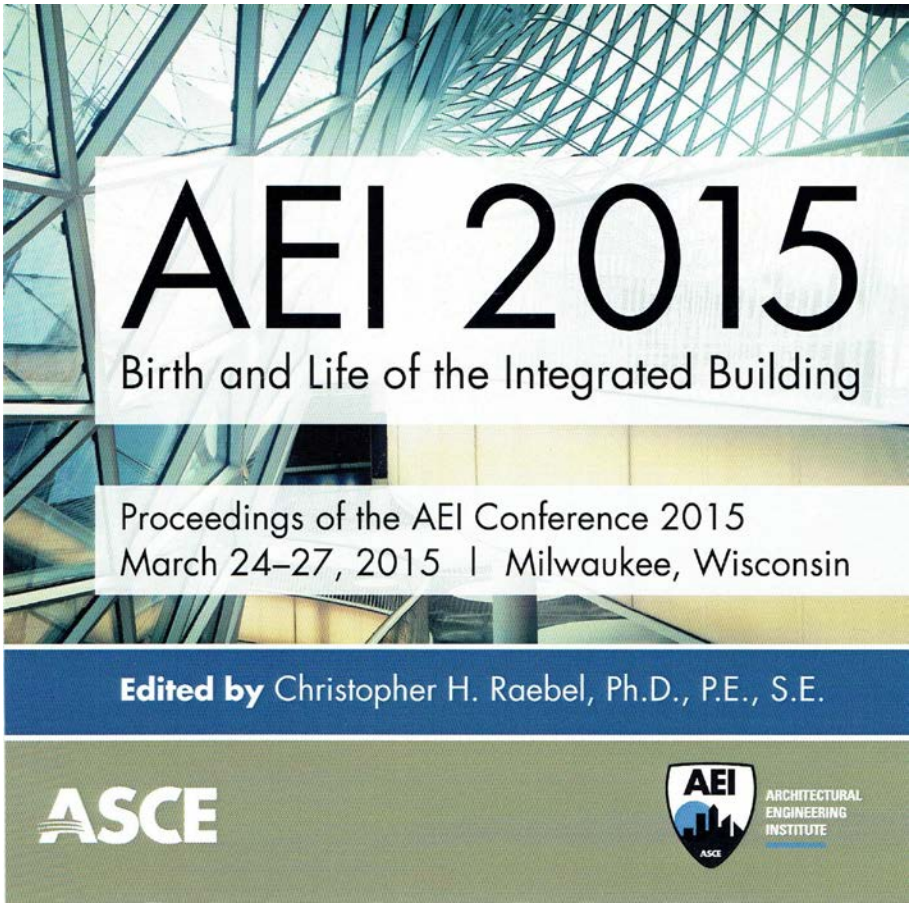
FABRIC FORMS FOR ARCHITECTURAL CONCRETE:
A STATE-OF-THE-ART REPORT

Author:
Robert P. Schmitz, P.E.
RPS STRUCTURAL ENINEERING, LLC
Brookfield, WI 53045-5504
Phone: 1-262-796-1070
E-mail: rpschmitz@rpschmitz.com
Web Sites: http://www.rpschmitz.com
http://www.fabric-formedconcrete.com
http://www.fabwiki.fabric-formedconcrete.com



FABRIC FORMS FOR ARCHITECTURAL CONCRETE: A STATE-OF-THE-ART REPORT

Robert P. Schmitz, P.E., M. ASCE

Milwaukee School of Engineering, M.S. in Structural Engineering, 2004
North Dakota State University, B.S. in Civil Engineering, 1984
University of Wisconsin-Milwaukee, B.S. Architecture, 1973
RPS Structural Engineering, LLC, Brookfield, WI 53045,
Phone: 1-262-796-1070,
E-mail: rpschmitz@rpschmitz.com
Web Sites: http://www.rpschmitz.com, http://www.fabric-formedconcrete.com,
http://www.fabwiki.fabric-formedconcrete.com

ABSTRACT

The use of a flexible formwork appears to be ill-suited for casting any concrete member. However, this method of casting concrete may in fact be used anywhere a rigid formwork is used and is beginning to attract attention as a method of construction.

