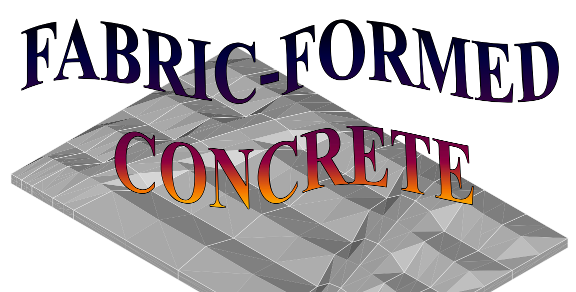

FABRIC FORMWORK FOR ARCHITECTURAL STRUCTURES
FIRST INTERNATIONAL CONFERENCE
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FABRIC-FORMED CONCRETE PANEL DESIGN

Introduction

Concrete wall panels have traditionally been cast using a rigid formwork. Although recently, ACI Committee 334 has introduced construction of shells using inflated forms. Straightforward methods of analysis and design are available for the traditionally cast concrete member – be it a concrete floor, beam, wall or column member.

To date, no design procedures or methods to predict the deflected shape of a fabric cast panel have been developed. A paper entitled "Fabric-Formed Concrete Panel Design", published by RP Schmitz in 2004, introduced a design procedure that allows one to design a fabric cast concrete panel.

The structural analysis program ADINA was employed to analyze the formwork and the concrete panel cast in it. The final panel form, function and performance of the fabric membrane and the reinforcement of the panel for design loads all add to the complexities of the panel's analysis and design.

Analytical modeling and design techniques presented in this paper will allow the design community another way to express themselves using a flexible fabric formwork. No longer will designers feel constrained by the limitations imposed by using a rigid formwork.

WORK BEING DONE AT THE UNIVERSITY OF MANITOBA

Figure 1. Model formwork and completed plaster casts (C.A.S.T. photos).

Figure 2. Full-scale formwork and completed concrete panel (C.A.S.T. photos).

Proposed Design Procedure

A four-step procedure is proposed that allows one to design a fabric cast concrete panel. For demonstration purposes, a 12-foot long by 8-foot wide by 3½-inch thick wall panel will be designed for self-weight and a ±30 psf lateral wind load using a concrete strength of 5,000 psi.

These steps are:

1. Determine the paths the lateral loads take to the points where the wall panel is to be anchored.
2. Use the load paths, defined in Step 1, to model the fabric and plastic concrete material as 2-D and 3-D Solid elements, respectively. These elements are arranged to define the panel's lines of support.
3. "Form-find" the final shape of the panel by incrementally increasing the thickness of the 3-D Solid elements until equilibrium in the supporting fabric formwork has been reached. This process is equivalent to achieving a flat surface in the actual concrete panel.
4. Analyze and design the panel for strength requirements to resist the lateral live load and self-weight dead load being imposed upon it.

By utilizing the above four-step procedure, it is expected that obtaining an optimal panel shape is possible.

FOUR-STEP DESIGN PROCEDURE

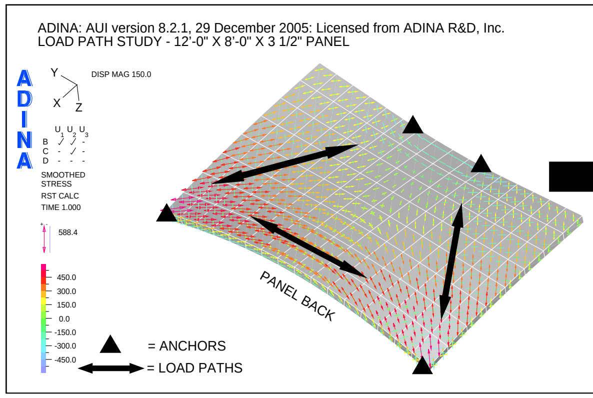


Figure 3. Step 1 – Determine Load Paths.

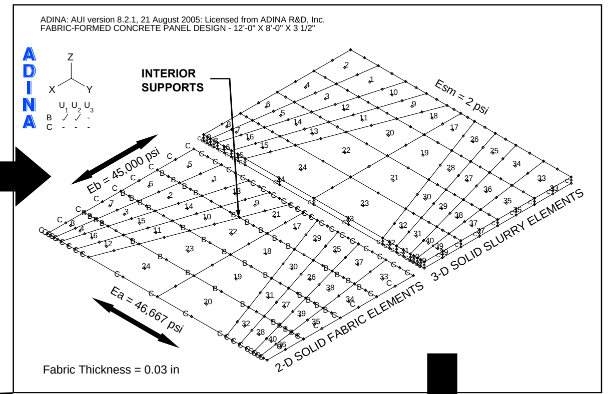


Figure 4. Step 2 – Define Formwork Design.

