Toward the Future of Fabric Formwork

An overview of the opportunities offered by this efficient forming system

by Hakim S. Abdelgader, Jarosław Górski, and Robert P. Schmitz

Since its invention by the Romans, concrete has been cast into all manner of formworks. Whether temporary or permanent, however, rigid formwork has been the traditional standard. Because concrete is the most widely used construction material, improvements in the economy of erecting concrete structures will have significant implications. One of the best opportunities for cost reduction is minimizing formwork costs—expenses that can represent about half the total cost of a concrete structure.[1,2] Fabric formwork is a potential solution toward this goal. As a compounding benefit, fabric formwork can also enable the casting of structurally efficient, variable section building components.[3]

Taking advantage of fabric forms, however, is a joint task of concrete technology specialists, structural engineers, and architects. Fabric structures exhibit material and geometric nonlinearities when loaded, so forms must be designed based on experimentation or structural analysis using software capable of shape-finding.[4,5] Education and research must focus on this barrier before the full potential of this formwork type can be realized.

Fig. 1: A revetment (Fabriform® Filterpoint) is installed in 1967 on the Allegheny Reservoir, New York *(photo courtesy of Construction Techniques, Inc.)*

Shape

Fabric formwork essentially behaves as a membrane under fluid pressure. It provides resistance through surfaces in pure tension and is extraordinarily efficient as compared with conventional formwork, which relies on resistance through bending.

Because fabrics can only resist tension forces, however, fabric formworks often require rigid boundary conditions. Exceptions include revetments that are "inflated" on the ground by pumped grout (Fig. 1). Boundary supports can also be minimal—for example, a tube can be formed by joining two parallel edges of a fabric sheet, and the tube can be suspended from open scaffolding (Fig. 2). Boundary supports may also be more restrictive, such as an external frame, cage, or other lateral restraints. In every case, the fabric will assume

Fig. 2: Fast-Tube™ is a commercially available column fabric formwork system *(photo courtesy of Fab-Form Industries)*

a pure tension geometry between the boundary restraints set by the formwork designer.

Pretensioning a fabric membrane will increase its rigidity and stability. A mild vertical tensioning of an otherwise unbraced fabric tube column form, for example, will laterally stabilize the column formwork.[6] Deflections in horizontal panel formwork can be modulated by prestress levels given to the formwork membrane.[4] Pretensioning of beam forms can shape a simple flat sheet of fabric to reduce concrete in beam tension zones.[6]

Fabric formwork can be sewn into numerous sizes and shapes in-place or in the factory. Some fabric formwork systems use no sewing at all and instead rely on standard construction connections such as nailing or bolting. Most forms can be achieved using simple flat rectangular sheets with no tailoring whatsoever. Smooth formwork can follow the natural flow of forces in a member, thus improving structural efficiency by reducing concrete volume as compared with prismatic forms.[2,6]

Environmental conditions, such as turbulent water in underwater applications, can have adverse influences on the final shape of fabric formwork. For example, fabric formwork placed in turbulent water will be subjected to buffeting, wringing, and kneading,[7] which may wrinkle the surface of the final structure, bend it, or squeeze out cement paste, thus producing a sandy surface and making the concrete vulnerable to abrasion. In such cases, attention must be paid to the method of immersion, the time of immersion, and the pore size of the fabric.

Ballooning

When concrete is placed into fabric formwork, "ballooning" results from the internal hydraulic pressure due to the weight of the fresh concrete and any pumping pressures that may be imposed. Because the ballooning phenomenon always occurs with fabric formwork, such formwork cannot be applied in structures where the bulging phenomenon is strongly disadvantageous.

The understanding and control of the ballooning phenomenon is central to fabric formwork design. Factors that affect the ballooning of fabric formwork include:

- Height of concrete and pumping pressure;
- Area of formwork exposed to pressures (for example, column diameter and tributary area);
- Connectivity of the fabric;
- Elasticity of the fabric;
- Pretensioning levels in the fabric;
- Concrete mixture parameters directly affecting fluid pressures (for example, slump flow and thixotropy); and
- Underwater concreting (external water pressure lowers concrete pressures on the formwork).

The correlation of these factors determines the strains in the formwork and therefore the final shape of the cast concrete, hence informing the appropriate selection of fabrics. A superior design will exploit the tension curvatures that naturally result to produce efficient structures. Strategic restraint of formwork deflections can be achieved by several methods, including tubular forms, exterior restraints (temporary jackets, nets, and rigid frames), interior "skeletons" (permanent form ties and ties to interior reinforcement), and pretensioning of formwork fabrics.

Type

Fabric formwork systems can be divided into four main groups: bags and mattresses, sleeves, shuttering, and open troughs.[2,8-11]

Bags and mattresses

Bags are an economical and convenient choice for forming foundations or protective structures (Fig. 3), and they can be placed over submerged pipelines as ballast.[12]

The flexibility and relatively small sizes of bags make them ideal for installation through confined spaces.[1,12,13] A variety of materials and a wide assortment of dimensions, porosities, volume capacity, and filling valve types ensure compatibility with specific applications. Although the simplest form is an isolated sack, the foundation structure in Fig. 3(a) demonstrates how more complex forms can be defined by increasing the connectivity of the fabric sections.

