PRESTRESSED FABRIC FORMWORKS FOR PRECAST CONCRETE PANELS

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INTRODUCTION

This paper describes a new method of forming precast concrete panels using a prestressed fabric formwork. Fabric formworks for above-ground applications is a new field, originating from architectural research and building experiments. Unlike conventional formwork technology, which relies on rigid and typically prismatic containers, fabric formworks are flexible. These flexible textile membranes are allowed to deflect under the weight of the concrete they contain, thus producing volumes defined by three-dimensional tension curves rather than planar surfaces.

The geometry of the formworks' deflections will vary depending on the weight and distribution of the concrete, the elasticity and prestress levels of the fabric membrane, and the boundary and intermediate support conditions provided. The three-dimensional geometry of fabric-cast concrete members is achieved by alterations in these constraints.

The panels described in this article are 2.4 m by 3.7 m (8 ft. by 12 ft.).

PRECAST CONCRETE PANELS FROM FLEXIBLE FORMWORKS

Flexible fabric formworks can produce two basic types of panels, "direct cast" panels, and "inverted shell" panels. These two basic types are described below:

Figure 1. Lower frame with intermediate "X" support in place prior to placement of fabric formwork membrane.

Figure 2. Complete formwork prior to placement of reinforcing steel: The fabric formwork membrane has been pre-tensioned over the lower frame and intermediate supports, and the upper frame is in place above the fabric membrane.

Figure 3. The 2.4 m X 3.7 m (8 ft. X 12 ft.) Concrete panel cast from the formwork illustrated in Figs. 1 and 2. Deflections in the formwork fabric have formed four funicular shell shapes in the unrestrained areas between the lower frame and intermediate X-shaped supports.

Figure 4. Another "direct-cast" concrete panel produced from the same lower frame and fabric formwork membrane as those illustrated in Figs. 1 and 2. In this case, however, intermediate supports were provided in a grid pattern. It will be noted that simple changes in intermediate support patterns will produce significantly different panel designs.

"Direct Cast" Fabric-Formed Panels: A Lower Frame, which matches the final dimensions of the panel to be formed, is prepared with intermediate supports placed inside it. *Figure 1* shows a lower frame with X-shaped intermediate supports. A fabric membrane is then pre-tensioned over this frame and intermediate supports. An Upper Frame, used to contain the wet concrete, is placed on top of the membrane and aligned directly above the lower frame, thus completing the panel mold. *Figure 2* shows the pre-tensioned fabric membrane and upper frame in place, ready for the reinforcing steel and concrete.

When wet concrete is placed in this mold, the fabric membrane deflects downward creating three-dimensional tension curves between the supports provided and, in this case, producing the panel shown in *Figure 3*. Using this method, a single membrane can be used to form a wide variety of designs by simply changing the design of the intermediate supports below the reusable fabric membrane. *Figures 4, 5, 6, 7* illustrate alternate designs using the same fabric membrane.

Inverted Shell Panels: By natural law, an inverted funicular tension geometry will produce a pure funicular compression geometry. By following this principle of geometric (and structural) inversion, a "direct cast" fabric-formed panel, such as that illustrated in Figure 3 can be used as a mold to produce lightweight

Figure 5. Another "direct-cast" concrete panel, showing experimental fabric-formed openings.

Figure 6. Fabric formwork rig used to produce the "direct-cast" panel shown in figure 7.

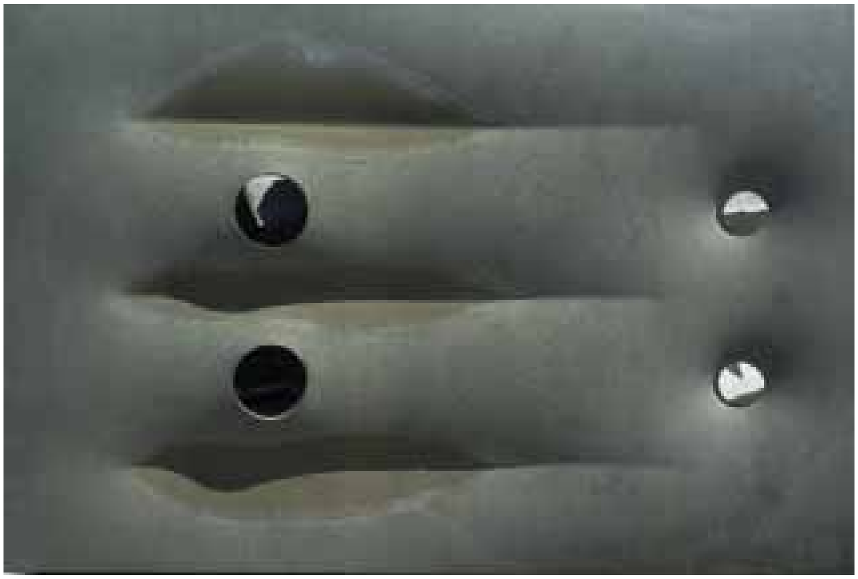

Figure 7. The "direct-cast" concrete panel formed from the formwork shown in Figure 6.

panels with compression shell geometries. *Figure 8* shows the Figure 3 panel inverted to act as a mold and awaiting the placement of reinforcing steel. *Figure 9* shows the lightweight shell panel cast from this mold. In this example, the panel's shells, or vaults, have a minimum thickness of 38 mm (1.5 in.) at the apex of the vault, while the integral perimeter, and diagonal "X" beams, maintain a uniform maximum thickness of 127 mm (5 in.).

