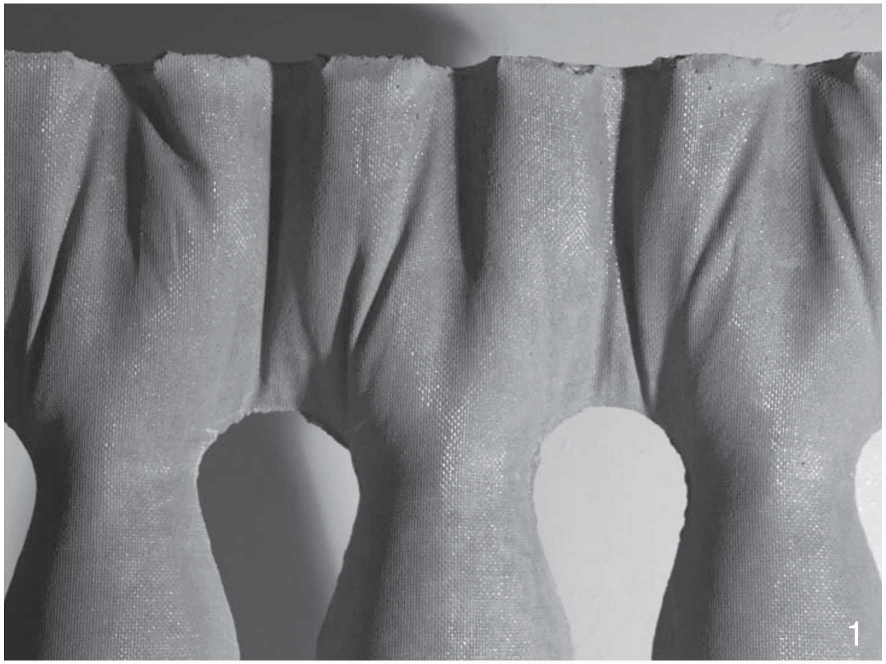
TunaHaki Theatre
Fabric-Cast Walls

Prepared for Armstrong + Cohen Architects and the TunaHaki Orphanage by:
Centre for Architectural Structures and Technology (C.A.S.T.)
University of Manitoba, Faculty of Architecture 2009

Cast-in-Place (CIP) Screen Wall

The C.I.P. wall is designed for simple, low-tech construction that can be accomplished without highly skilled labour or heavy machinery. The height of the formwork is limited to allow hand mixed batches of concrete to be easily lifted and poured into the mold using buckets. There is also a desire to reduce the amount of wood required to frame and support the formwork with an emphasis on designing an assembly that is reusable.



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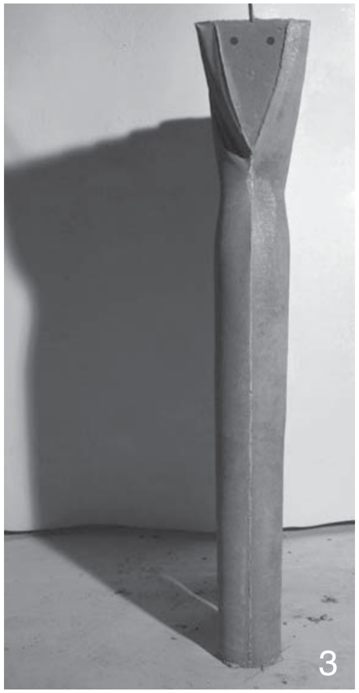

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The C.I.P. screen wall is designed to form a series of small vertical columns joined by a horizontal beam that connects the tops of these columns and forms an open screen. The openings in the wall allow air and light to filter through the wall while reducing self-weight and consumption of raw materials.

1,2,3 After a series of model construction tests, a full scale concrete prototype was constructed to asses the ease of formwork construction, fabric installation, and stripping.

4 At 1.1m tall the screen wall is proportioned to the size of a child with consideration given to the ease of pouring a hand-mixed batch of concrete. Multiple “lifts”, or levels, can be constructed one on top of another to construct tall walls with continuous reinforcing steel running vertically through the columns and horizontally through the beam portions.

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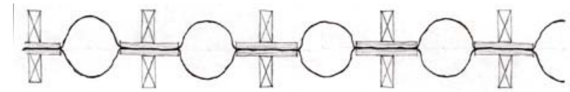

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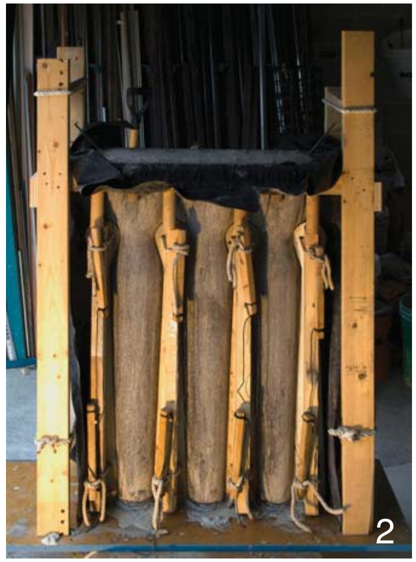
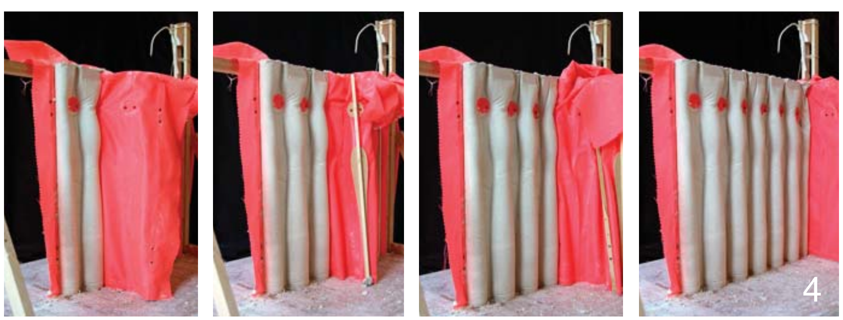
1,6 The formwork is comprised of two opposing rectangular sheets of fabric (we used an inexpensive woven geotextile). Perforations in the wall are made by a series of vertical plywood cutouts - called '*impactos*' - that are attached to the fabric on either side of the mold and pressed against each other to form the wall openings. The fabric is stapled to the plywood impactos, permanently setting their spacing and eliminating the need to reposition impactos on the fabric between pours. Above the impactos, along the top of the formwork, the fabric is stapled to a horizontal member that defines the top edge of the pour. The plan (6) shows plywood impactos supported by dimensional lumber. The fabric between each set of impactos naturally forms a column that is circular in section.

