Bomnong L'or Centre, Cambodia

FABRIC FORMWORK FOR REINFORCED CONCRETE

Using an unconventional method of casting concrete in fabric formwork, StructureMode teamed up with humanitarian design organisation Orkidstudio and local people of the Cambodian coastal city of Sihanoukville to build a new school and community centre in the city's urban heart.

Geoff Morrow, StructureMode, London, UK

The Bomnong L'or Centre (goodwill centre) has been running for over ten years and provides much-needed supplementary education to local children and adults.

The new centre now provides four large teaching, administrative and service spaces. Orientated on the site to harness seasonal winds that rush inland off the Gulf of Thailand, the centre's split and offset roof draws air through the teaching spaces below, with large eave overhangs designed to prevent sunlight reaching the walls. By adopting an entirely passive climatic strategy and combining both traditional and unconventional construction techniques, the building aims to stand as an example of good and affordable design by reinterpreting the Cambodian building typology.

Prior to this project, StructureMode was keen to use fabric to cast reinforced concrete structures because of its many structural, aesthetic and commercial benefits. Dr John Orr, at the University of Bath, has found that casting concrete in fabric reduces the depth of carbonation in 20MPa characteristic strength concrete to the equivalent of that expected in 50MPa concrete cast in a traditional way. He has also found that when 100mm cylinders of concrete are cast in fabric, they are 30% stronger than normally cast samples.

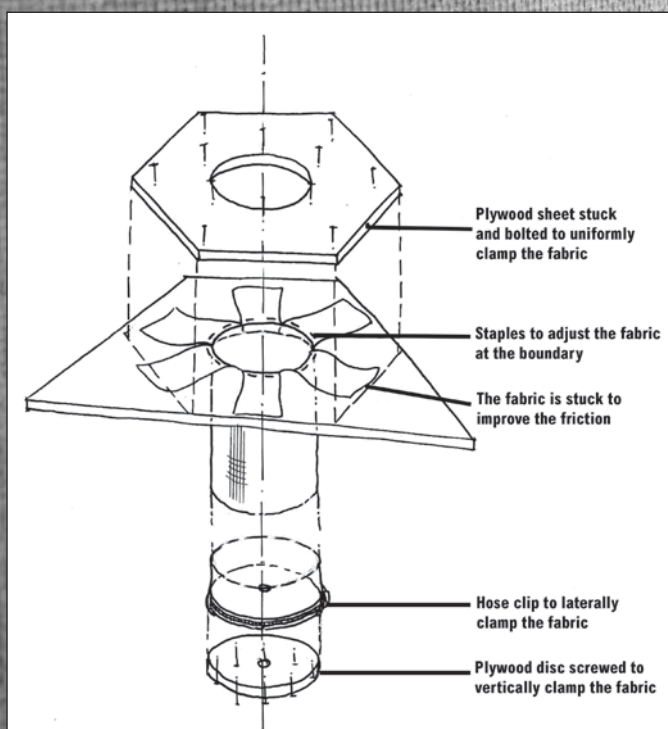
In addition, Professor Mark West at the University of Manitoba has suggested that since fabric allows the cross-section of a concrete element to be easily varied along its length, a reduction of around 30–40% in concrete volume may be achieved for an equivalent strength of rectangular section.

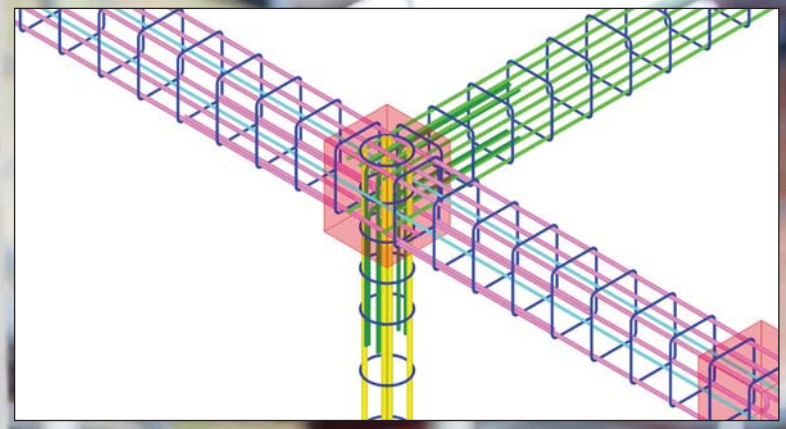
Research, physical testing and subsequent structural analysis have now determined the elastic moduli and Poisson's ratio of a particular fabric manufactured by Proserve.

