Design, analysis and construction of a bending-active tensile hybrid structure

Evy L. M. SLABBINCK *, Seiichi SUZUKI[a], Anja MADER[a], Florian A. JONAS[a], Jan KNIPPERS[a]

*Institute of Building Structures and Structural Design (ITKE), Faculty of Urban Planning, University of Stuttgart, Germany, Keplerstrasse 11, 70174 Stuttgart- Germany, e.slabbinck@itke.uni-stuttgart.de

[a] Institute of Building Structures and Structural Design (ITKE), University of Stuttgart, Germany

Abstract

This paper examines the design, simulation and construction of a bending-active tensile hybrid structure, designed as cantilevered roof, part of the *ITECH Research Demonstrator 2017-18,* a collaborative project between ITKE and ICD. The hybrid structure, which will be referred to as 'pringle' for the continuation of this paper, investigates the complex reciprocal interaction between bending and torsion in a plate and pure tension in two surface elements, their interdependence in the simulation process and advantage during construction.

The structure is a local bending-active tensile hybrid, which is self-stressed-equilibrated [1] and thus resolves the forces, to keep the bending-active plate in bending and torsion, within the system itself. The structural parts and connections of the pringle are solely composed out of glass fiber, i.e. a GFRP bending-active plate-ring with slim constant rectangular cross-section, kept in shape by two PTFE coated GF structural fabrics, attached to the edges of the ring to create a top and bottom surface. The initially straight plate is custom fabricated and combines the high strength and high bending compliance qualities of GFRP. The bending and torsion of the plate is used as a mechanism to prestress the membranes, to generate structural stiffness, and to fit the overall designed shape of the demonstrator. The amount and direction of torsion and bending required is in direct relation with the curvature and prestress alignment to withstand external loading and to have a rigid overall equilibrium shape. The 3D geometry of the structure is solely held in shape by the prestress of both membranes, which avoids the pringle going back to a ring-shape. The top membrane has a sagging curvature and the bottom membrane a hogging curvature to take forces caused by wind suction and uplift. The asymmetric curvature and prestress direction in both membranes generate an elliptical shape in top view and a curved shape in both side views.

Due to the reciprocal interaction between both types of structural elements, the structural behavior of the pringle is highly complex and requires a nonlinear form-finding process. This interaction together with the observed material property variations, membrane orientation, prestress direction, and custom bound connections have a great influence on the simulation results and the overall behavior of the structure. This 3D shape and every construction step is modeled, form-found and analyzed by a parametrical numerical approach in FEM.

This paper also presents the fabrication of the pringle, which includes a custom designed construction process. The main aspect of this process involves the bending and torsioning of the initial flat GFRP plate, prestressing the membrane by using the springback-effect of a geometrical over-torsioned shape, and stepwise completion of the material connection between plate and membrane.

References

[1] E. L. M. Slabbinck, S. Suzuki, J. J. Solly, A. Mader and J. Knippers, "*Conceptual framework for analyzing and designing bending-active tensile hybrid structures*," in *Interfaces: architecture, engineering, science: Proceedings of the IASS Annual Symposium 2017*, Hamburg, Germany, September 25-28, 2017, A. Bögle and M. Grohmann Ed., 2017.