2 Corresponding impactos on opposing sheets are squeezed tightly against each other. We used a twisted rope to do this instead of steel connectors. This simple method of attachment is inexpensive and reusable (described in detail in the Appendix below).

3,4,5 The fabric taken up in the formation of the circular sections of the columns produces an excess of fabric along the upper beam portion of the mold, forming deep folds that can be captured in the hardened concrete. If the fabric is captured it must be cut to be removed, destroying the mold. These extra fabric folds can be controlled by giving them their own impactos to "use up" the extra fabric, and to guide their curvature into an ornamental "entablature" (3,5). A vertical pre-tensioning of the fabric along the impactos prevents horizontal wrinkles from forming in the column shafts .

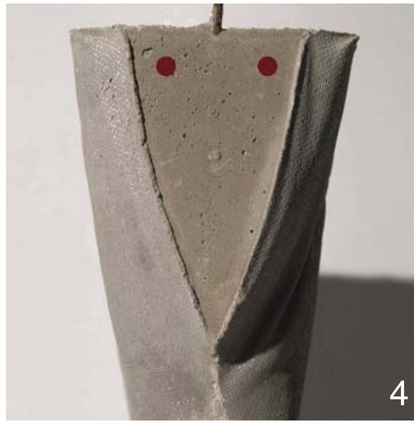


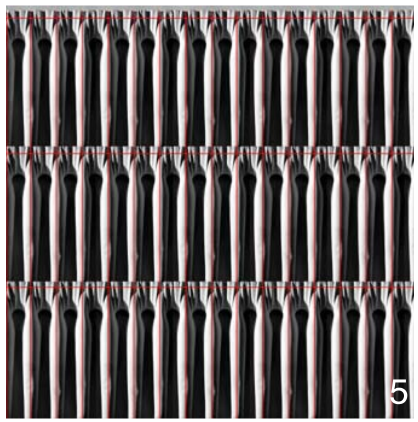


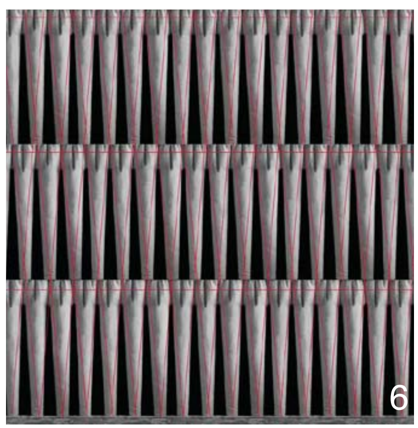
The two sheets of fabric, along with their impactos, form a self-supporting two-part mold. 1 and 2 show the two sides of a test mold. The rigid, horizontal, top-edge member (concealed by fabric in photos) sets the height of the pour and the spacing of the impactos. We recommend that the spacing of the impactos be set by a flexible rope or fabric strip as indicated by the dotted line in 3. This will facilitate easier stripping of the formwork as it allows the mold walls to be flexibly peeled back, one column at a time (4). If the rigid horizontal member was permanently attached to the impactos each entire half-mold would have to removed as one unit.

A ‘hard’ spacer, such as a board or pipe, is required to establish the position of the first and last impacto and to bring the rope or fabric spacer taught, aligning all the intermediate impactos in the process.

5 One half of the formwork has been removed from this plaster model, revealing the ropes that attach opposing impactos and connect the two sides of formwork.





