or less of GHG emissions created. Site-derived earthen materials would further reduce this percentage.

As this casting method is refined, the authors continue to create more control for these un-stabilized infill panels. The authors had initial concerns that the roof framing would be too light to support the 640 lbs of material in the poured earth bag. However, the geometry of the design supported the material until it became self-supporting. Further research will determine the timing of the material's transition from liquid to self-supporting, and the timing of its shrinkage.

The surface of the poured earth retains the impression of the fabric and undulates with the stretch of the material. This creates a tactile wall surface with a different feel from panelized pours (see Figure 4). The weight of the material is visible in the quilt-point pattern swellings. This test pairs fabric formed concrete posts and bond beam structure with the fabric formed earth.

References

O'Geen, C., and C. P. Harris. 2022. "Fabric Formed Poured Earth: Using Urban Site Soils in Fabric to Eliminate Portland Cement." In proceedings of the ARCC-EAAE 2022 International Conference, 375-382. Miami, FL, March 2-5.

amáco, 2017. "CONSTRUIRE EN TERRE COULÉE, FORMATION PROFESSIONNELLE," 17, 21, activities report

Barret, J and T. Wiedmann, 2007, A Comparative "Carbon Footprint Analysis of On-Site Construction and an Off-Site Manufactured House" SEI & ISAUK Research Report 07-04

Chandler, A. and R. Keable. "Achieving Carbon Neutral Structures Through Pure Tension: Using a Fabric Formwork to Construct Rammed Earth Columns and Walls." Proceedings of the 11th International Conference on Non-conventional Materials and Technologies (NOCMAT2009). September 2009, Bath, UK.

Chandler, A. and R. Pedreschi, eds. 2007. Fabric Formwork. London: RIBA.

Gauzin-Müller,D., M. Fuchs. 2020 "construire en terre coulee: une revolution?" D'architectures 278 – Mars '20.

Grometer, S. "Rammed Earth: from Pise to PISE." In The art of Natural Building, Second Edition", Edited by Kennedy, J., M. Smith, C. Wanek, 189-194. Gabriola Island, British Columbia; New Society Publishers, 2015.

West, M., 2017. "The Fabric Formwork Book: Methods for Building New Architectural and Structural Forms in Concrete." New York: Routledge.

***Catherine Page Harris**, MLA UC Berkeley, MFA, Stanford University, teaches Landscape Architecture and Art at University of New Mexico. Built work resides at CO'G McLean Residency, Detroit, The Sevilleta National Wildlife Refuge, Marble House Project, VT, and Deep Springs College, CA. Recent projects include "Poured Earth Collaborative", "Variance Line", "sharing a drink", and "Trans-species Repast".*

***Charlie O'Geen** teaches in the architecture department at the University of Michigan and holds a B.S.Arch and M.Arch from SUNY Buffalo as well as an additional M.Arch from the Cranbrook Academy of Art. O'Geen's work investigates the exploitation of existing site conditions for use as building systems, in opposition to conventional building practices which are materially consuming.*