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FABRIC FORMWORK FOR CONCRETE STRUCTURES AND ARCHITECTURE

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Summary. Fabric formwork uses a flexible textile membrane in place of the rigid formwork materials usually used in concrete construction. When wet concrete is contained by a thin formwork membrane, the flexible fabric container deflects into a repertoire of precise tension geometries. This produces naturally efficient structural curves, unprecedented sculptural forms, and extraordinary surface finishes. Fabric formworks can be used to form columns, walls, beams, trusses, slabs, panels, and thin-shell structures in both precast and in-situ construction. Due to the great efficiency of tension membrane formworks, the formwork itself is extraordinarily light. Further reductions in materials consumed in construction can be achieved by more efficiently shaping the concrete members formed in these flexible molds. These savings provide a direct means to more sustainable architectural and engineering constructions in both advanced and basic building economies. Of particular interest in this presentation are funicular thin-shell structures formed from simple fabric sheet molds.

1 HISTORY

Several 19th and early 20th Century patents exist for fabric formwork, and early full-scale construction projects using sackcloth fabrics to form ribbed parabolic vaults were built in Mexico in 1951 by Felix Candela [1] and an unspecified project in (then) Rhodesia [2], fabric formworks were not commercially adopted until very recently. The mid-Nineteen Sixties saw the introduction of nylon fabric formwork used on the ground and under water for erosion control, pond liners and pile jackets [3][4] [5] [6]. In the 1970's the Spanish architect Miguel Fisac used thin plastic sheets as formwork for precast textured wall panels [7] [8]. The first broad flowering of this technology for above-ground structures, however, awaited the introduction of very inexpensive and powerful polyolefin (polyethylene and polypropylene) geotextile fabrics in the mid Nineteen-Eighties. Seminal work from the late Nineteen-Eighties and early Nineteen-Nineties includes that of Kenzo Unno, an architect in Tokyo Japan, who has invented several fabric formwork systems for in-situ cast concrete walls [9][10] and Rick Fearn, a builder and businessman in Canada, who invented a number of fabric formwork techniques, leading to the development of foundation footing and column formwork products now manufactured and sold by Fab-Form Industries in Surrey BC [11]. Also during this period the co-author of this article, Mark West, invented a series of techniques for constructing fabric-formed walls, beams, trusses, columns, slabs, panels, and thin-shell vaults [12][13][14][15][16][17][18][19][20][21]. All these methods use flat untaylored fabric sheets.

2. ADVANTAGES OF FABRIC FORMWORK

2.1 Improvements in surface quality and strength

When permeable membranes are used as formwork, these act as filters allowing air bubbles and excess mix water to bleed out though the mold wall, leaving a cement-rich paste at the surface of the cast. This produces immaculately fine-grained finishes unknown to other methods of concrete construction. This also produces a stronger and more durable “case hardening” of the concrete through a significant improvement in its compaction and water-cement ratio. [22][23][24][25][26][27][4]

2.2. Simply formed variable section structures -- self-forming funicular molds

Flexible fabric sheets can be easily formed into variable-section beams or trusses that follow their bending moment curves [14][15][20]. The most elegant use of fabric sheets for structural shaping of concrete members, however, is in the production of funicular shells and panels. For example, funicular compression shell and vault structures can be formed through the simple act of inverting the tension curves obrained by a loaded fabric sheet. In this instance the symetrical inversion of tension and compression geometries is perfectly matched by the symetrically oposite resistance capacities of the materials involved, i.e. the fabric in tension and the concrete in compression.

Thin-shell compression vaults and double curvature thin-shell wall panels may be cast directly from hanging fabric sheet molds as was done by Felix Candela for insitu construction [1] or as in recent tests of precast fabric-formed shell production at CAST (figs. 1, 2, 3). Alternately, a hanging, concrete-covered, fabric sheet can be inverted to be used as structure directly, or as a rigid mold for producing multiple precast funicular vaults (figs. 4, 5, 6). (This proceedure essentially scales-up the well known physical model constructions of Heinz Isler.) C.A.S.T. has developed, with Fabrene Inc., a coated, polyethylene fabric specifically made for funicular mold-making applications. This fabric has a fuzzy non-woven matting heat-welded to one side. When concrete is placed on the fuzzy side, the fabric is permanently captured by the concrete. When the mold thus formed is turned over for use, it presents the smooth coated side of the fabric as a release surface for this (now) rigid funicular mold (figs. 4, 5, 6)

Because these molds are formed with a flat textile sheet, a flat-sheet reinforcing textile (for example AR glass fiber cloth) will adopt the same geometry as the mold surface. In this way, reinforcement can be easily installed, even when the fabric molds produce complex, deeply folded, forms. The simple geometric congruence of mold material and reinforcing material is one key to the practical reinforcement of these otherwise complex thin-shell forms. Non-structural shells, ex. wall panels, can also be constructed using random fiber reinforcement.

Fig. 1.
Flat sheet fabric mold for a double curvature shell

Fig. 2.
3cm thick, 5m long, carbon reinforced shell cast from the fabric mold shown in fig.3

Fig. 3.
4cm thick, thin-shell, fiber-reinforced wall panel

Fig. 4.
Test of hanging, fuzzy-backed Fabric, coated with 5mm GFRC

Fig. 5.
The fig. 4 funicular mold inverted, showing the plastic-coated release surface

Fig. 6
1m x 3m funicular test mold

2.3 Fabric buckling and buckling resistant form

Of particular interest to our present research are the buckled fabric forms obtained from a stressed flat-sheet fabric mold. We suspect that buckling perpendicular to the principle lines of tension stress in a loaded fabric sheet will naturally provide buckling-resistant corrugations in a thin-shell compression shell cast from such a ‘buckled’ mold surface. We are particularly interested in following this line of thought with engineers capable of modelling and analyzing these new fabric-formed shapes (figs. 7, 8, 9).

Fig. 7.
Corrugations in shell vault along principle stress lines

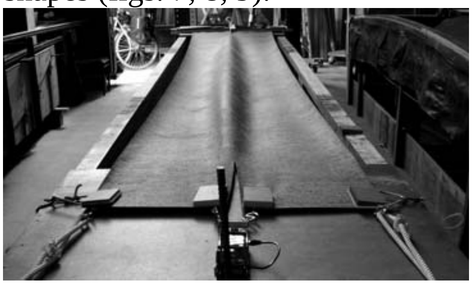

Fig. 8.
Flat fabric sheet buckled by selective Pre-stressing, prepared for a 6m shell mold

Fig. 9.
2m model funicular shell mold buckled by selective prestressing

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