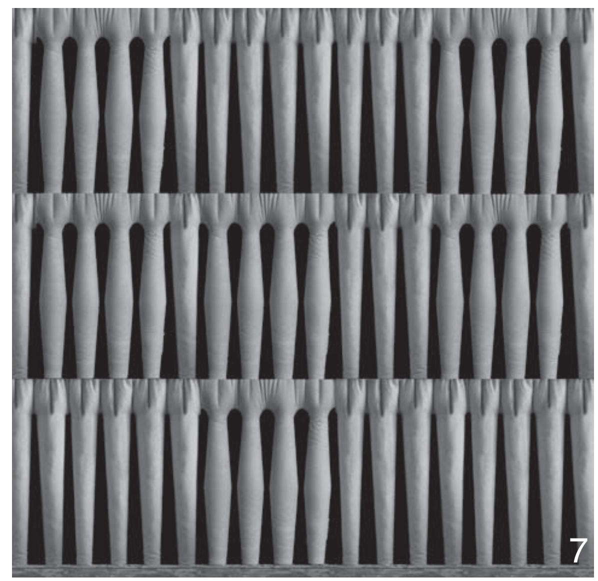


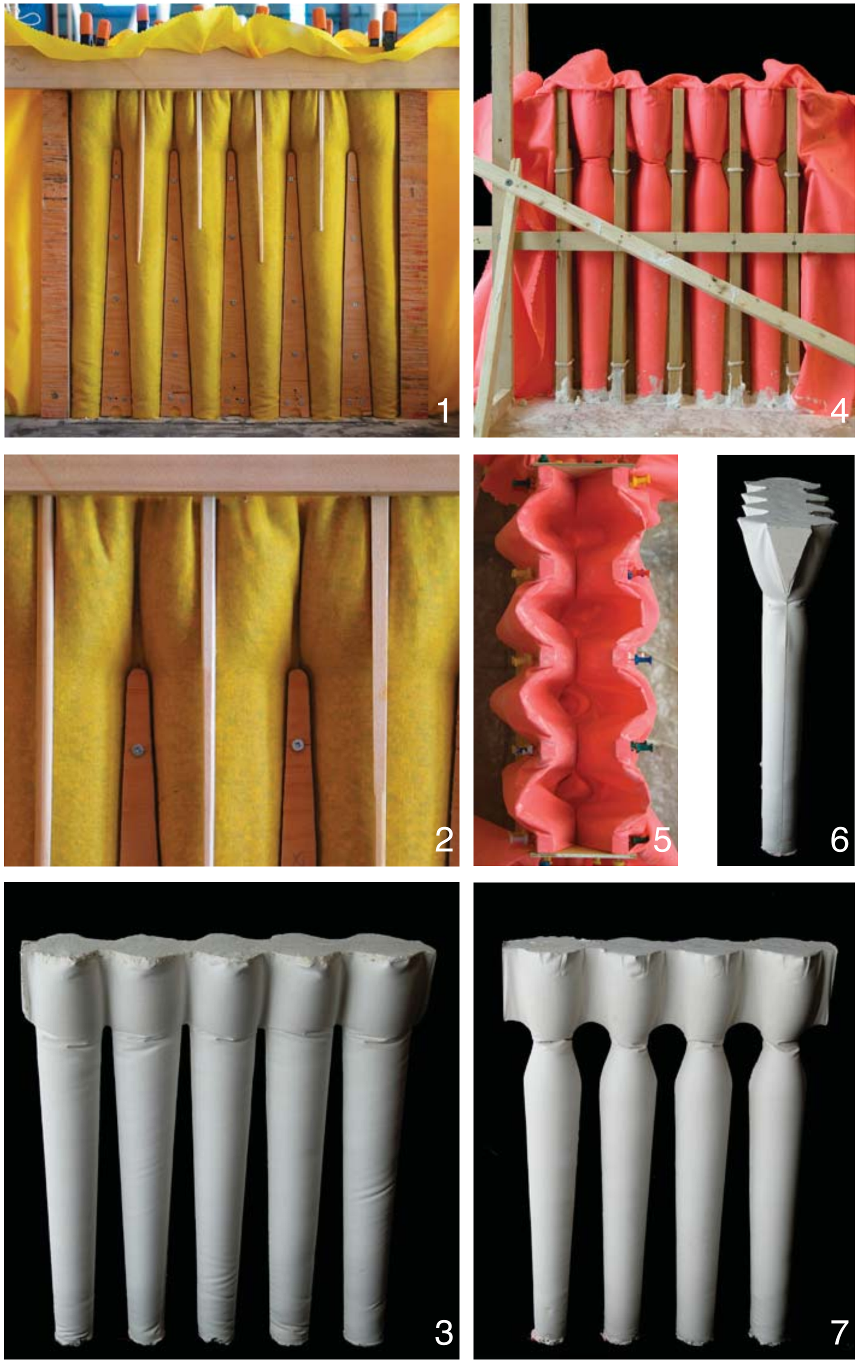
The construction process for the C.I.P. wall consists of a series of self-supporting "lifts" where each subsequent formwork assembly is supported by the previous pour. This is illustrated in photos 1,2,3. Here the fabric formwork is shown extending beyond the screen wall to form a structural column to be poured sequentially with the screen wall. The assembly may also be used to connect the screen wall to a previously cast structural column or to further extend the screen wall on its own. The height of each course, 1.1m (3 1/2 ft), is based on a reasonably comfortable height from which to lift and pour a hand-mixed batch of concrete.

4 Profile of full-scale concrete model with the location of horizontal beam reinforcing shown.

5,6 Two versions of a three-course screen wall showing location of steel reinforcing.

7 A three-course screen wall utilizing a combination of two different impacto shapes.





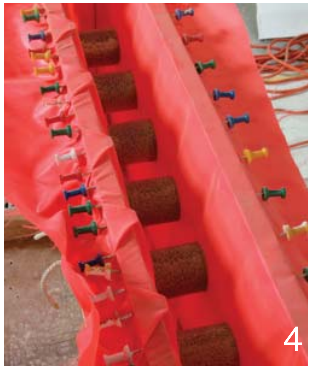
Plaster models of several different C.I.P. screen wall explorations:

1,2 Investigating the use of dowels to mediate bulging and folds in the beam portion of the cast. These fabric formworks are filled with sand to give a first rough model of the hydraulic pressure of concrete.

3 Early plaster cast formed without dowel impactos or vertical pre-tensioning of fabric.

4,5,6 A mold without the rigid top edge member. The free fabric edge at the top allows the fabric to naturally form the upper beam condition.

7,8 Without a ridged board along the top edge, the fabric can only be pre-tensioned (using pins) along the impactos (5). Photo 8 shows a close up of the resulting buckled folds in the “neck” of the column below the beam portion of the cast. These folds can be removed by pulling the fabric above these folds upwards to a rigid horizontal board installed along the top edge of the formwork.

