Digital Design and 3D Additive Manufacture of UHMWPE-Reinforced Concrete Composite Elements

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Introduction

Background: To reduce the impact from the pollution from conventional coal combustion energy generation, a variety of renewable alternatives have been developed, including that energy from tides and wave to generate electricity. Various wave energy convertors (WECs) have been developed since 1993. However, to promotion this application, we are keen on techniques to provide a significant reduction in the levelized cost of energy (LCOE).

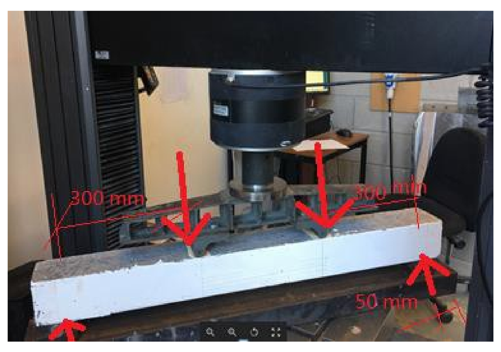
Pelamis WEC (Drew et al, 2009)

Project aims: This project proposed to develop the underlying technological steps that can enable lower-cost, formwork-free, 3D manufacture of individual concrete elements reinforced with a novel, ultra-high performance, non-corroding fibre tendon, i.e. Ultra High Molecular Weight Polyethylene (UHMWPE) for WECs. This obviates the need for formwork and falsework and will use an unbonded post-tensioned structural format, which will allow a reduction in concrete element thickness but more significantly, being permanently isolated from the concrete, unbonded tendons are able to be de-stressed, re-stressed and/or replaced should they become damaged or need their force levels to be modified in-service and provide enhanced overload performance.

WEC Structure Elements

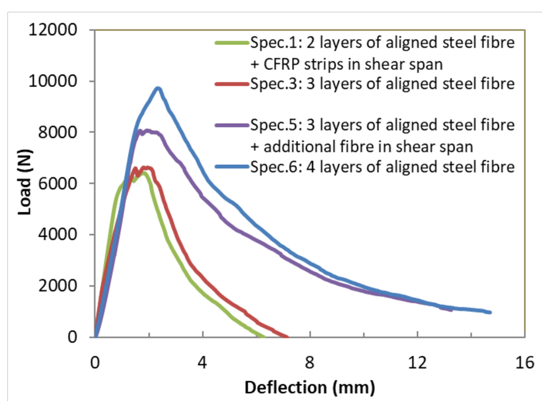
Steel fibre reinforced element: it was expected that the steel fibres can be used to replacing shear links in 3D print manufacture of the elements to significantly reduce the manufacture cost. Steel fibre alignment simulated the possibly process in 3D print in layers.

Steel fibre alignment



Four-point flexural test

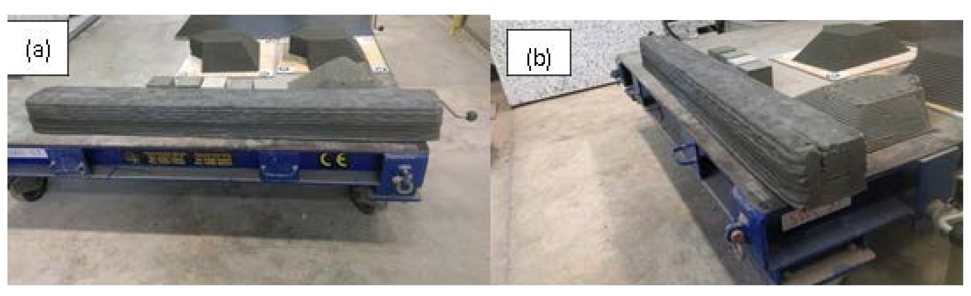
Behaviour of the steel fibres beam: four-point flexural test was carried out for beams.



- Steel fibres were aligned laid with 10mm interval from the bottom face
- CFRP strips can be replaced by an additional layer of fibre
- Bearing capacity was increasing with fibre layers

Steel fibres used to replacing shear links

3D print beam: four-point flexural test was carried out for beams.

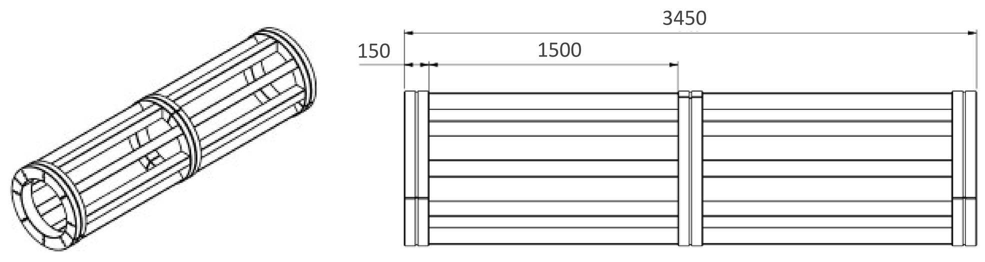


3D print beam

Prototype Truss Design

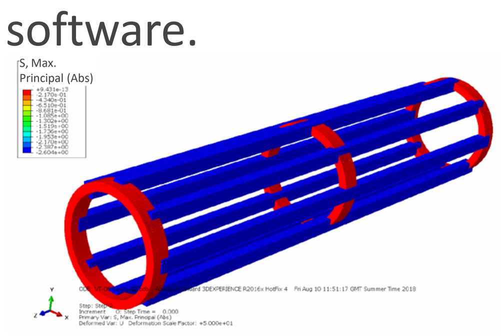
Why truss: the truss is the optimum solution for the structural elements based on strength, weight and material costs.