This paper will highlight a few of those engineers, architects, designers and researchers worldwide who have made use of this unique way of forming concrete and focuses on fabric formworks for use in forming concrete members used in architectural works.

A significant amount of research remains to be done to bring this unique method of forming concrete into everyday practical use by the construction industry. Researchers in the university faculties of architecture and engineering (structural) as well as design practitioners in these fields will surely benefit from this paper, which provides a state-of-the-art update on the use of fabric as a formwork for concrete construction.

INTRODUCTION

Background. An article by Mark West, Director of the Centre for Architectural Structures and Technology (C.A.S.T.) at the University of Manitoba, Canada, published in *Concrete International* was the author's first introduction to flexible formwork [1]. For more than a decade professor West and his architectural students at C.A.S.T. have been exploring the use of flexible formwork for casting concrete wall panels and other members. There are not many people in the U.S. aware of this unique method of forming concrete and most of the research being conducted at the present time is in Belgium, Canada, Chile, Denmark, England, the Netherlands, Scotland and Switzerland. See the Research Papers webpage on the International Society of Fabric Forming website listed under 'FURTHER INFORMATION' for current researchers.

This paper is based on an article written by the author and published in *Concrete Plant International* which came as a result of an ACI Fall Conference Formwork Session presentation and a recent paper for The 3rd International Conference on Civil Engineering and Urban Planning (CEUP 2014) held in Wuhan, China [2], [3].

First Formworks. Since its invention by the Romans, concrete has been cast into all manner of formworks whether temporary or permanent. All-rigid formworks including rubble, brick and wood have become the containment form of choice for our modern concretes and an industry standard practice ever since humankind first sought to contain these early forms of mortar and "concrete" in their structures, Figures 1 and 2.

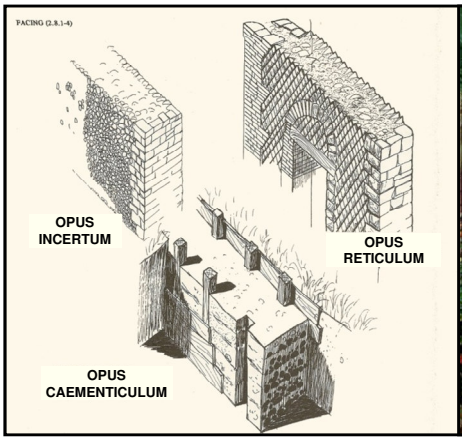


Figure 1. Vitruvious, Ten Books on Architecture
(I.D. Rowland and T.N. Howe, Editors)

Figure 2. Roman wall, Alexandria Egypt, (RPS Photo)

Historically both civil engineering and architectural projects have benefited by the use of fabric as a formwork for concrete containment. This versatile means of containing concrete saw some of its first use in civil engineering works such as erosion control. Developed and patented by Construction Techniques, Inc. in the mid-1960's Fabriform® is the original fabric-formed concrete system. Their products include Articulated Block, Filterpoint, Unimat, Concrete Bags and Pile Jackets, Figure 3. See Fabriform's website listed under 'FURTHER INFORMATION'.