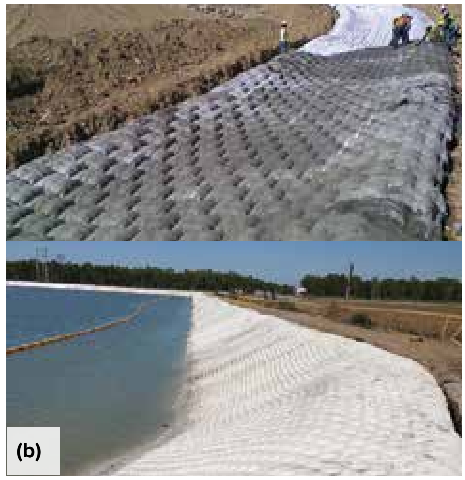

Fig. 3: Bags and mattresses are economical choices for forming concrete foundations and blankets: (a) a pipeline foundation element; and (b) canal liners and breakwater protection[12,14]

Fig. 4: Sleeve formwork can be used to form jackets for repair of damaged piles[13]

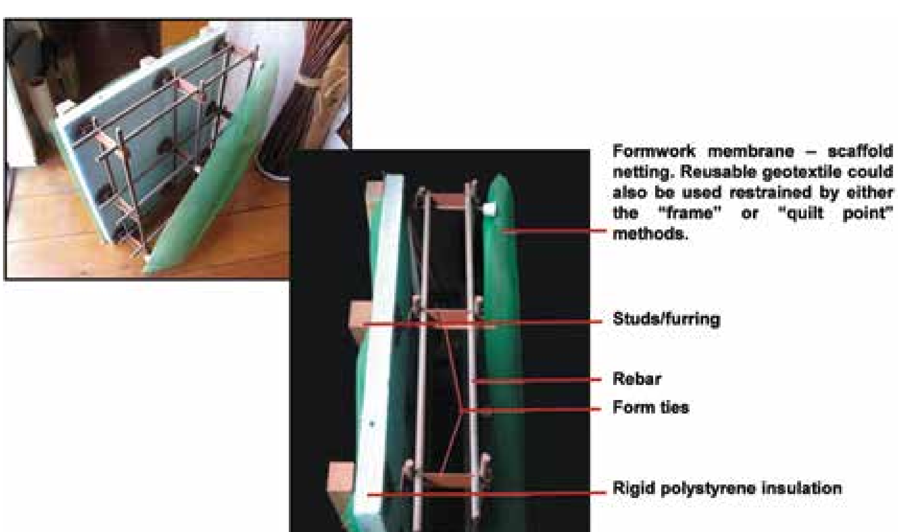

Fig. 5: Unno's Zero-Waste Formwork *(photos courtesy of M. West)*

Articulated block mattresses (AB mats), shown in Fig. 3(b), form cable-reinforced systems that resist erosive forces such as wave action. AB mats are typically used to protect coastlines, canals, rivers, lakes, reservoirs, underwater pipelines, bridge piers, and other marine structures from propeller wash, ship wakes, wind waves, currents, and high-velocity flows. They are also used for landfill caps, down chutes, and collector channels.[2,13]

Sleeves

Sleeves are lightweight cylindrical tubes. As mentioned previously, they can be made from flat, rectangular sheets of fabric. However, custom profiles can also be easily achieved. Sleeves can also be used to form pile jackets (Fig. 4), made by pumping concrete into a fabric sleeve installed around a damaged pile.[10,13]

Sleeves are also used to create columns in earth cavities below the floor of a structure. This technique involves drilling holes through the floor of a structure and snaking a fabric tube down the hole with the assistance of a steel pipe. This technique solves the problems associated with grouting or backfilling cavities in areas underlined by mines or scouring.

Shuttering

Fabric can also be used as shuttering—a temporary surface to confine concrete. In the cast-in-place (CIP) wall formwork system proposed by Kenzo Unno,[15,16] a layer of fabric is used to form one surface of a concrete wall (Fig. 5). A layer of rigid insulation or a second layer of fabric is used to form the other surface of the wall. The two layers are connected using standard form ties, connected to the fabric directly (at "quilt points") or to an exterior framework of pipes or studs. While the fabric may be held vertically by the reinforcing steel itself, additional lateral bracing is required.

Troughs

The open trough group includes flat fabric sheets supported horizontally and

Fig. 6: Open trough fabric forms: (a) site-cast precast panels *(photo courtesy of M. West)*; **(b) spread footings** *(photos courtesy of Fab-Form Industries)*; **and (c) precast variable-section beams** *(photo courtesy of R.P. Schmitz)*

filled from above with concrete. This is probably the first application of fabric forms, as it is described in the United States.[2,12] Applications include precast panels (Fig. 6(a)), strip or pad footings (Fig. 6(b)), and CIP or precast-ribbed slabs or variable-section beams (Fig. 6(c)).[2]

Future Development

Fabric formwork for concrete can be applied effectively in a wide range of applications and can replace timber or steel formwork. The future development of fabric formwork will depend on research on such topics as:

- Feasibility of various types of fabric as formwork, including woven geotextiles like polyethylene or nylon;
- Structural interaction and adhesion between concrete and formwork fabrics;
- Optimum pore size, percentage of open area, and fabric thickness for specific kind of structures;
- Optimizing structural shapes based on pure tension geometries assumed by fabric formworks;
- Development of modeling and design/analysis software for fabric formwork and variable section fabric-cast members; and
- Technology of reinforcement placement in efficiently curved, variable section, fabric-formed beams.

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Selected for reader interest by the editors.

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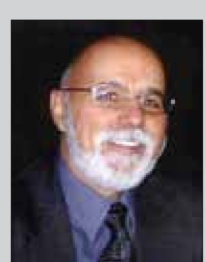

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