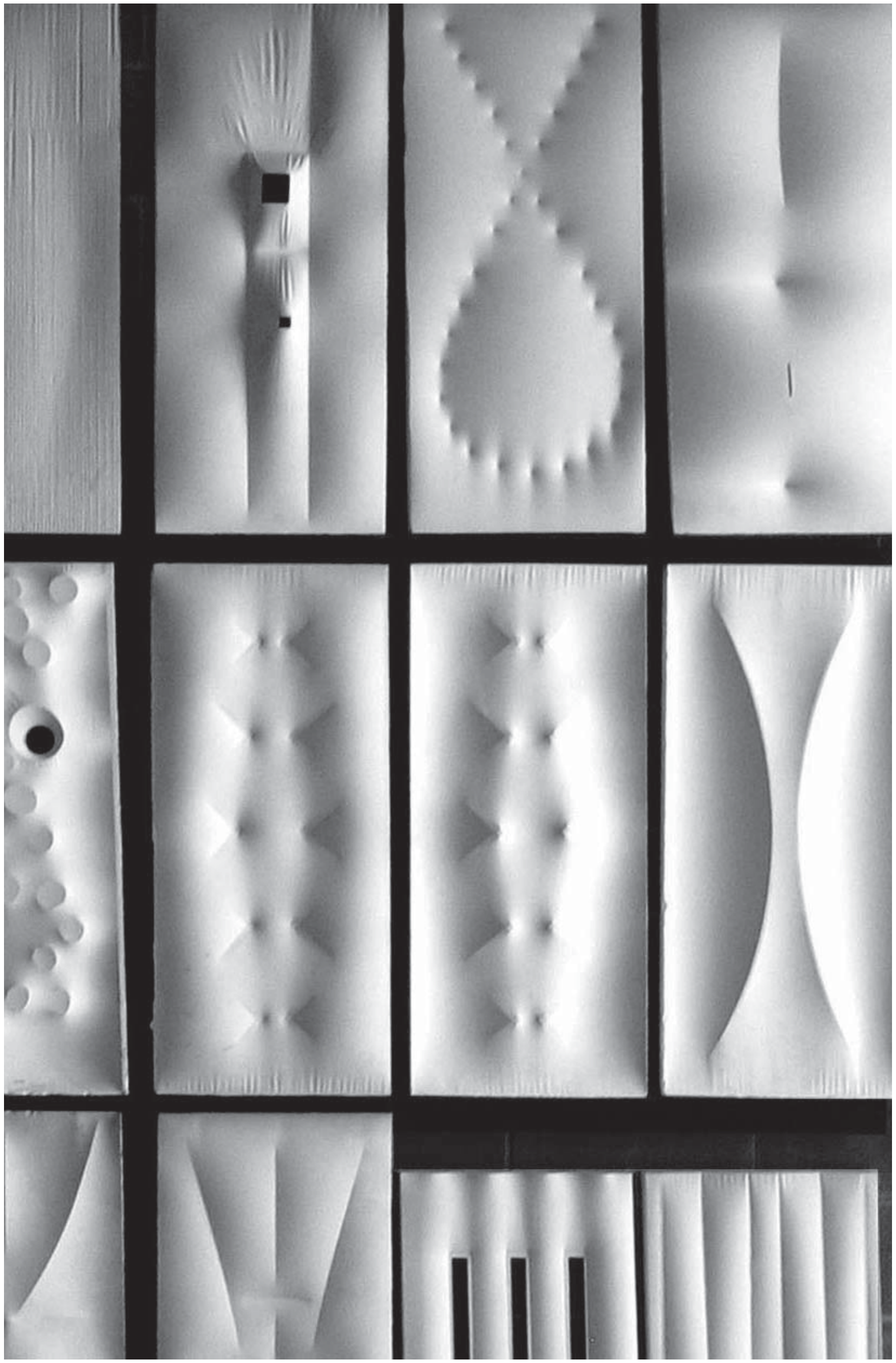


1 Further explorations include a combination of complete perforations and partial-depth impactos, where a space is left between the impactos to form a thin, solid, portion of the wall (2). In this case the impactos may be spaced and restrained from the outside by horizontal beams or buttresses, or by standard wall form-ties.

Partial-depth impactos form a series of pilasters rather than columns in-the-round. Because the impactos on opposing sides are not touching each other, the size, shape, orientation and spacing of impactos on each side of the wall can be quite different, allowing a wide range of possible wall sections and facade designs.

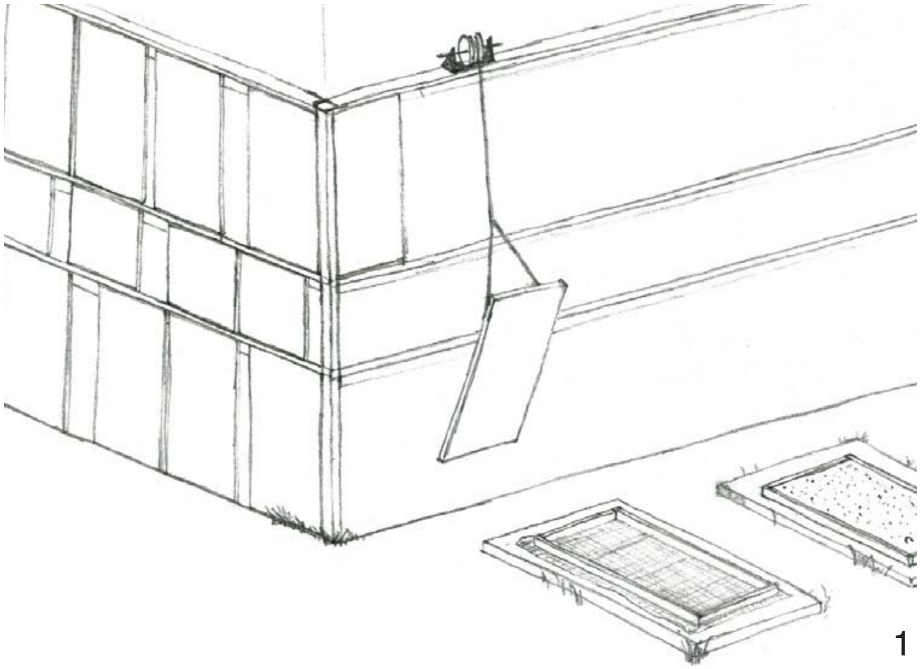
3, 4 Perforations in such a wall are created by block-outs, identical to those constructed for standard rigid wall forms. In this model we used foam cylinders to model full-scale block-outs.

5 Partial depth impactos leave an imprint of their shape on the wall while forming a unique entablature that connects the pilasters to a top beam section with perforations.



Tilt-Up Panels

Fabric formwork can be used to produce a screen wall composed of individual pre-cast or tilt-up panels. The construction process is identical to traditional tilt-up or precast panel construction except that the formwork uses fabric to shape the concrete.