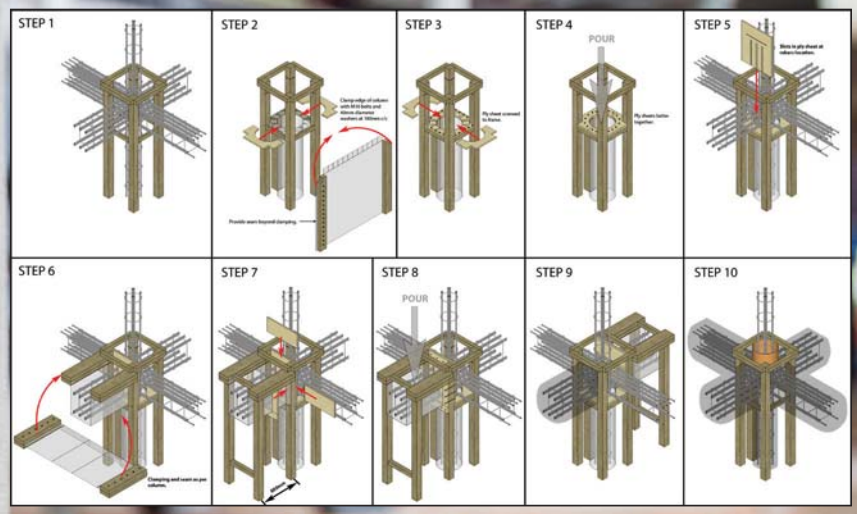
Using the properties determined from our tests, along with Grasshopper to generate fabric meshes and Oasys GSA to form-find and analyse the fabric, the test results were replicated in our computer models. The analysis predicted the same deflected fabric geometry as that measured when concrete was poured inside the actual fabric during the test.

This gave us confidence that we could calculate a fabric pattern for any desired shape of concrete section, in advance and without further physical testing.

Prediction of the fabric geometry was essential to ensure adequate cover exists to the reinforcement along the full length of all beams and columns.







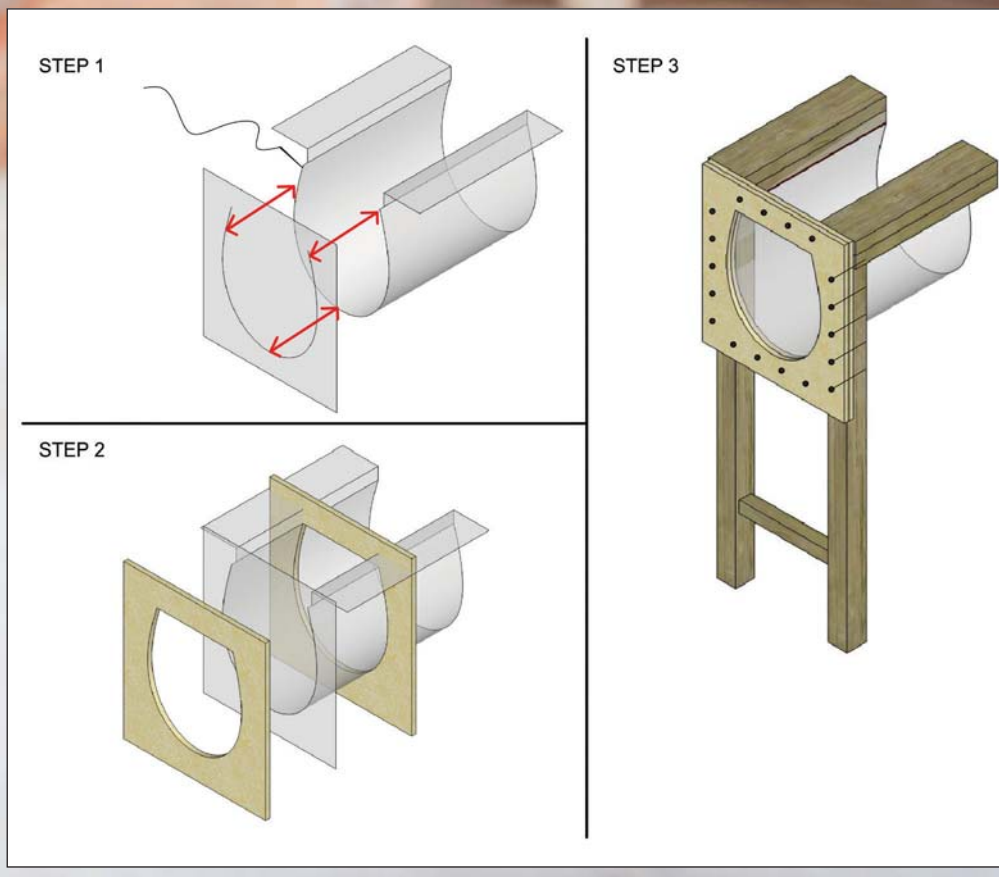


Figure 4, top: 3D colour-coded reinforcement detail.
Figure 5, middle: Construction sequence.
Figure 6, bottom: Cantilever beam formwork detail.

