Building a Way to Build

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A simple method of constructing variable section reinforced concrete beams has been invented by Mark West and his students at the University of Manitoba's Centre for Arcitectural Structures and Technology (C.A.S.T.). The first full-scale beam using this method was cast in the spring of 2003 at the Conforce Structures precast concrete factory in Winnipeg, Manitoba with Christopher Wiebe, Fariborz Hashemian and Phillip Christensen. This 12 metre (40 ft.) prototype of inexpensive geotextile fabric (Figures 1 & 2).

This method provides a simple way to produce complex structural curves that place material only where it is needed, resulting in structural members that are more efficient and more beautiful than conventionally formed concrete.

STRUCTURAL ART

Figure 1. First 12 metre (40 ft.) prototype reinforced concrete beam cast from a prestressed fabric form at the Conforce Structures factory, Winnipeg, Manitoba, 2003.

Figure 2. 12 metre (40 ft.) prototype beam.

This work follows closely that of structural engineers such as Robert Maillart, Pier Luigi Nervi, Eladio Dieste, Heinz Isler, and others, who can rightfully be called "structural artists". In this tradition, sculptural and architectural beauty is discovered by taking dictation from natural law. In each case, engineering and structural elegance is matched by an innate sculptural beauty and accompanied by constructional simplicity and an economy of means appropriate to a specific building culture. In this approach science and poetry are made together as equivalent acts

METHOD

A single, flat, rectangular sheet of fabric, with two hems sewn along opposite edges, is allowed to drape down into the space formed between two flat tables as illustrated in figure 3. Flexible splines are inserted into the hems on both sides. When the splines are brought closer together, the downward deflection of the fabric increases. When the splines are moved apart the deflection is the

Figure 3. Installation of fabric formwork sheet.

Figure 4. One of four 5 meter (16.5 ft,) prototype simply supported beams

splines are curved, the longitudinal profile of the member will be correspondingly curved. The complex three-dimensional curves of this prototype beam were achieved by stretching a flat rectangular piece of woven polyolefin geotextile fabric in a basic wooden framework made of 2x4s and plywood. Wrinkles and other unwanted undulations in the fabric sheet can be eliminated or reduced by prestressing the formwork membrane in one or more directions. These same prestressing forces are used to reduce lateral deflections in the formwork membrane caused by the fluid pressure of the wet concrete. The tension forces required to do this are small, accomplished by hand, in this case by one worker with, at most, a simple lever or block and tackle. The formwork fabric for this 12 metre (40 ft.) beam weighs less than 10 kg, (20 lb.), can be stored in a space of less than .028 m3 (2 ft3) (Fig. 4), and cost less than $80 U.S.

MORE EFFICIENT BEAMS

In conventional prismatic beam design the sectional area of concrete and steel are sized to resist the maximum bending moment, and this section is applied uniformly across the entire length of the beam — despite the fact that the bending moment of any beam varies across its length from zero to maximum. This strategy causes the great majority of material in a uniform section beam to be used inefficiently. A beam that follows the shape of its bending moment diagram, on the other hand, has a depth (resisting moment arm) that varies in proportion to its bending moments.

In an efficiently proportioned beam, the tension and compression materials both work at optimum stress levels along the entire length of the beam. The net effect is a beam that places material onlyhere it is needed and uses that material at optimum stress levels at every point along its span. This strategy is well known, being used most often for long span structures where dead weight is a controlling factor of the design. Because rigid moulds have been used since the invention of concrete, we have grown entirely accustomed to the construction economies of rigid formworks (the economies of which dictate rectangular prismatic beams) as well as the structural inefficiencies imposed by uniform sections. By replacing rigid formwork panels with a flexible fabric membrane we can easily produce moulds that closely follow the most efficient structural shape for any fixed combination of support and loading conditions. The beam's transverse sections also vary along its length to reduce concrete in the tension zones, while distributing concrete to the compression zones. We estimate that this 12 metre prototype double cantilever beam requires half the concrete

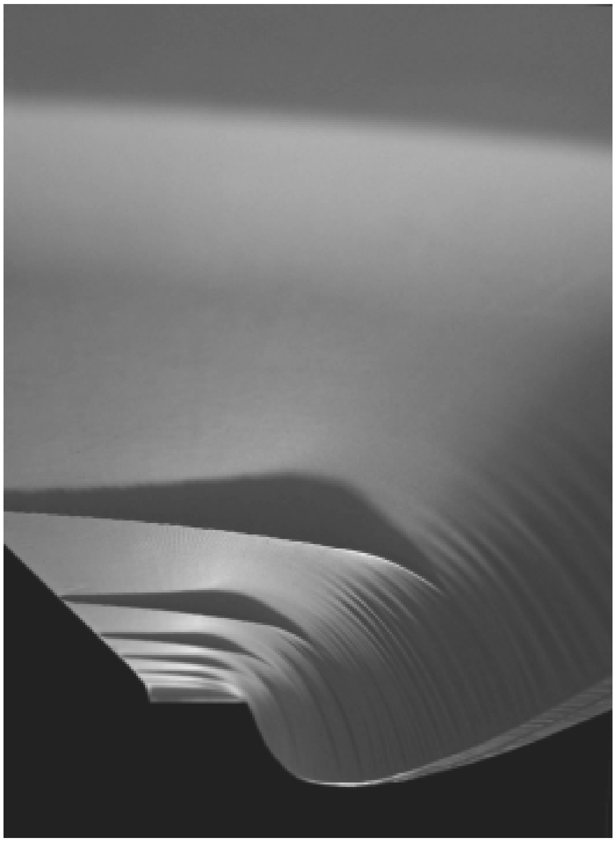

Figure 5. Plaster model of fabric-formed "Tee-beam"

and reinforcing steel of an equivalent rectangular beam.

Four additional 5 Meter (16.5 ft.) simply supported beams designed for structural testing were constructed in the Spring of 2004 (figure 4). Load tests on these will begin in early 2005. In addition to finding an efficient formwork system, a simple method of reinforcing a variable section beam needed to be found as well. The standard use of vertical Stirrups to form a "cage" and to provide shear reinforcement was rejected as being too complex; a variable section beam would require each stirrup to be a different shape and size. A simpler method was invented using a significantly reduced number of steel bars. Furthermore, structural theory states, and our recent structural tests confirm, that beams shaped to follow their bending moment curves actually eliminate shear stresses as their shape resolves internal forces into a simplified flow of pure tension and compression. The ability to form efficiently curved beams promises significant reductions in reinforcing steel and significantly simplified reinforcing design and construction.

CURRENT AND FUTURE WORK

These first prototype beams, and the ease and economy of their production, serve as a proof of concept and indicate the larger implications of this new method. By simply altering the tension of the fabric, a single flat sheet can form a multitude of efficient beam geometries. New 3-D modeling software for fabric formwork is being developed by collaborators at Bath University in England. This software will facilitate the use of this technology by design firms internationally. All our work is being done in the public domain.

The forms made available by this work are given directly by materials subjected to simple actions of force. By following a path of simplicity and reduction we discover a reborn sensuality; long dormant materials appear to be stirring. This new way to build opens previously unforeseen architectural possibilities that are just beginning to be explored.

ACKNOWLEDGEMENTS

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