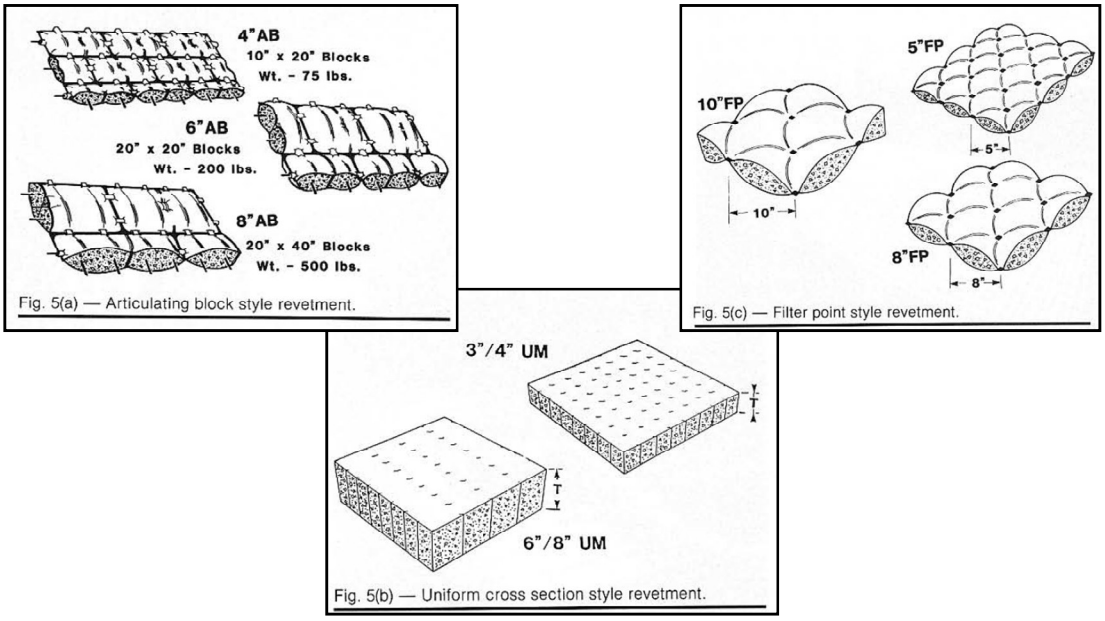


Figure 3. Fabric forms for concrete (B. A. Lamberton, Concrete International, 1989 Vol. 11).

Engineers who have reported on the use of fabric-formed concrete lining used for slope protection include Phildysh & Wilson [4] and Lamberton [5]. See Figure 4.

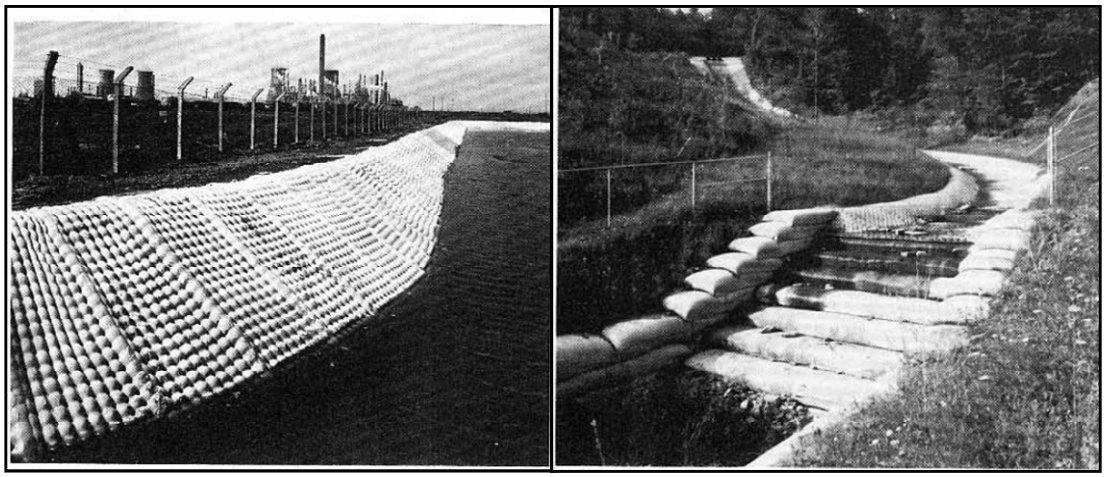


Figure 4. Fabric forms for concrete (B. A. Lamberton, Concrete International, 1989 Vol. 11).