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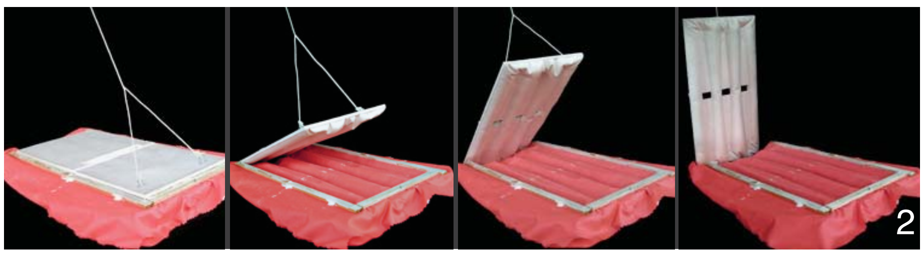

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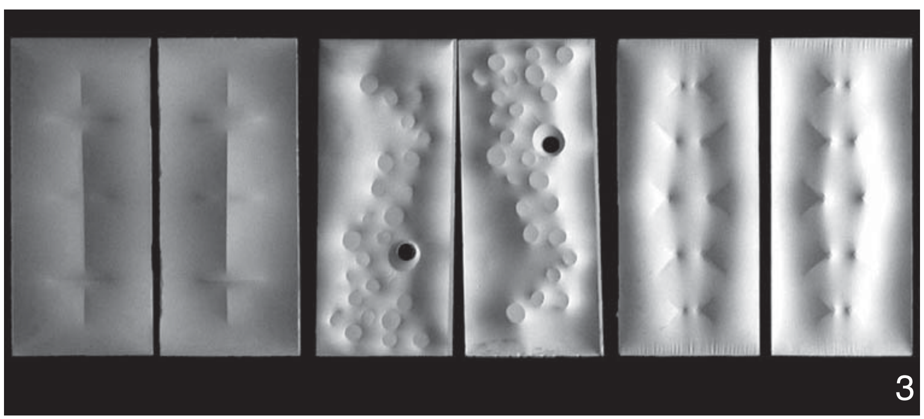

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Panel Face Design

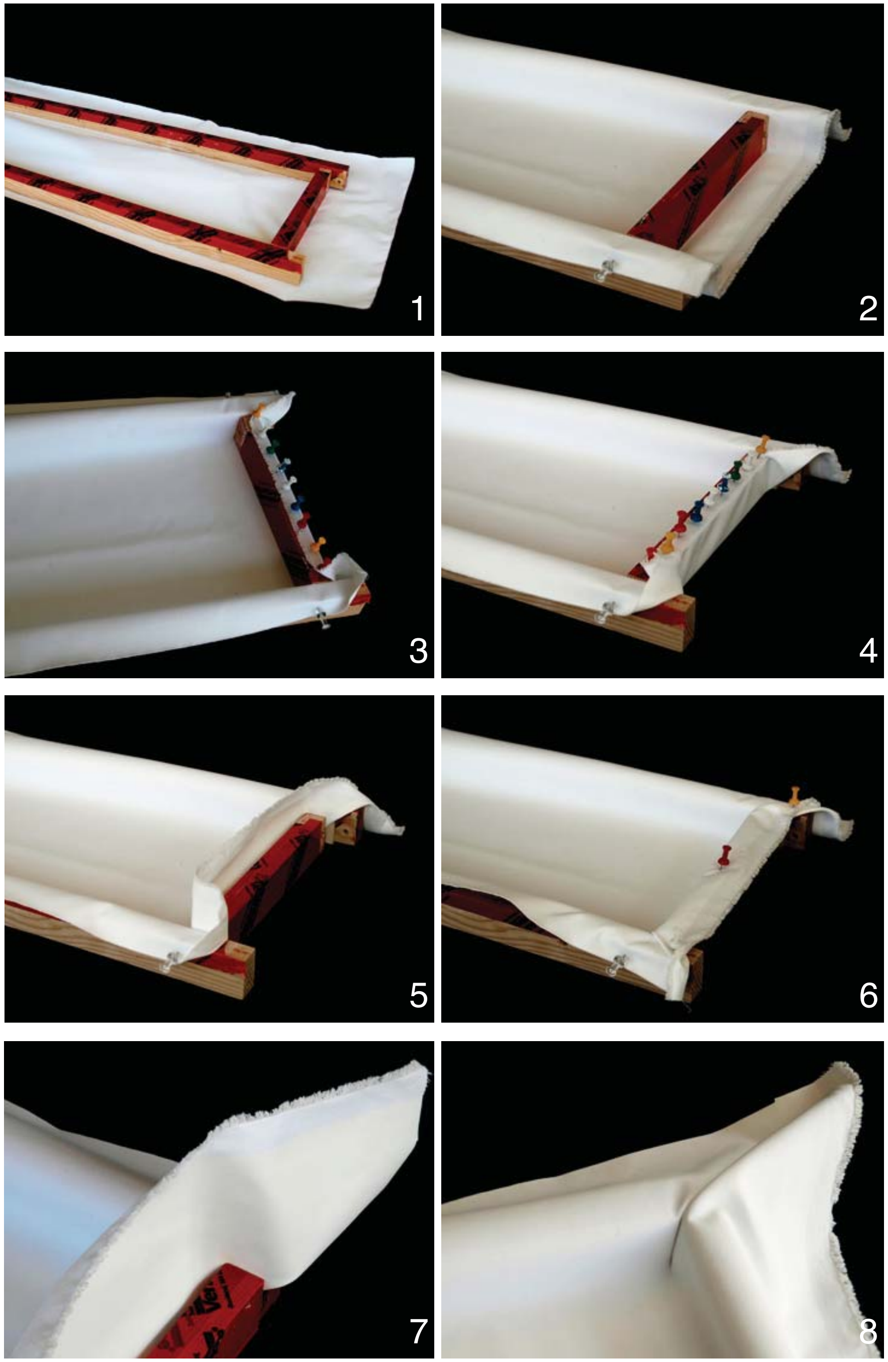
Constructing tilt-up panels requires a flat, level base on grade to carry the frame assembly. Alternatively, the formwork could be built using the building's ground floor slab.

Each formwork assembly can be reused many times with the same pattern, or a new design can be created within the frame using the same fabric membrane. We do not know the maximum number of re-uses for a particular fabric sheet, but believe that it will certainly prove to be more reusable than wood. If and when replacement is required, polyethylene fabrics are very inexpensive.