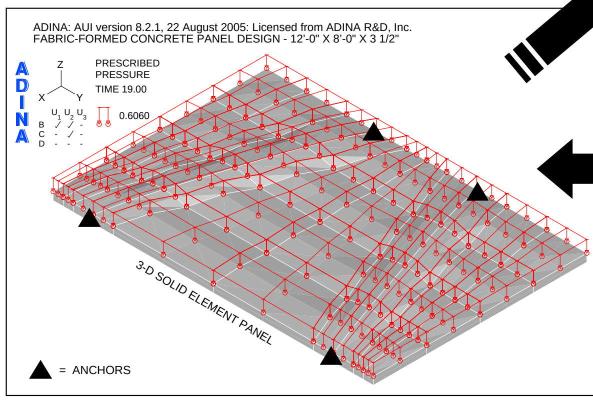


Figure 6. Step 4 – Panel Analysis and Design.

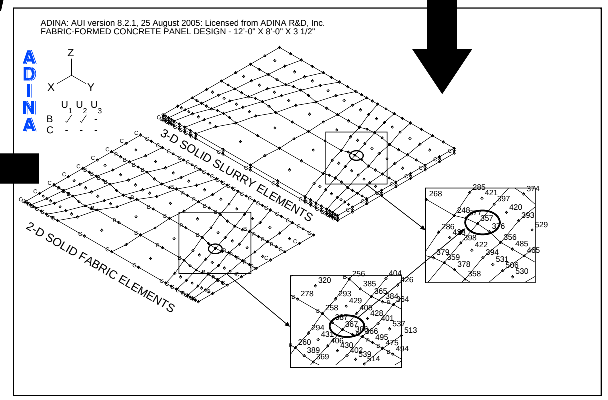
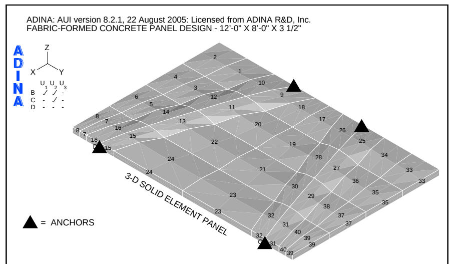


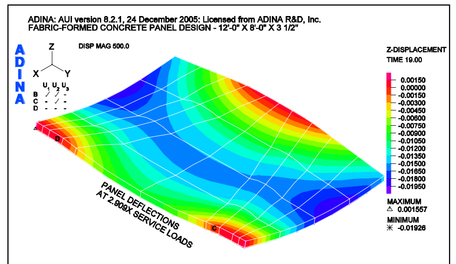
Figure 5. Step 3 – "Form-find" Panel Shape.

PANEL ANALYSIS AND DESIGN RESULTS



Panel wt. = 4941 lbs (21,977 N)

Figure 7. Panel Model.



Δ_{max} **= 0.0066-in (0.168 mm) (Service)**

Figure 8. Panel Deflections.

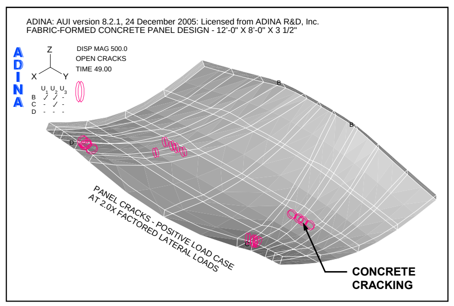


Figure 9. First Panel Cracks, Back.

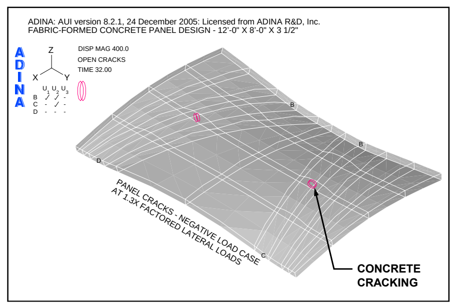
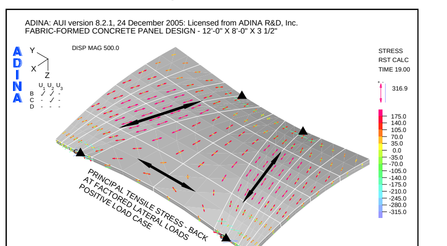
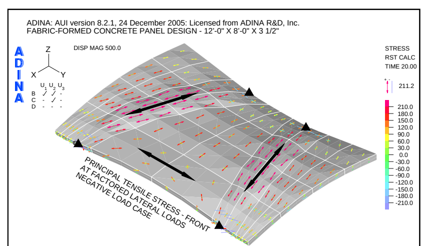


Figure 10. First Panel Cracks, Front.



σ_{max} **= 193 psi (1.3 MPa)**

Figure 11. Panel Principal Stresses, Back.