Modern-day Formworks. One of the first architects to use a flexible formwork in an architectural application was the late Spanish architect Miguel Fisac with his 1970's design of the Juan Zurita residence in Madrid, Spain, Figure 5. His use of rope and plastic sheeting to create these precast panels imparts a sense of "warmth and softness" to an otherwise cold and hard substance.

Figure 5. Juan Zurita residence (Studio Miguel Fisac).

Another architect whose work has softened up concrete is Japanese architect Kenzo Unno. Working independently of Fisac he has developed several cast-in-place (CIP) fabric-formed wall systems since the mid-1990's. The Kobe earthquake on January 17, 1995 provided the motivation for Unno to create residential designs that are intended to provide safe housing using simple methods of construction with as little construction waste as possible. Using standard wall ties and the wall's reinforcement for support of the fabric membrane his quilt-point restraint method, for example, creates a pattern reminiscent of a quilt for the Eiji Hoshino Residence, Figure 6.

Figure 6. Quilt-like formwork pattern used for the Eiji Hoshino Residence (Mark West photos).

For the Susae Nakashima "Stone Renaissance" house a "frame" restraint method was employed using pipes at a slight angle to restrain the fabric and give these walls their own distinct character, Figure 7.

Two other practitioners that come to mind are Sandy Lawton, a Vermont, USA design-builder, and Byoung Soo Cho, a Seoul, South Korea architect. Lawton used geotextiles to form the columns, walls and floors for a nontraditional "treehouse" which was completed in 2007 and Cho crafted a Korean visitor center and guesthouse completed in 2009 using geotextiles to form its walls. See 'FURTHER INFORMATION' for links to these designers' websites.

Industries are sometimes slow to embrace new technologies and industries utilizing fabric formworks are few. Several industries that have benefited by using flexible formworks are; Fab-Form Industries, Ltd. based in Vancouver, British Columbia, Canada, Monolithic (air inflated domes) based in Italy, Texas, USA and Concrete Canvas Ltd. based in Pontypridd, UK.

It has been said "The beautiful rests on the foundation of the necessary. – Ralph Waldo Emerson". This quote aptly applies to fabric-formed structures as well

beginning with the foundations. Since 1993 Richard Fearn, owner and founder of Fab-Form Industries, Ltd., has developed and marketed several fabric forming products including; Fastfoot® for continuous and spread footings; Fastbag® for spread footings and Fast-Tube™ for piers and columns. See Fab-Form Industries' website listed under 'FURTHER INFORMATION'.

