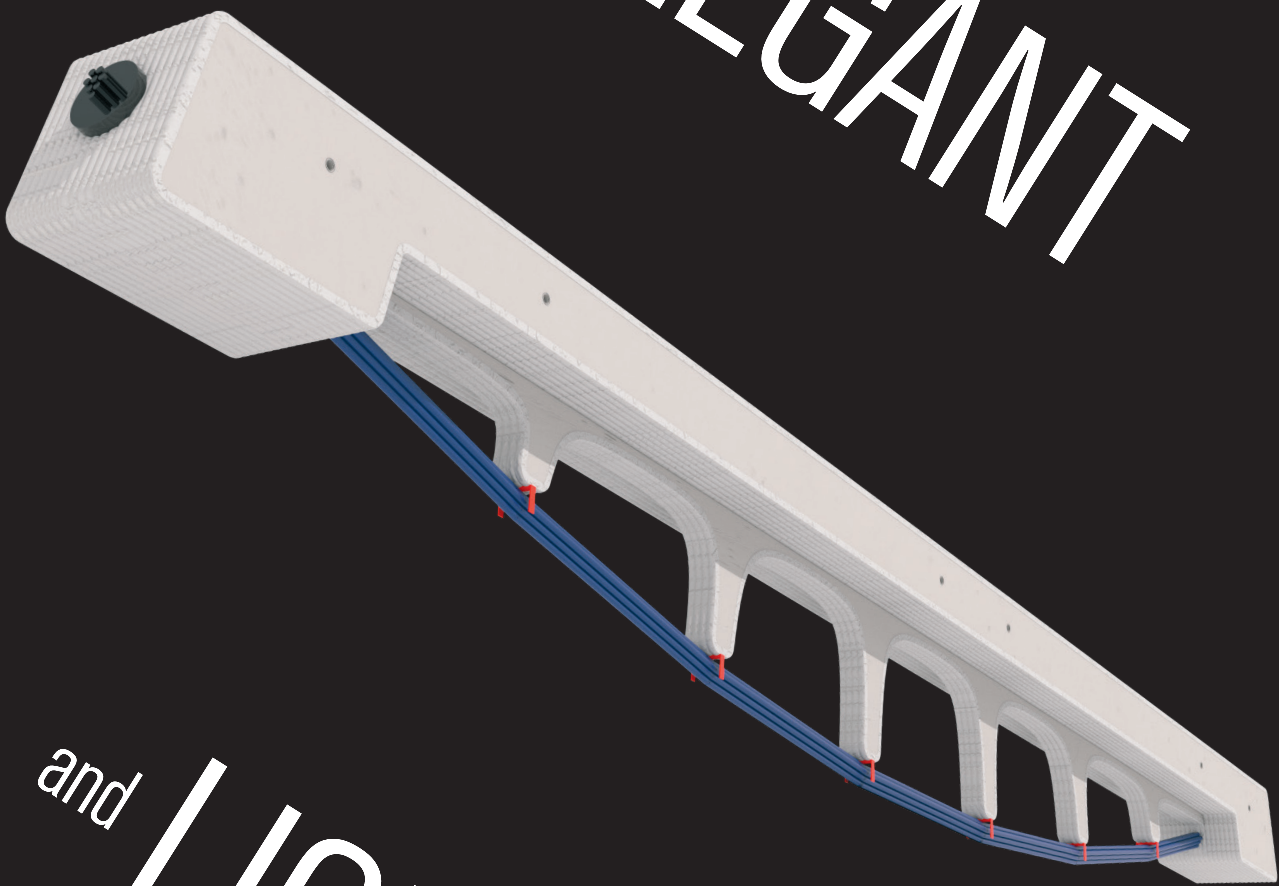
minimass™

an introduction to 3D printed concrete beams for bridges and buildings

can concrete be ELEGANT



and LIGHTWEIGHT?