Figure 1, main image: Fabric formwork-cast column at Bomnong L'or Centre.
Figure 2, top left: Unwrapping concrete test column.
Figure 3, bottom left: Sketch design for fabric test.

(Photos: Lindsay Perth.)



Figure 7, above left: Sowing the fabric formwork. Figure 8, above middle: Completed fabric formwork installed. Figure 9, above right: Casting upper concrete columns. Figures 10 and 11, below left and right: Completed columns at Bomnong L'or Centre.

Careful variation of the fabric pattern along a beam length could allow reduction of the volume of concrete without compromising the strength of the section. However, this would have required manufacture of curved reinforcement, which was not available locally in Cambodia. Furthermore, the necessary speed of construction on this project made it impossible to achieve.

During a collaborative design session, the research and testing that had been undertaken was mentioned to Orkidstudio, which was very enthusiastically received. The Orkidstudio said there were lots of skilled tailors locally who could manufacture the fabric formwork if the patterns could be provided.

Furthermore, the use of fabric would have the following additional project-specific benefits:

- Using fabric meant much of the formwork manufacture was prefabrication, meaning it would be made off-site and in parallel with other site operations, which saved valuable time on the programme.
- Prefabrication reduced on-site formwork installation times and also facilitated working around the frequent and heavy monsoon rains.
- Deskilling of the construction process, which was beneficial since the operatives would be mostly inexperienced Orkidstudio volunteers and local people.
- Reduced the amount of timber used in the construction, compared to traditional timber formwork. This is a particular advantage in Cambodia as illegal deforestation means large sections of sustainable timber is impossible to source. This is why the falsework was limited to only small sections.

Key to the success of this project was keeping the details as simple as possible – everything had to fit together perfectly on-site and the sequencing had to be right from start to finish. One of the critical details to resolve was how to connect four curved beams and two circular columns – simply.

It was decided that the best and quickest way to do this was to use rectangular cuboids at the junctions, formed using the falsework necessary to suspend the fabric edges while pouring the concrete (see Figure 4, previous page).

Communication of the construction method was also critical, since it was a new type of technique. To achieve this, colour-coded 3D reinforcement diagrams were prepared, such as the one shown in Figure 4. This was easy for the site operatives to understand and it helped ensure everything fitted together at the junctions.

A series of diagrams was prepared that set out every step in the fabric formwork installation and concrete casting construction sequence, as shown in Figure 5.

Another critical fabric detail was the end of the cantilever beams, which needed careful attention. This was an area where the fabric would naturally crease and buckle unpredictably and inevitably result in reduced cover to the steel reinforcement. To resolve this, it was decided that it would be best to clamp the fabric in a plywood template, cut to the exact profile the adjacent beam fabric would take under hydrostatic pressure. This would certainly resolve the issue, but it meant that if the predicted deflected shape was inaccurate then the adjacent fabric would crease. However, there was confidence in the analysis and so work proceeded on this basis. Figure 6 shows the construction detail and we are pleased to report that no creasing occurred.

Installation process

The fabric formwork manufacture and installation process are shown in Figures 7–9. The whole process went remarkably smoothly so that both concrete buildings, plus another steel-framed building, were constructed within the eight-week target.

It was necessary to pour using buckets as the ready-mixed concrete truck couldn't navigate the last 200m to site, since the road was too narrow and twisting with large holes.

Figure 1 shows the quality of concrete finish achieved throughout. Notice the fabric pattern on the concrete and the quality of finish, which is particularly remarkable considering the inexperienced labour executing the work, the interruptions due to monsoon rains and the very fast programme. This was achieved because of the fabric porosity. Air pockets and excess water in the concrete can escape through the fabric during vibration, which assists greatly in avoiding surface blemishes and also results in the improved durability and strength mentioned above.

The Bomnong L'or Centre is now a cornerstone of the community and used on a daily basis as a place to meet, play, learn and work. ■