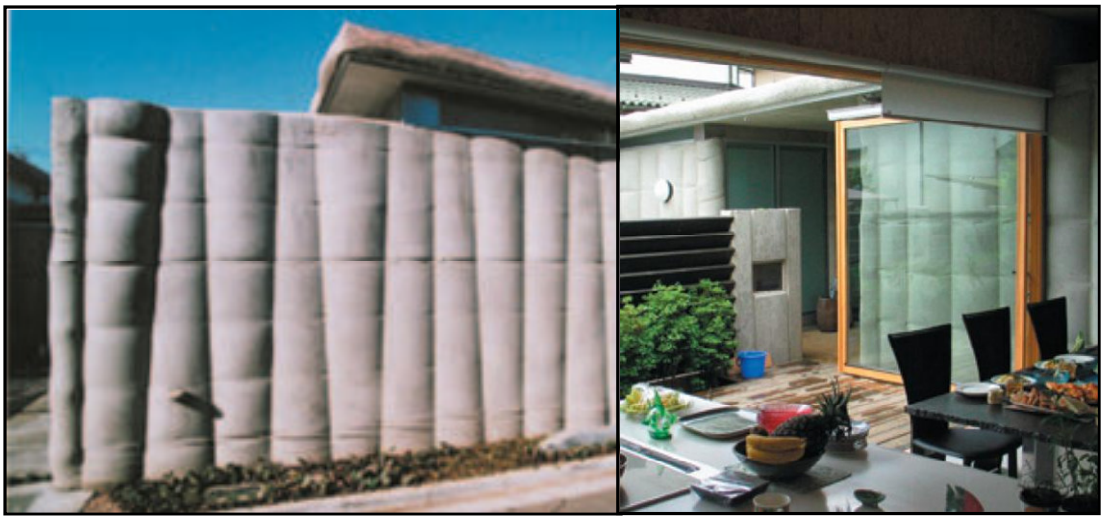


Figure 7. Susae Nakashima "Stone Renaissance" house (Kenzo Unno photo).

Several methods of construction using inflated forms have been available since the early 1940's but it was only recently that ACI (American Concrete Institute) Committee 334 (2005) introduced a standard guide for the construction of thin-shells using inflated forms.

David South, president and founder of Monolithic is the co-inventor of the Monolithic Dome and has been constructing thin-shell domes for more than 40 years. Monolithic's basic steps for constructing a dome are inflating an airform fixed to a foundation, applying a layer of polyurethane foam, hanging reinforcement and applying up to five layers of shotcrete. The inherent tensile strength of the PVC-coated or polyester fabric used for the airform allows it to be inflated to a sufficient strength to support all the applied construction materials until the concrete has cured to the point where the dome is self-supporting. Monolithic's use of fabric allowed the construction of thin-shell domes to once again be done economically. See Monolithic's website listed under 'FURTHER INFORMATION'.

William Crawford and Peter Brewin are directors and co-founders of Concrete Canvas Ltd., UK. Their approach to creating a concrete structure is similar to Monolithic's by using inflation to support the PVC form temporarily. However, that is where the similarity ends. The structures, which can be used as emergency shelters has a PVC form impregnated with concrete that hardens upon hydration leaving a self-supporting structure in place. The companies' concrete impregnated canvas may also be used in civil engineering projects for erosion control. See Concrete Canvas' website listed under 'FURTHER INFORMATION'.

Formwork Applications. These examples highlight where flexible fabric formwork has been used forming architectural applications. Fabric forming applications include:

- Walls
  - Cast-in-place
  - Precast
    - Shotcrete thin-shell curtain wall systems
- Beam and floor systems
  - Trusses
- Columns
- Vaults
  - Prefabrication of thin-shell funicular compression vaults
  - Molds for stay-in-place concrete formwork pans
- Foundations
  - Continuous and spread footings
- Civil engineering works
  - Revetments, underwater pile jackets
  - Coastal and river structures

While it is true that a flexible fabric formwork may be used nearly anywhere a rigid formwork is used, a significant amount of research remains to be done to bring these systems into everyday practical use by the construction industry. Standards and guidelines for using flexible fabric formworks need to be developed for the design community to take full advantage of this unique method of forming concrete members.

As noted above countries with architectural and engineering students conducting most of the current research include Belgium, Canada, Chile, Denmark, England, the Netherlands, Scotland and Switzerland. The most prolific research currently being conducted is under the direction of Professor Mark West, Director of the Centre for Architectural Structures and Technology (C.A.S.T.) at the University of Manitoba, Canada.

BASIC PRINCIPLES

An Introduction to Flexible Formwork. Professor Mark West, Director of C.A.S.T., at the University of Manitoba, Canada and his architectural students have been some of the most prolific researchers as to how flexible formworks can be used to express architectural concrete members. A visit to C.A.S.T. in June of 2004 exposed the author to this unique method of forming concrete members. Professor West and his architectural students at C.A.S.T. first began exploring the use of flexible formwork for precasting concrete wall panels in 2002, [6], [7]. The shape a wall panel could take was first explored using a plaster model with various interior support and perimeter boundary conditions as shown in Figure 8. The cloth fabric, when draped over interior supports and secured at the perimeter, deforms as gravity forms the shape of the panel with the fluid plaster as shown in the completed plaster casts. Once a satisfactory design with plaster has been obtained, a full-scale cast with concrete can be made.

