Numerical design concept for submerged, axially loaded grouted connections

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Summary
Axially loaded grouted connections in submerged ambient conditions fail due to local crushing of grout material, which is pumped out of the connection because of water ingress. This leads to relative axial displacements and a gradual failure. Therefor, a finite element design procedure has been developed to depict this new kind of fatigue behaviour by local stress analyses of grout material nearby the shear keys.

1. Axially loaded grouted connections

1.1 Load bearing

Grouted connections (GC) are hybrid connections, which join two telescoped steel tubes by filling the annulus in between with grout. This type of connection is used to join the support structure with the foundation of an offshore wind turbine or platform. To ensure greater bond weld beads (shear keys) artificially increase the steel tube's surface roughness.

1.2 Critical failure mode

Different to previous research in dry ambient conditions e.g. [1] axially loaded grouted connections under submerged ambient conditions show a fatigue failure due to local grout crushing at the shear keys combined with wash out of crushed material [2, 3]. This leads to a gradual failure in form of increasing relative axial displacements, cf. Fig. 1.

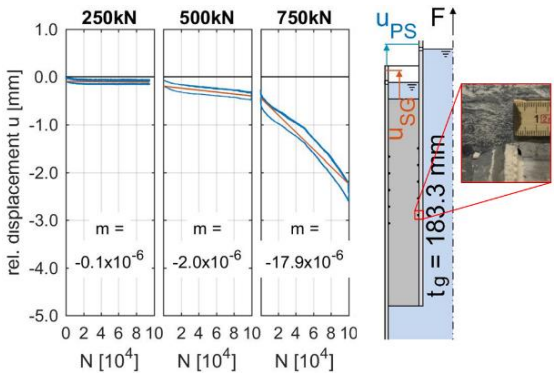

Fig. 1: Gradually increasing relative axial displacement of test specimen, depiction of local crushing around shear key (right) [3]

2. Numerical design concept

2.1 Finite element model

Due to rotation symmetric boundary and loading conditions, a 2D, rotation symmetric finite element model with the nonlinear material law "Concrete Damaged Plasticity" is generated for the following design procedure, cf. Fig. 2.

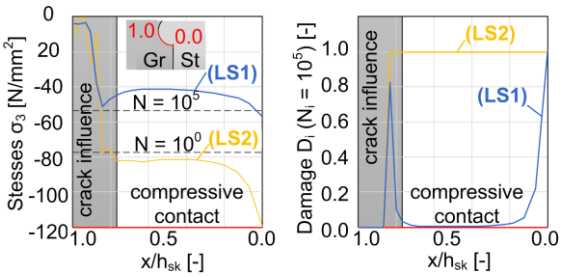

Fig. 2: Compression stress for two load stages (LS) in grout (left) and related damage (right) [acc. 4]

2.2 Design procedure

Based on the local grout crushing described in [3], compression stresses are evaluated in the grout material around the shear keys without crack influence, see Fig. 2 (left). According to Model Code 2010 these compression stresses are utilized in combination with special S-N curves for concrete to compute the allowable number of cycles for each element around the shear key till failure. The connection failure is defined by the limit state when all elements along the shear key exhibit a damage greater than 1.
The design procedure is validated by different laboratory tests of axially loaded grouted connections with different filling materials and geometries, carried out in the research project GROWup [3].

3. References

[1] Ingebrigtsen T et al. Fatigue Safety and Overall Safety of Grouted Pile Sleeve Connections. Proceedings of the 22nd Annual OTC Houston Texas; 1990
[2] Schaumann P et al. Überwiegend axial wechselbeanspruchte Grout-Verbindungen in Tragstrukturen von Offshore-Windenergie-anlagen. Schlussbericht Hannover; 2018.
[3] Raba A. Fatigue behaviour of submerged axially loaded grouted connections. Dissertation. Leibniz Universität Hannover. 2018
[4] fib Model Code for concrete structures 2010. Fédération Internationale du Béton. Berlin, 2013.