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Building in concrete with an ultra-lightweight knitted stay-in-place formwork: Prototype of a concrete shell bridge

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Abstract

A novel formwork system is presented as a material saving, labour reducing and cost-effective solution for the casting of bespoke doubly curved concrete geometries. The approach uses a custom knit technical textile as a lightweight stay-in-place formwork with integrated solutions for the insertion of additional elements, and is fabricated as a nearly seamless fabric. Using weft knitting as the textile formation technique minimises the need for cutting patterns, sewing, welding or gluing, when compared to conventional weaving and gives the possibility to integrate channels, openings, have varying widths and directional material properties, thus broadening the geometric design space. The system has been tested through a small-scale concrete footbridge prototype, built using a pre-stressed hybrid knitted textile and a bending-active structure that acted as a waste-free, stay-in-place, self-supporting formwork. Through the gradual buildup of strength in thin layers of concrete, formwork deformations during casting were minimised. This allowed for low tensioning of the fabric and the possibility to use more pressure (e.g. during shotcreting) in applying the subsequent concrete without intermediate support from below. The computational design and fabrication of the knitted textile formwork included integrated channels for the insertion of bending-active rods, tensioning ribbons and features for controlling the concrete casting. The analysis and process of increasing the stiffness of the lightweight and flexible formwork is presented. The hybrid approach results in an ultra-lightweight formwork that is easily transportable and significantly reduces the need for falsework support and scaffolding, which has many advantages on the construction site.

Keywords: weft-knitted, textile, stay-in-place formwork, hybrid, bending-active, cement, coating, layered, concrete

1 Introduction

Advancements in computational methods and CAD environments have enabled architects to easily explore intricate geometries, leading to the question of how to build these forms. While digital fabrication has created new opportunities for the fabrication of complex and unique forms, controlling the costs and using material efficiently in custom concrete construction still remains a challenge.

In the construction industry, the most common formwork solutions for simplifying the creation of single-curved concrete elements are reconfigurable modular systems such as the Peri Rundflex [1], RMD Kwikform Trapeze [2] or Doka H20 [3].

Formwork for doubly-curved surfaces is typically created from timber or foam by using subtractive fabrication methods [4]. Especially when the formwork is used only once, this results in excessive material waste and high costs of up to 75% of the total production costs of the concrete structure [5]. Furthermore, these formwork systems need significant falsework and scaffolding, which further reduces site accessibility and often imposes additional demands on the foundations.

Various adaptive formwork systems have been investigated for more efficient manufacturing of bespoke concrete elements. For example, the doubly curved cladding elements of the Arnhem train station in the Netherlands, were manufactured using a flexible mould that could be reconfigured with linear actuators [6] [7] [8]. Other examples of adaptable systems are flexible moulds [9] combined with reshapable materials such as wax [10] and moulds made out of milled frozen sand [11]. Typically, these kind of solutions are limited to moderately curved surfaces with no undercuts.

Other approaches to the fabrication of bespoke concrete elements use state-of-the-art 3D-printing technologies. Recent work by Contour Crafting [12], XTreeE [13] and D-Shape [14], and at Loughborough University [15], have demonstrated the potential of printing techniques involving layered extrusion and the deposition of concrete to reduce or even eliminate formwork altogether. However, the direct production of curved 3D-printed concrete elements is still relatively slow and requires further developments to overcome some of the remaining practical limitations. Furthermore, since with the current technology reinforcement cannot be introduced as part of the extrusion process, structural elements that are compliant with design standards such as Eurocodes cannot yet be produced.