Truss type: the 3D-circular Vierendeel truss is the optimum formal due to the convenient construction method and low manufacture cost.

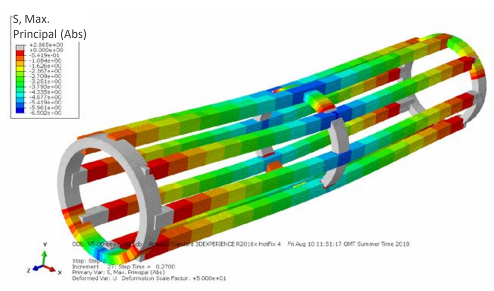


Optimum designed truss for lab test

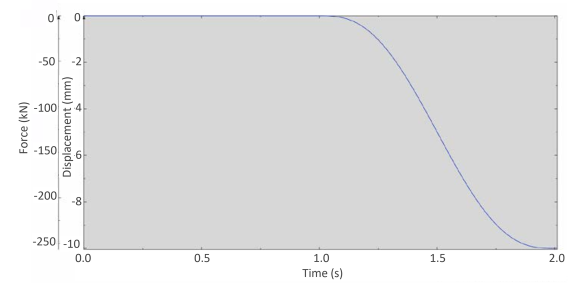
Digital design & analysis: digital design and bending test simulation were carried out with Abaqus software.



Simulation Step 1: Post-tensioned



Simulation Step 2: Wave-bending loaded



Loading/Displacement vs. Time

- Various prestress applied up to 3.4MPa, which ensures all elements of the truss are in compression to SLS
- 255 kN loading
- 10 mm deflection

Truss Manufacture

Precast of the elements: with the current available supplier, the first prototype truss was manufactured in the precast industry.

Precast elements

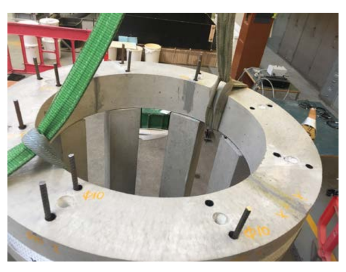
Truss assembly: the elements were then delivered to the lab and assembled.

Step (a)

Step (b)

Step (c)

a) Assemble the first half
b) Install the link ring
c) Assemble the second half and the link with the first half



All elements were connected with steel dowels and epoxy resin grout

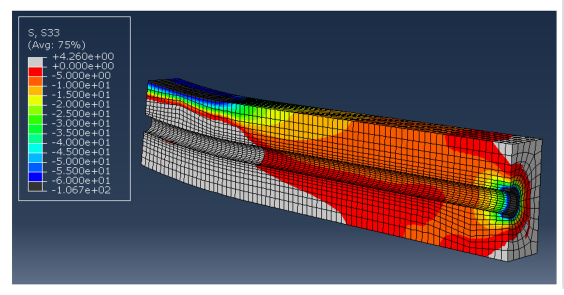
Truss assembled

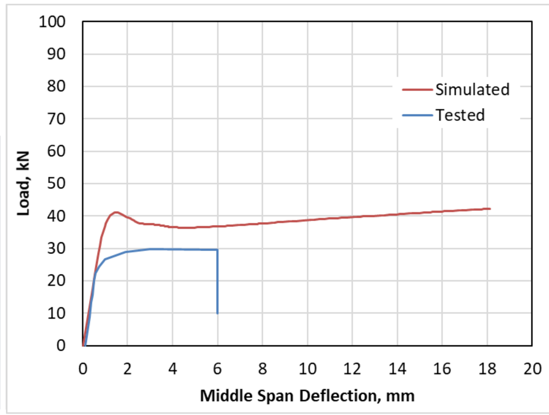
Post-tension and Bending Test

3D Beam:

- CFRP strips used for shear as the beam cannot reinforced with steel fibres.
- Prestress was set to 3.4 MPa following the initial FE analysis results and 4-point bending test done.
- Further FE simulation was carried out with the concrete material set to Concrete damaged plasticity (CDP) model

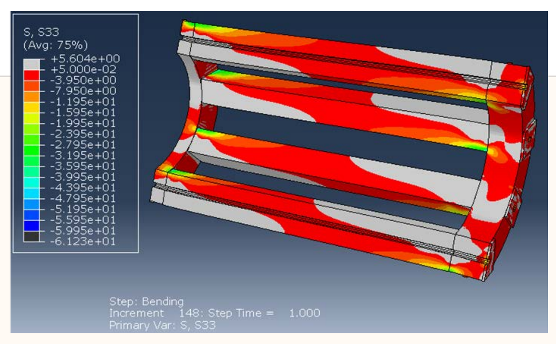
Grey area: possibly be damaged in tension
Black area: possibly be damaged in compression





Truss:

- Prestress was set to 1.0 MPa with 8 Ø5 mm steel wires (due to various test limitations).
- 3-point test and further FE simulation with CDP model were carried out.



Grey area: possibly be damaged in tension
Black area: possibly be damaged in compression

Conclusion & Future Work

Conclusion:

- Concept for digital design and 3D additive manufacture of UHMWPE-reinforced concrete composite elements has been demonstrated.
- Steel fibre reinforced element was demonstrated to have satisfactory shear resistant.
- A 3D printed beam and a Vierendeel truss were prestressed and bending tested, coupled with further FE simulation using CDP model .

Future work:

- Supply chain for element manufacture using the 3D-print technique, steel fibre reinforcement and truss assembly with UHMWPE rope post tension on site need to be built in the UK.

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