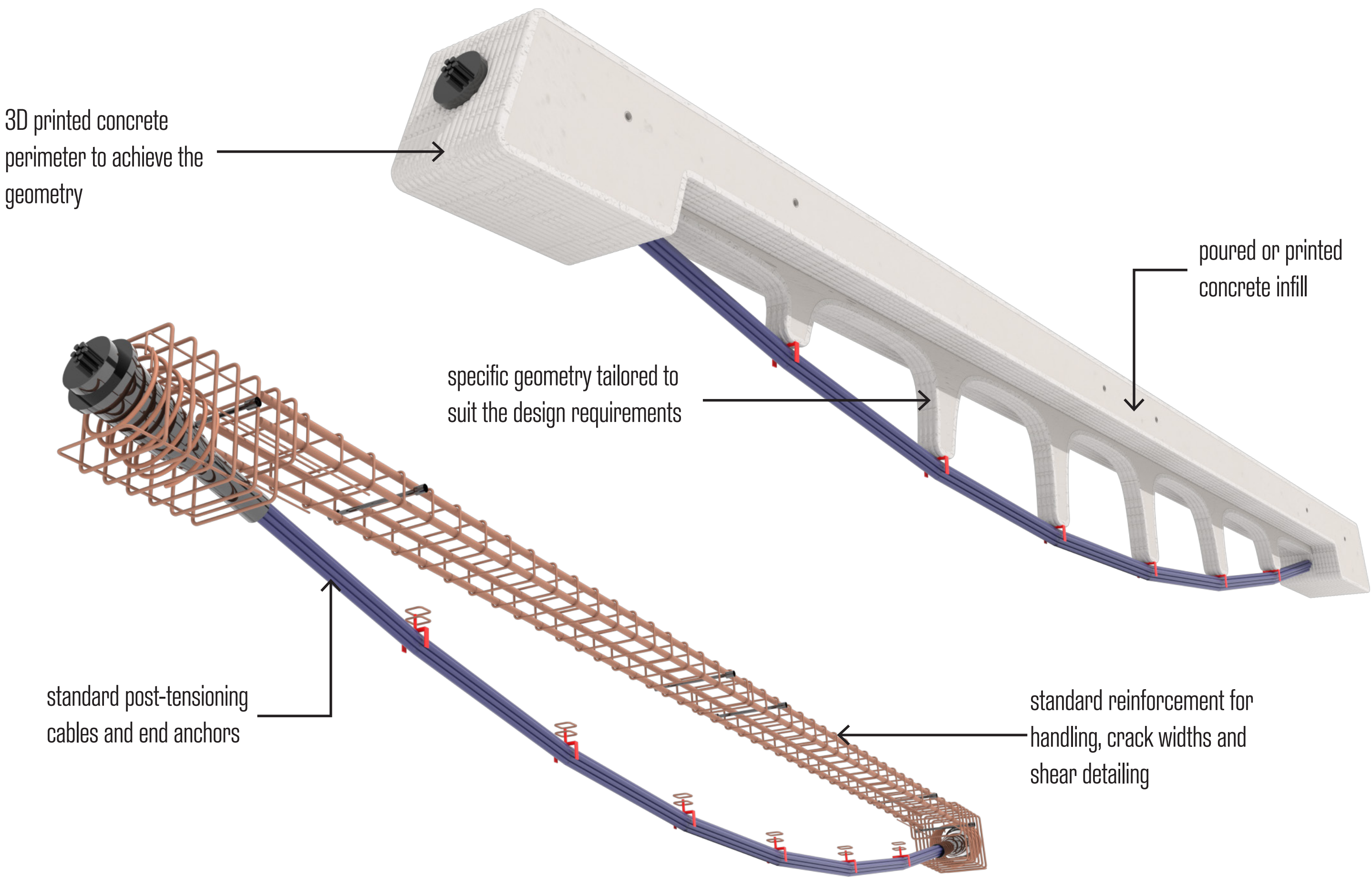
About minimass

Minimass is the name of a range of new structural elements made using 3D printed concrete, developed by Net Zero Projects Limited (NZP), based in UK. The aim of Minimass is to drive down both the cost and the carbon footprint of concrete structures, by using design optimisation and digital manufacturing techniques. The Minimass approach strictly follows Eurocode requirements.

For more information about Minimass, refer to the website at http://minimass.net

There are two families of minimass beam: type “MM-01” and type “MM-02”. The first is calculated as unreinforced and used in situations such as long-span roof construction, where live load deflection is not a significant concern. The second is designed as reinforced concrete, following all the requirements of Eurocode 2 and associated documents. Type “MM-02” is more commonly used for floor beams or bridge beams, with dimensions to suit loading and span requirements. These beams are post-tensioned to achieve an extremely efficient design, using the minimum material.

Introducing the MM-02 beam type:



3D printed beam characteristics

As this is a new type of concrete structure, here are some of the important characteristics of the minimass approach.

Texture, feel and finish

3D printed concrete gives a layered finish and not a formed or cast finish. That gives the beam surface a texture which speaks of the manufacturing technique. However, from a structural point of view, the layering process is such that a bond forms between the layers, preventing de-lamination or the occurrence of layers within the solid material.

Fig. 1: Layering on a physical prototype.

Fig. 2: homogeneous concrete texture despite the layering process.

Manufacture

The Type MM-02 beam is manufactured off-site in a number of stages.

1. Day 1: 3D printing of the perimeter of the element
2. Day 1: Cutting of any openings, addition of any inserts
3. Day 2: Placement of reinforcement cage
4. Day 2: Pouring of infill concrete
5. Day 7: Initial stressing of the cables
6. Day 7: Ready for transport or placement on site.

