Offshore & Dredging Engineering

Technische Universiteit Delft

Numerical modelling of the state-dependent bending stiffness of steel wire ropes used for abandonment and recovery operations

During Abandonment and Recovery (A&R) operations, steel wire ropes (figure 1) can experience torsional deformation. This deformation is a result of the helical configuration and the tension gradient in the rope due to its self-weight. The latter is very high when the ropes are used in deep water operations. Since the static component of the torque is constant over the length of the rope, it unlays in the direction of the greater tension while winding up in the direction of the lesser tension. The torsional energy in a steel wire rope can lead to instability of the straight shape of the rope. Tension and bending stiffness of the rope will play the most important role in the process. Instability of a wire rope can lead to hockling and loop formation which, in turn, may translate into irreversible damage to the rope, delaying the A&R operation. Currently, a very low value for the bending stiffness is used to predict these failure mechanisms, leading to conservative values for the allowable tension and torsional deformation. This reduces the time window in which operations involving steel wire ropes will be allowed. To improve the understanding of wire rope instability, research into the state-dependent bending stiffness of steel wire ropes has to be performed. Therefore, the objective of this thesis is to numerically model the state-dependent bending stiffness of steel wire ropes used for A&R operations.

Most analytical models describe the bending stiffness to be dependent on tension and curvature of the wire rope. This bending behaviour of steel wire ropes is found to be dominated by friction between the wires. In theory, large differences are found between the theoretical minimum and maximum value for the bending stiffness. Assumptions made in these models could cause the outcome to be uncertain and could affect the large difference between these theoretical limits. Analytically generated results for simple strands and spiral ropes match those experimentally found quite well for a limited curvature range. Stranded steel wire ropes used in A&R operations (figure 1) are difficult to model analytically due to their complex configuration. Therefore, numerical modelling has to be used to describe the bending behaviour.

In this thesis, a numerical model which can be used to generate the state-dependent bending stiffness of arbitrary steel wire rope configurations has been developed. The bending stiffness due to friction has been numerically modelled using the finite element programme MSC Marc. A sensitivity study has been performed to test the boundary conditions and settings of the numerical model. A practical implementation of the obtained results is carried out to develop insight into the variation of the bending stiffness along a wire rope length. A subroutine is written to implement the obtained bending stiffness into a model consisting of several beam elements which can be used to simulate steel wire ropes during, for example, A&R operations.

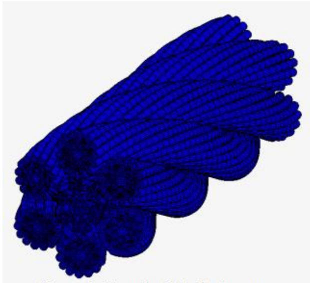
Figure 1: Stranded steel wire rope

The results for simple strands from the new numerical model match the analytically generated ones quite well. The results of larger rope configurations show less resemblance. Compared to the analytical results, the numerically generated results show a less extreme difference between minimum and maximum bending stiffness. This difference is influenced by the level of detail of the mesh. It seems likely – but cannot be confirmed with the available data – that the maximum bending stiffness for simple strands will match the theoretical ones if the element size will be considered infinitesimal. It is concluded that the developed modelling method generates valid results for arbitrary wire rope configurations as long as the level of detail of the mesh is sufficiently high and the correct model length is taken into account.

A critical situation during an A&R operation, when high torsional deformation, low tension and a low bending stiffness occur simultaneously, is simulated. An indication is given for the likelihood of loop formation and hockling when performing an A&R operation in certain sea states.

Experiments should be performed to test the validity of the numerical model. The new insights into the state-dependent bending stiffness should be used to create an experimental set-up to find the critical parameters that result in loop formation and hockling. Further studies into friction modelling in FEM are needed to reduce the computational time when wire rope complexity is increased.

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