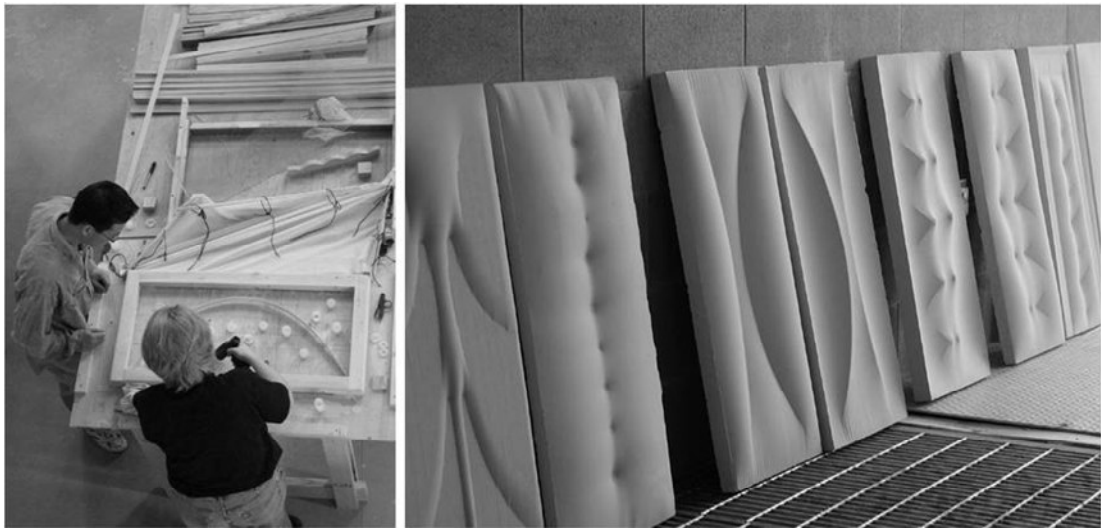


Figure 8. Model formwork and completed plaster casts (C.A.S.T. photos).

The casting of a full-scale panel using concrete requires finding a fabric capable of supporting the weight of the wet concrete. For this purpose, a geotextile fabric made of woven polypropylene fibers was utilized. Assorted interior supports were added to the formwork and the flexible fabric material was pretensioned at the perimeter, Figure 9. Depending upon the configuration of these interior support conditions, three dimensional funicular tension curves are produced in the fabric as it deforms under the weight of the wet concrete. The completed panel is shown in Figure 10.

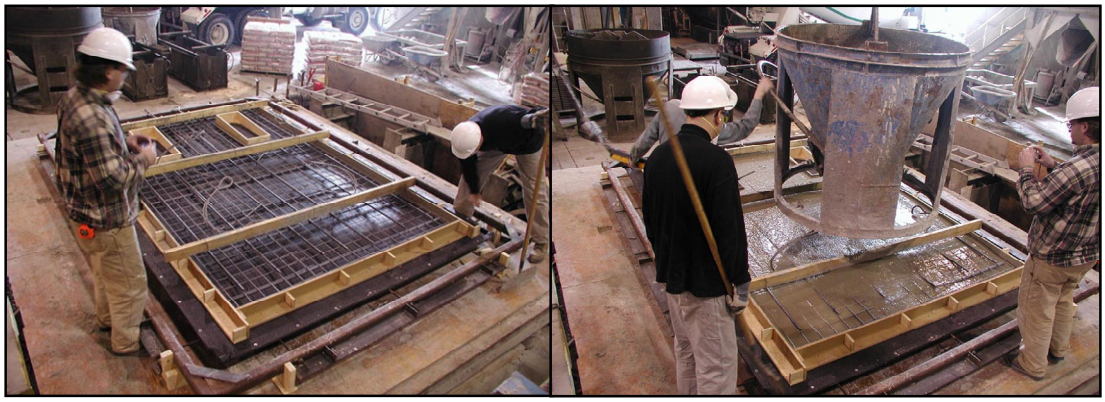


Figure 9. securing fabric, placing reinforcement and concrete in full-scale wall panel formwork (C.A.S.T. photos).