1,2 Panels can be lifted into place using the existing structure as a crane. Each panel can be lifted and installed as soon as the concrete has cured, eliminating the need for storage, and the formwork can be used for additional casts.

3 Alternately, a fabric-cast panel may be used as the mold for "invert-cast" panel production. Three examples are shown here of fabric-casts and their corresponding invert-cast panels. In this case, the thin and thick portions of the initial cast are reversed in the final panel production.

Although inverted panel casts are mentioned here as an option, this document concentrates on direct-cast production techniques.



Fabric + Frame Assembly Options

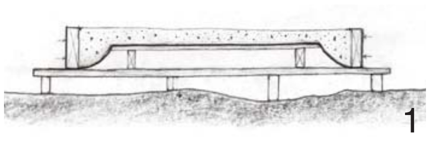
The perimeter frame for the panel formwork sets the fundamental dimensions of the panel - length, width and maximum depth. The models shown here are 1:5 scale versions of 100cm x 380cm x 15cm panels. Recommended full-scale fabrics would be coated woven polyethylene tarps. These would be waterproof forms that allow easy de-molding and would protect frame members from the concrete. The fabric should be able to stay with its frame so that it does not have to be re-set for each pour.

The frame may be laid directly on top of the formwork fabric (1), in which case the cast panel edges will all be formed directly by the inside surface of the frame. This arrangement allows the fabric to be horizontally pre-tensioned (stretched) on all sides and in any direction

Alternately the fabric may be draped over one or more sides of the frame. Photo 2 shows the fabric draped over the long sides of the frame, with the shorter end frame piece(s) placed on top of the fabric. This arrangement allows the fabric to be pre-tentioned longitudinally only (3,4). The long edges will be fabric-formed, and the short edges will be formed directly against the surface of the frame.

The fabric may also be draped over all the frame edges (5,6). This will give the panel four fabric-formed edge surfaces. The corner detail in this case is similar to folding a “hospital corner” on a bed sheet. Photos 7,8 offer close-up views of this technique, where the extra fabric in the corner is folded and tucked inside the frame joint. If this tuck is not made, the extra fabric will bunch and buckle into the corner of the frame. This can be done, but the panel will not de-mold without lifting the fabric out of the frame with the cast panel and pealing the fabric off the concrete.

Treatment of Fabric at Edge Condition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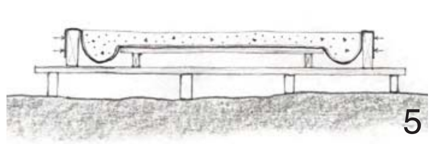
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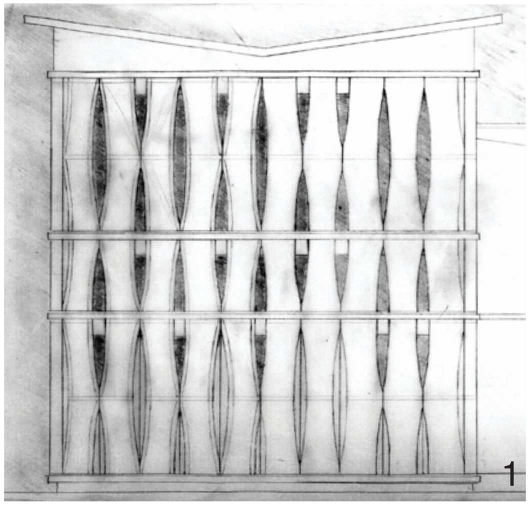
The schematic section drawing 1 and model photo 2 show a formwork fabric placed beneath the frame edges. In this case, the shape of the panel's structural edge beam will terminate in a sharp edge around the perimeter of the panel (3,4).

Fabric placed beneath the mold frame edges can be pre-tensioned. If this pre-tensioning is done evenly in both longitudinal and transverse directions (like stretching a drum head) it can produce a taught skin free of wrinkles (3). If the fabric is stretched in one direction only, it can induce pronounced linear wrinkles aligned with the direction of the pre-tensioning, as seen in 4.

The schematic section drawing 5 and model photo 6 show a formwork fabric draped over the frame edges. In this case, the shape of the panel's structural edge beam will terminate in a curved edge at the perimeter of the panel (7).

Because the fabric must draped down from the top of the frame edges, this configuration does not allow the fabric to be stretched (pre-tensioned) into place. A relaxed, draped, fabric will form limpid wrinkles that distribute themselves without a particular directional bias.



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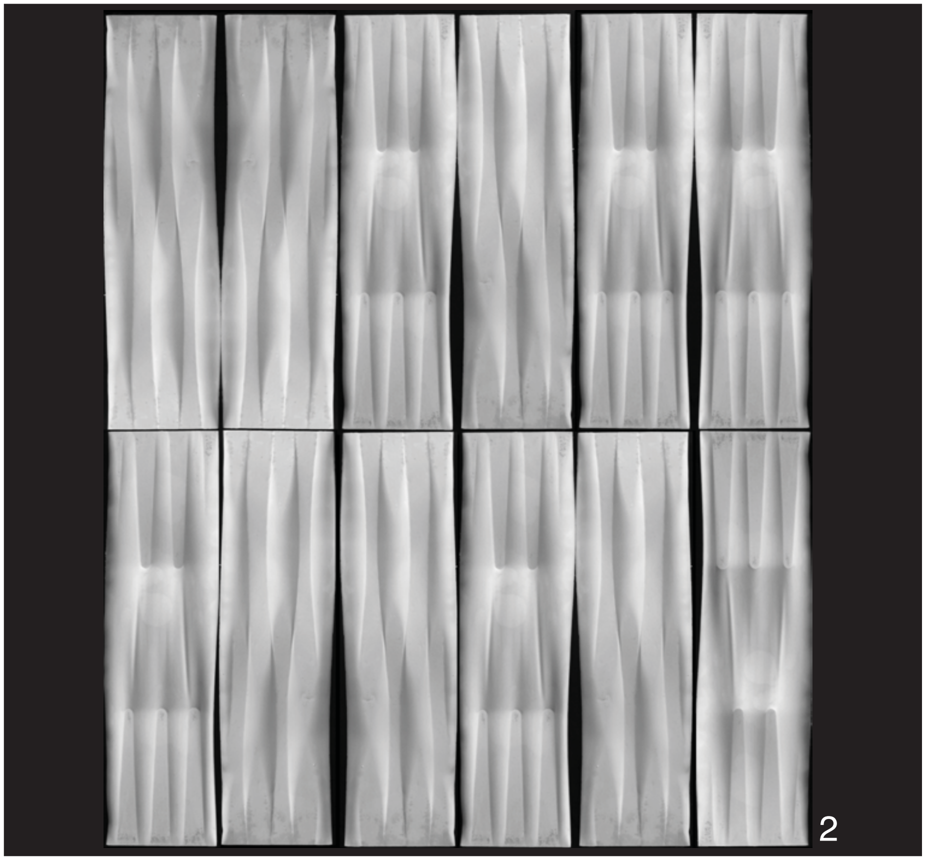