σ_{max} **= 289 psi (2.0 MPa)**

Figure 12. Panel Principal Stresses, Front.

MATERIAL PROPERTIES

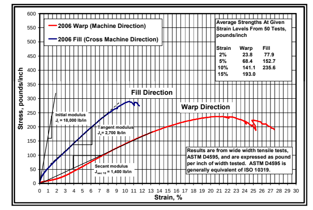


Figure 13. Amoco 2006 Stress-Strain Curves. (1 lb/in = 175.13 N/m)

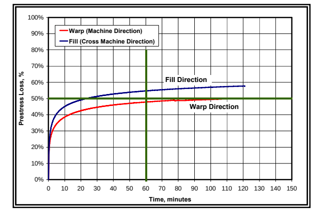


Figure 14. Amoco 2006 2% Prestress Loss Curves.

- **Geotextile Formwork, material is *elastic-orthotropic.***

t = 0.03-in (0.762 mm)	Thickness
$E_{warp} = E_a$ = 46,667 psi (321.8 MPa)	Modulus of Elasticity, Machine Direction
$E_{fill} = E_b$ = 90,000 psi (620.5 MPa)	Modulus of Elasticity, Cross Machine Direction
G = 23,333 psi (160.6 MPa)	Shear Modulus
v = 0.0	Poisson's Ratio

- **Figure 14 shows relaxation curves.**

2% prestress in Cross Machine Direction – take a 50% reduction in Modulus of Elasticity, E_b.
½% prestress in Machine Direction – no reduction in Modulus of Elasticity, E_a.

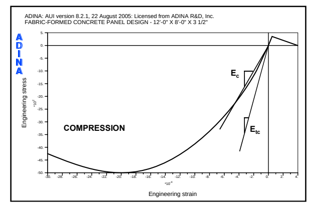


Figure 15. Concrete Stress-Strain Curve. (1 psi = 6.9 kPa)

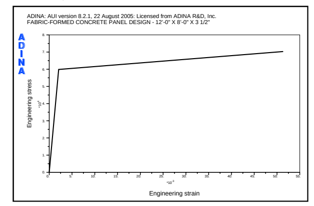


Figure 16. Rebar Stress-Strain Curve. (1 psi = 6.9 kPa)

- **Concrete material properties.**

t = *varies-in* (mm)	Concrete panel thickness
E_c = 4,074,281 psi (28,091.2 MPa)	Secant Modulus of Elasticity
E_{tc} = 7,129,991 psi (49,159.6 MPa)	Initial Tangent Modulus of Elasticity
f'_c = 5,000 psi (34.5 MPa)	Compressive strength of concrete (SIGMAC)
ε_c = 0.002	Compressive strain of concrete at SIGMAC
f'_{uc} = 4,250 psi (29.3 MPa) (SIGMAU, assumed @ 85% of f'_c)	Ultimate compressive strength of concrete
ε_{uc} = 0.003	Ultimate compressive strain of concrete at SIGMAU
$f_r = 5\sqrt{f'_c}$ = 353.6 psi (2.4 MPa)	Uniaxial cut-off tensile strength of concrete
$D_c = 2.172 \times 10^{-4}$ lb-sec²/in⁴ (2,321 kg/m³)	Density
v_c = 0.20	Poisson's Ratio
Φ_p = 0.55	Strength reduction factor for plain concrete

- **Reinforcing steel material properties.**

E_s = 29,000,000 psi (199,948 MPa)	Young's Modulus of Elasticity
E_{ts} = 290,000 psi (2,000 MPa)	Strain hardening (Tangent) Modulus
f_y = 60,000 psi (413.7 MPa)	Initial yield stress
$D_s = 7.339 \times 10^{-4}$ lb-sec²/in⁴ (7,843 kg.m³)	Density

CONCLUSIONS AND FUTURE RESEARCH

The potential benefits for using a flexible formwork include:

- **Geotextile fabric is strong, lightweight and inexpensive.**
- **A more efficient design is possible by using less concrete and reinforcing where required.**
- **Improved surface finish and durability of the concrete product are possible due to the filtering of air bubbles and excess bleed water through the geotextile fabric.**
- **Very complex shapes are possible, which increases freedom of design expression.**

The advancement of *FABRIC-FORMED* concrete member design would be furthered by:

- **The development of computer software which would automatically "form-find" the panel shape and then allow it to be analyzed.**
- **Design verification by analysis and testing of full-scale wall panels.**
- **Investigate the role creep plays in the geotextile fabric formwork during the design process.**
- **Investigate reinforcement options, fiberglass rebar, alkali resistant (AR) glass textile and carbon-fiber grids.**
- **Development of new fabrics, with improved properties over those of geotextile fabrics, for use as flexible formworks.**