Supporting Elements. Geotextile fabric as a formwork has a number distinct advantages including:

- The formation of very complex shapes is possible.
- It is strong, lightweight, inexpensive, reusable and will not propagate a tear.
- Less concrete and reinforcing are required resulting in a conservation of materials.
- Filtering action of the fabric improves the surface finish and member durability, Figure 10 and 11.

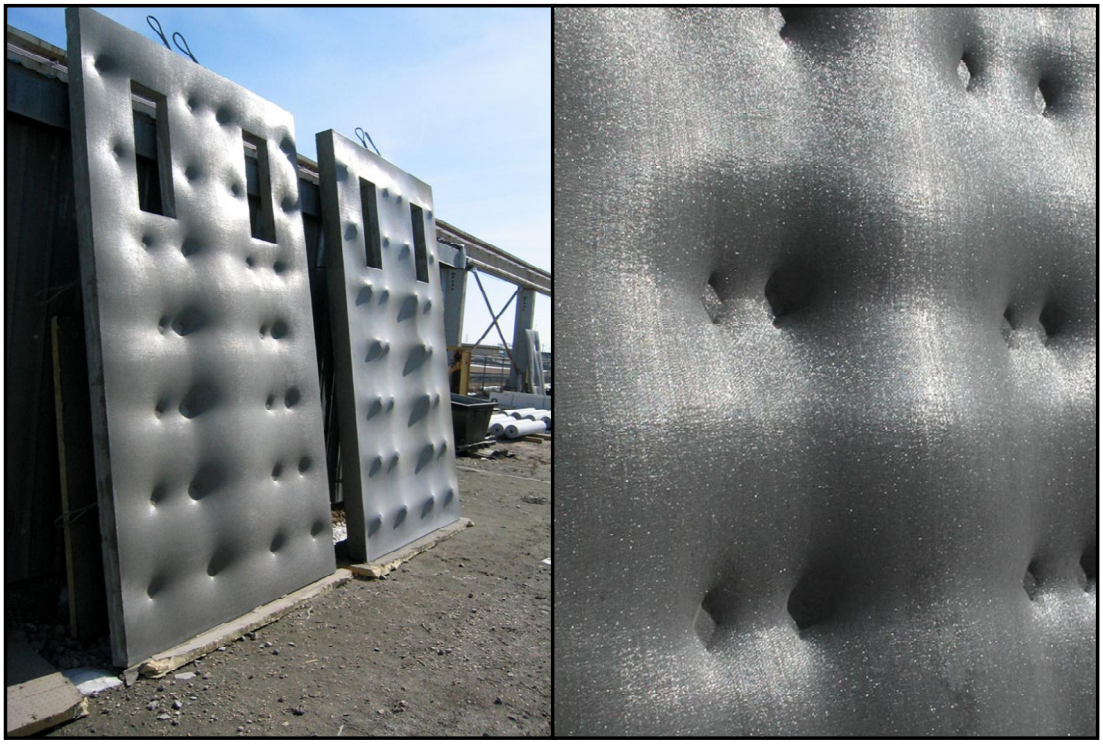


Figure 10. Completed concrete wall panels and surface detail (C.A.S.T. photos).

Figure 11. Filtration of excess water and air bubbles through geotxtile fabric (C.A.S.T. photo).