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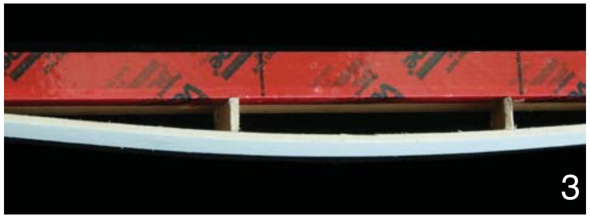
Panel Edge Options

1,2 The flexibility of fabric formwork makes it possible to easily form panels with either straight or curved edges. This allows the formation of curved wall openings formed by gaps between individual panels.

3,4,5 Curved edges can be formed by springing a thin edge spline (plywood, thin-sawn lumber or sheet metal) against the side(s) of a panel mold frame. A mild pre-tensioning of the formwork fabric along the length of such a curved edge will help remove wrinkles that might otherwise form due to the curvature of the edge.



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Panel Face Design

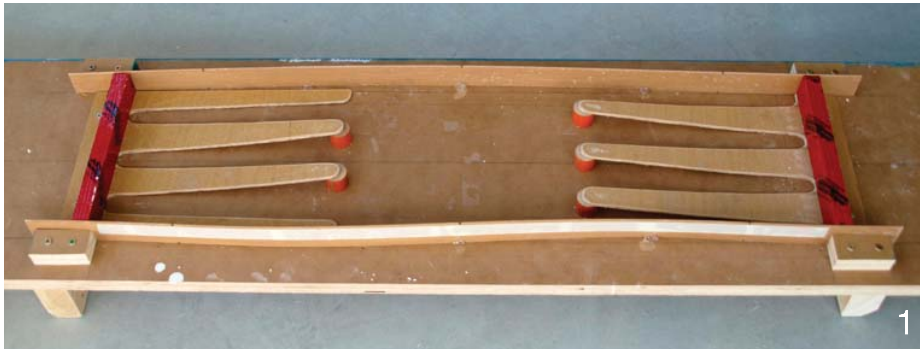
Panel face designs are made by placing intermediate supports beneath the formwork fabric. These may be made from any locally available materials - lumber, plywood, piping, rope, masonry units, etc. (1, 4). Objects placed beneath the fabric make their own impression, plus the impression made by the fabric as it negotiates between these supports and the edge frames.

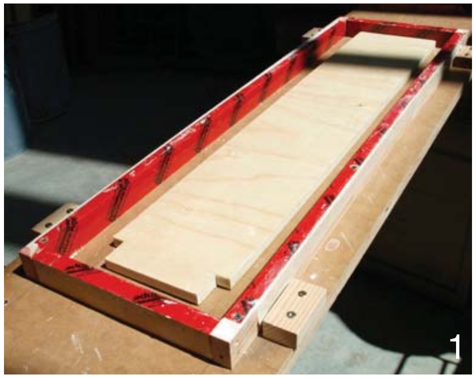
Our strategy for placement of intermediate supports provides a full 15cm depth along the panel's boundary edges while reducing the thickness of the concrete in the panel's face. This approach provides a sculpted surface of reduced weight and material, with stiff 'beams' on all four sides.

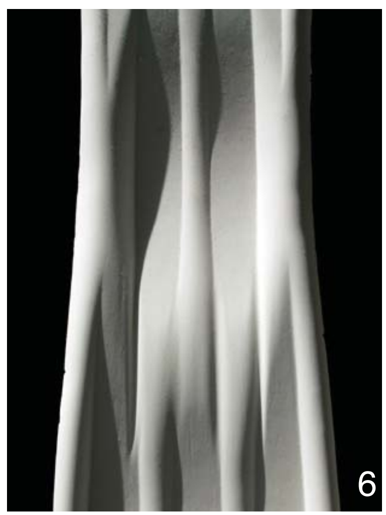
2 The formwork fabric is stretched over the frame and intermediate supports. This example shows the fabric pulled (pre-tensioned) in the long direction. This emphasizes longitudinal folds, and diminishes (or eliminates) perpendicular folds. Similarly, pulling the fabric in the transverse direction would emphasize transverse folds and diminishes longitudinal folds.

The plywood supports in this example (1,2,3) are designed to bend under the weight of the concrete to produce gently curved impressions.

Design options are unlimited. Examples here include impressions given by point supports, ropes (4), dimension lumber and selected linear prestress of the fabric itself (5).







Strategies for reducing concrete in the central portion of a direct-cast panel include providing a slightly raised “table” inside the mold’s edge frame (1). The deeper troughs created between the edges of this ‘table’ and the frame form the panel’s edge beams. Further low-relief impressions (2), may be formed by placing objects on the ‘table’ or by changing the profile of the table’s edges.