Besides the cast concrete shell panel shown in Figure 9, two Glass Fiber Reinforced Concrete (GFRC) panels were also produced using the same process of inverting a direct cast panel to produce a compression shell panel. *Figure 10* shows the lower frame and intermediate supports for one such shell panel mold, and *Figure 11* shows the mold it produced. *Figure 12* shows the GFRC Panel cast from this mold. This panel varies in thickness from 13 mm (0.5 in.) to (38 mm (1.5 in.).

Figure 14 shows another fabric-formed mold and *Figure 15* shows the GFRC thin shell panel cast from this mold. Both the Figure 11 and Figure 14 molds were cast from the same fabric membrane and lower frame. The differences in these two molds are solely the result of different intermediate support designs

Figure 8. The "direct-cast" panel shown in Figure 3 is shown here inverted to act as a the mold for a funicular compression vault. It is shown ready to receive reinforcing steel and concrete.

Figure 9. Lightweight compression vault panel cast from the inverted Figure 3 formwork shown in Figure 8 above. This panel varies in thickness from 38 mm (1.5 in.) to 127 mm (5 in.).

Figure 10. Lower frame and intermediate supports used to produced the Figure

Figure 11. Fabric-cast mold for the Figure 12 GFRC shell panel. This mold was produced from the Figure 10 intermediate support design.

placed within the lower frame.

GENERAL OBSERVATIONS

It will be appreciated that the number of different designs one can produce from such a process are unlimited, and further, that each geometric pattern of intermediate supports will produce its own set of compression shell geometries by virtue of the fabric's structural 'intelligence' in producing pure tension surfaces and corresponding funicular geometries.

Furthermore, following the fundamental natural laws governing funicular structures, the funicular load diagram for the shells or vaults formed by this method are perfectly described by the vertical section through the mold along any axis as illustrated in *Figure 13a,b,c.* It will be noted that the funicular vaults or shells published here were not produced by a uniformly distributed loading pattern. Because the upper surface of the initial direct-cast pour was screeded flat and the wet concrete allowed to "pond" in the fabric's deflections, the true funicular load for the shells and vaults cast from these molds will be seen to increase towards the center of the deflections and decrease towards the membrane's supports (as described by the curves found in the molds' vertical sections). Molds with geometries providing funicular compression resistance to other load patterns can be produced by changing the loading regime used in the production of the direct-cast mold. For example, a mold for a funicular compression shell supporting a uniformly distributed load can be produced by loading the flexible formwork membrane uniformly. Similarly, funicular resistance geometries for concentrated loads can be produced by inducing point loads on the mold's formwork membrane, and so forth.

RESEARCH METHODS

The field of an architecture seeks integration, and following this architectural imperative, the research project described here attempted to accomplish several tasks simultaneously: 1) provide a new method for producing efficient structural geometries, 2) provide constructional proof-of-concept prototypes for industrial production using these methods, 3) examine the behavior of specific formwork fabrics during the casting process, 4) develop a method of obtaining "architectural" quality concrete finishes using standard industrial concrete mix designs and placement regimes, 5) expand the sculptural and architectural potential of concrete construction.

Figure 12. Lightweight GFRC shell panel produced from the Figure 11 "direct-cast" mold. This panel varies in thickness from 13 mm (0.5 in.) to (38 mm (1.5 in.).

Figure 13a. Diagram of a vertical section through a direct-cast mold showing the funicular deflection of the formwork membrane caused by the weight of the wet concrete.

Figure 13b. Diagram showing the direct-cast mold inverted and used as a mold to cast a thin-shell panel (shown in black).

Figure 13c. The loading diagram (above) that will produce pure compression in the shell structure (below) is identical to the vertical section through the mold that produced the shell.

Figure 14. "Direct-cast" mold used to produce the Figure 15 GFRC shell panel.

Figure 15. Lightweight GFRC shell panel cast from the Figure 14 mold.

While this work was not done by engineers, it nevertheless assiduously follows the fundamental logic of natural law, as accomplished initially through small scale physical models, and finally through full scale pours. The engineering analysis of these structures awaits future work with our engineering collaborators.

FORMWORK FABRICS

The flexible formworks described here used uncoated high density woven polypropylene geotextiles for the formwork membrane. Woven polypropylene and other polyolifin textiles offer several distinct advantages: 1) They are extremely inexpensive, 2) They do not adhere to concrete, so no release agents are required in the casting process. 4) Their permeability allows air bubbles and excess mix water to bleed out, leaving an immaculate surface with increased compaction and strength. 5) They are very tough, and can withstand rough treatment by workers in the field. 6) They will not propagate a tear. 7) They are reusable.

The primary shortcoming of these fabrics, with respect to their use in prestressed formworks, is that they suffer a significant relaxation of tension shortly after prestressing. This makes the gauging of prestress forces in the membrane difficult to predict and control. Heat of hydration my exacerbate this relaxation.

FUTURE ENGINEERING ANALYSIS

At present, we have no reliable method for predicting the magnitude of deflections in the formwork membranes under a variety of loading regimes, and the structural behavior of these shell and vault structures is currently untested. This work will be done with engineering collaborators through finite element analysis, three-dimensional modeling, and physical testing of both formwork and fabric-cast concrete structures.

CREDITS

This work took place between January and April, 2002 at the University of Manitoba's Centre for Architectural Structures and Technology (C.A.S.T.), and at two precast factories in Winnipeg, Manitoba: Conforce Structure's Ltd., and Lafarge Canada Construction Materials Group. This work was done with six graduate students from the University of Manitoba's Department of Architecture: Spencer Court, John Melo, David Thomas, William Vivas, Chris Wiebe, David Wittman, with financial support from the Canadian Precast Concrete Institute (CPCI), Manitoba Chapter.

REFERENCES

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