It also as several disadvantages including:

- Relaxation can occur due to the prestress forces in the membrane.
- There is the potential for creep in the geotextile material, which can be accelerated by an increase in temperature as might occur during hydration of the concrete as it cures.
- The concrete has to be placed carefully and the fabric formwork must not be jostled while the concrete is in a plastic state.

However, until new fabrics are developed the benefits of using geotextiles far out-weighs any disadvantages.

CONCLUSIONS AND FURTHER RESEARCH

Conclusions. By utilizing a flexible fabric formwork, such as a geotextile, several advantages have been noted:

- The formation of very complex shapes is possible.
- Geotextile fabric is strong, lightweight, inexpensive and is reusable.
- Improved surface finish and durability – due to its filtering action.
- A more efficient and sustainable design is possible since material is placed only where it is needed — "form follows function".
- Flexible fabric formwork increases freedom of design expression and can spark the imagination of architects and designers to think beyond the simple prismatic shape.
- The development of a fabric formwork system has the potential to significantly reduce man's impact on the environment in terms of materials and energy usage.

Further Research. The advancement of FABRIC-FORMED concrete would be furthered by:

- Design and modeling verification for research work being done on precast concrete wall panels is needed.
- Investigating reinforcement options:
  - Fiberglass rebar
  - Alkali resistant (AR) glass textile
  - Carbon-fiber grids
- Finding the most advantageous reinforcing textiles for the reinforcement of all fabric-formed members including thin-shell shapes.
- The development of new fabrics, with improved properties over those of geotextile fabrics, for use as flexible formworks.
- The development of standards and guidelines for use in precast and cast-in-place forming systems are needed for this method of forming to be of practical use to the design community.

FURTHER INFORMATION

Readers interested in additional information are encouraged to visit the following websites especially, the C.A.S.T. website at the University of Manitoba where numerous examples and literature on this topic may be found.

- Author's research dedicated website: http://www.fabwiki.fabric-formedconcrete.com/
- The Centre for Architectural Structures and Technology (C.A.S.T.) at the University of Manitoba, Canada: http://www.umanitoba.ca/cast_building/
- The International Society of Fabric Forming (ISOFF): http://www.fabricforming.org/
- Fabriform, Ohio, USA: http://fabriform1.com/
- Byoung Soo Cho Architects, South Korea: http://www.bchoarchitecs.com/
- Sandy Lawton ARRODESIGN, Vermont, USA: http://www.arrodesign.org/
- Fab-Form Industries, Ltd., BC, Canada: http://www.fab- form.com/
- Monolithic (air inflated domes), Texas, USA: http://www.monolithic.com/
- Concrete Canvas Ltd., Pontypridd ,UK: http://www.concretecanvas.co.uk/

REFERENCES

[1] West, Mark. October 2003. "Fabric-Formed Concrete Members." *Concrete International* Vol. 25(10), pp. 55+.

[2] Schmitz, Robert. 2010. "Fabric forms for architectural concrete", *Concrete Plant International* June (3): 102-109.

[3] Schmitz, Robert. 2014. "Fabric-Formed concrete: A novel method for forming concrete structures", Proceedings: Civil Engineering and Urban Planning III published by CRC Press, Taylor & Francis Group, ISBN 798-1-138-00125-1.

[4] Phi Pildysh, M. & Wilson, K. 1983. Cooling ponds lined with fabric-formed concrete. *Concrete International* 5 (9): 32-35.

[5] Lamberton, B.A. 1989. Fabric Forms for Concrete. *Concrete International* 11(12): 58-67.

[6] West, Mark. April 2002. "Fabric-Cast Concrete Wall Panels." Materials Technology Workshop, Department of Architecture, University of Manitoba, Canada. [Internet, WWW]. *Address:* http://www.umanitoba.ca/cast_building/resources.html

[7] West, Mark. April 2004. "Prestressed Fabric Formwork for Precast Concrete Panels." *Concrete International* Vol. 26(4), pp. 60+.