Fire

Fire resistance is an important consideration for these types of beams, with post-tensioning below the main body of the concrete and the use of 3D printed concrete itself. Fire testing has been carried out on a MM-02 example beam (full details can be supplied), showing that the 3D printed concrete behaves in the same way as traditional poured concrete.

The approach for fire resistance of the external steel cables depends on design requirements. It is possible to leave the cables exposed under certain circumstances, for example if designing a roof structure with no fire resistance requirements or if designing a structure which is predominantly loaded by live load, where the beam can be designed to withstand the loss of the steel cables during a fire event. However, where that is not the case, it will be necessary to provide fire protection and this is proposed to be achieved using a plastic (or metal) duct around the cables which is grouted at the end of the construction. This provides the necessary level of concrete cover to the cables to achieve the fire resistance period. Note that it is possible to source cables with an intumescent layer embedded in the individual cable sheathing but this is more common in North America than Europe.

Fig. 3: demonstrating the printing of the perimeter

Fig. 4: reinforcement within the printed perimeter

Fig. 5: concrete poured within the permanent formwork

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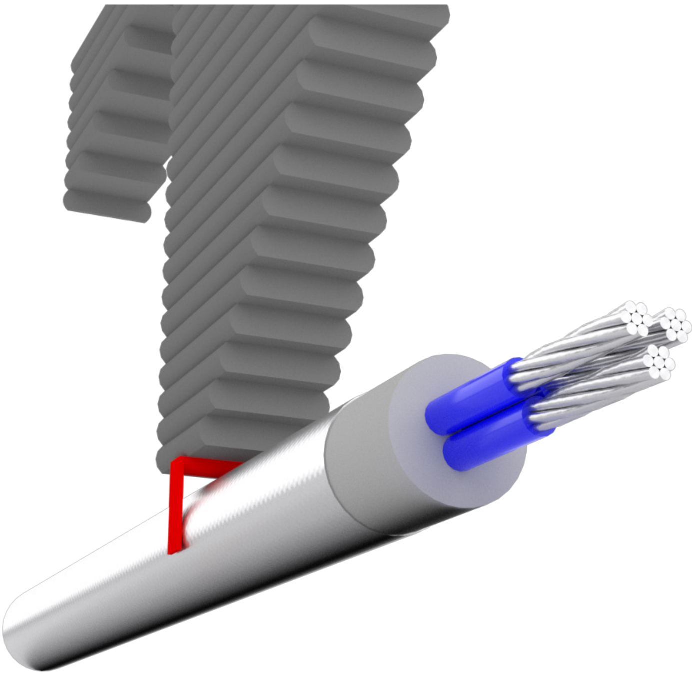


Fig. 6: Grouted duct to provide fire protection

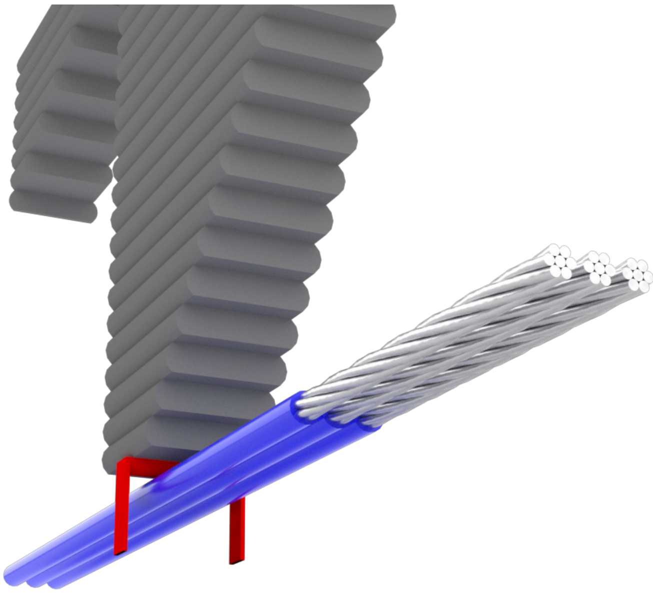


Fig. 7: Embedded intumescent layer within the individual cables

Fig. 8: Example MM-02 beam after 132 mins at 1100 deg. C - minimal signs of damage

Testing

A series of physical prototypes have been built and tested over the course of the last two years.

The first set of prototypes was designed using unreinforced, 3D printed concrete, to test the principle and performance of the beam at the extreme case of having no tension reinforcement in the concrete itself. Three 6m long test beams were built and loaded to destruction at the Structures Lab of the Danish Technical University, Copenhagen. Full details of the testing can be provided on request, with the resulting academic paper having been submitted to the technical journal of the Institution of Structural Engineers, "STRUCTURES". The paper is in the peer review phase, with the aim to publish in the near future.