An undulating ‘table’ can be provided by using thin plywood or sawn lumber pieces placed beneath the fabric as gently curving splines (4,5,6). Care is taken here to assure that the edges of the cast maintain their full structural depth. Examples 3,5,6 also use a curved spline edge frame, as described previously in “Panel Edge Options” above.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Wrinkled Form-Liners

Another panel face option is to use the formwork fabric as a form-liner to give a wrinkled texture. This is probably less interesting and less useful for the TunaHaki Theatre panels because it is a strictly decorative (though quite beautiful) application that would tend to increase the amount of concrete needed rather than reduce it. In any event, it is mentioned here so you will have a full range of options before you.

Photo 3 shows a pre-cast concrete panel cast in the formwork shown in 4, in which a crumpled fabric form-liner is placed on a flat surface. A close up of the crumpled fabric is shown in 2. Photo 1 is a close-up of the cast concrete.

It will be appreciated that the wrinkles in the fabric form-liner effectively cut into the structural section of the panel. The texture given by such a form-liner should be considered an additional concrete ornamentation on top of the structural thickness of the panel.

The edge detail for such a mold demands some attention, care and special materials, raising questions about the appropriateness of this technique for construction in Moshi. 5 shows the wrinkled fabric cut in a straight line at the edge of the mold (a job that requires some skill and care). A soft styrofoam sheet is placed on the inside surface of the mold frame and pushed against the cut edge of the fabric, thus sealing the edge of the mold.

An alternate edge detail (6) uses a soft foam rubber strip that is simply pressed down on top of the wrinkles with no edge cuts required. The foam rubber is sealed with a thin plastic tape, allowing its release from the concrete. Wrinkles should not be pressed down at the edge by a rigid mold frame, as this will produce undercut folds that will be captured in the concrete.


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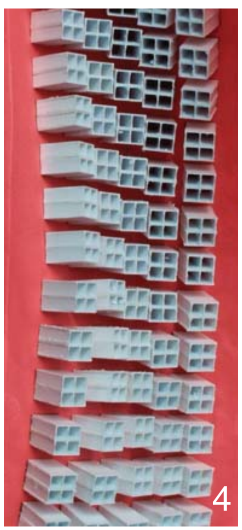
Masonry Perforations

Perforations can be cast directly into precast panels using hollow compressed earth blocks, clay tile, or concrete units (1). The widely available masonry units bond with the concrete, becoming integrated within the wall.

The hollow blocks are set against the surface, of the formwork fabric (4). They may be held in place by dead weight placed on top of them, or by tieing them to a matching flat surface (ex. plywood rectangle) on the opposite side of the fabric.

The units project beyond the surface of the troweled (top) side of the panel, allowing a spatial mirroring of the shape of the surface on which they rest beneath the fabric. Photo 8 shows the units following a curved surface, while the troweled surface remains flat. This could help to soften the panel's otherwise brutal top surface.

Tieing these units to the fabric allows them to actively engage in altering the impressions left by the fabric (2,3,5,6,7). For example: 2 shows the units pushing and pulling the fabric let and right. 3+7 show the units twisting the fabric.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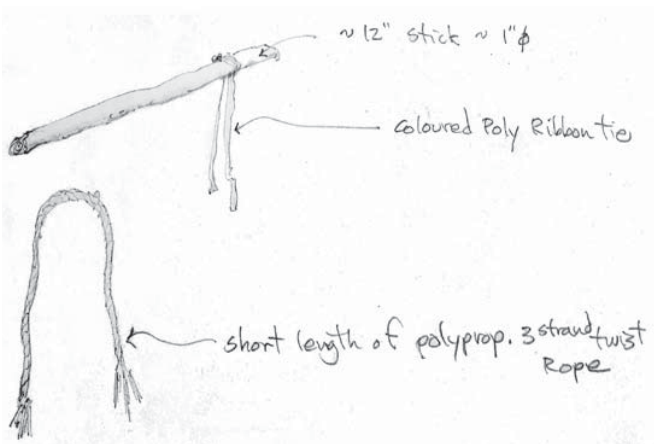
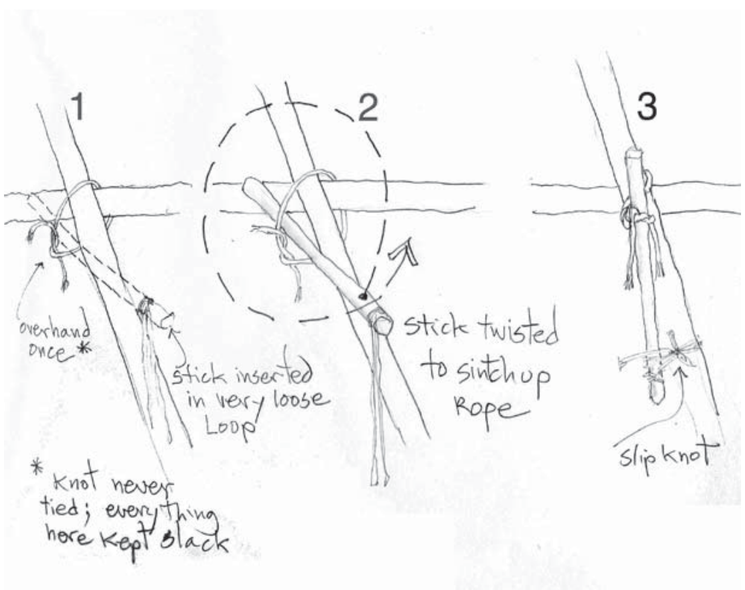
APPENDIX

“Thai-Tie” Twisted Rope Connectors

This excellent and inexpensive connector is used in Thailand (and perhaps elsewhere) to connect scaffolding parts. It is both flexible and secure. The sketches (Left Top and Left Bottom) describe the parts and method. If the rope slips when it is twisted tight, this is because the diameter of the rope is too small relative to the diameter of the stick. Increasing the diameter of the rope (or decreasing the diameter of the stick) will solve this problem.



The connector parts are bundled together for storage and transport: one stick + one rope, bound together with the small tie that is attached to the stick.



Here are two photos of Thai-Tie connections at C.A.S.T., connecting steel pipes in one case, and squeezing formwork *‘impactos’* together in another.