Fig. 9: Test set-up for 6m long DTU test beams of type MM-01

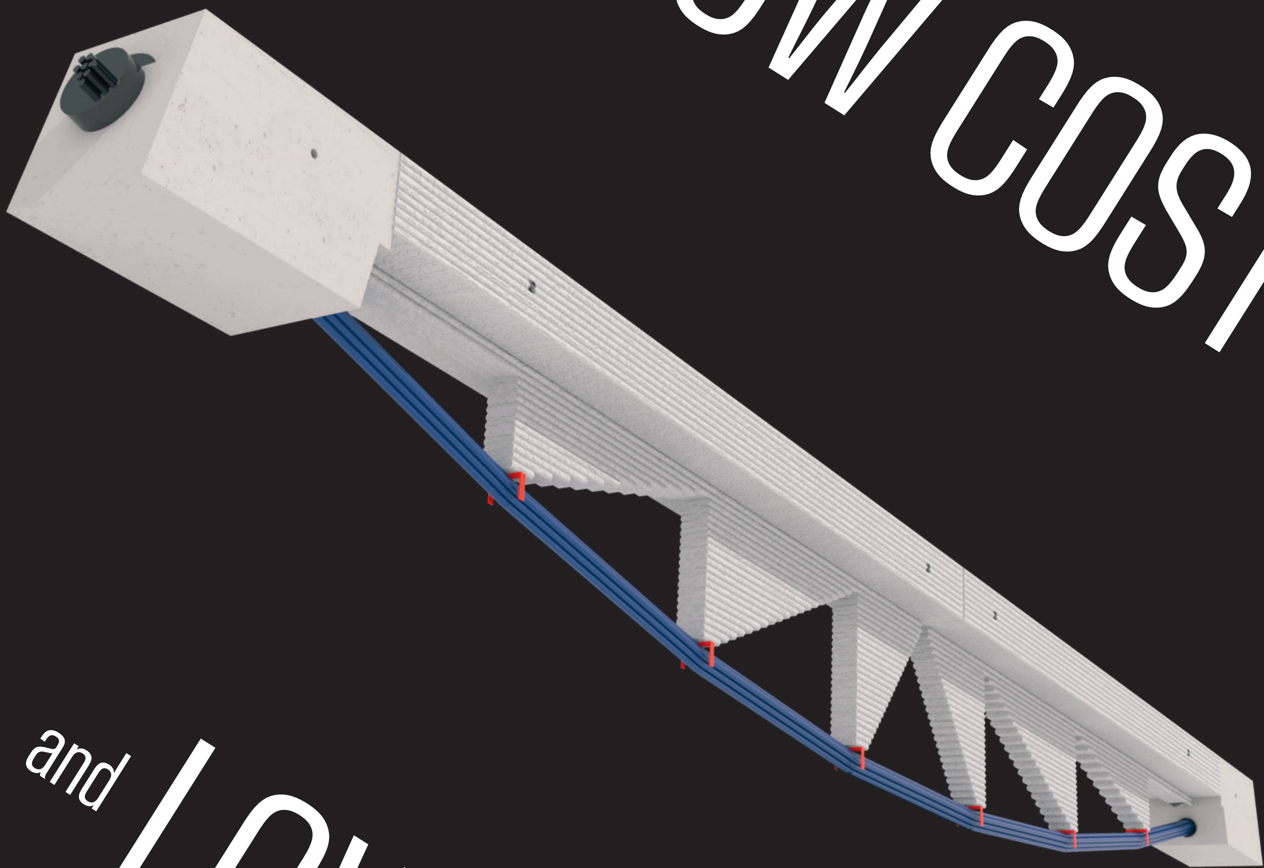
The second physical test to take place was a fire test, with a 2m long beam placed in a furnace for 132mins at up to 1100 degrees C. This test took place with the reinforced concrete version of the beam and no applied fie protection to the steel cables. The aim of the test was to demonstrate the ability of the beam to transition the load from the steel cables, into the concrete such that the cables can be sacrificed during the fire scenario whilst still maintaining the required strength capacity. The test was successful and a full fire test report can be provided on request. The test was carried out by one of the leading test agencies in UK, Efectis UK & Ireland, in their Belfast test laboratory.

Fig. 10: Fire test set-up at Efectis, Belfast, showing full integrity at 2hrs fire duration

The third set of physical tests were carried out at the Structures Lab of the University of Cambridge, as part of a testing programme funded by a grant from Innovate UK. This set of tests demonstrated the conservative methodology of the minimass design, showing the reserves of strength within the concrete cross-sections.

Fig. 11: University of Cambridge testing

how can a beam be LOW COST



and LOW CARBON?