Bend stiffness of submarine cables – an experimental and numerical investigation

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ABSTRACT

In this paper, a set of full-scale experimental tests have been performed to study the non-linear bend stiffness of submarine cables. A dedicated test-rig has been developed based on the four-point bend method, which enables the application of a constant bend moment over a section of the cable. The results show significantly non-linear response and strong temperature effects. A numerical model has been developed, taking into account the temperature dependent visco-elastic shear deformation in the bitumen layer. The predictions of the model are compared to the results from the full-scale bend tests.

KEYWORDS

Submarine cables, bend stiffness tests, four-point bend

INTRODUCTION

Bend stiffness of a submarine cable is non-linear and affected by temperature and bending rate. These non-linear effects are primarily resulting from shear deformation in the bitumen layer that is used as corrosion protection on the armour wires. Non-linear properties of cable materials such as the lead sheath, as well as friction effects in the helically stranded components, will also contribute to the non-linear behaviour during cable bending. During an installation analysis, the cable bend stiffness is a cable parameter that has a high impact on the analysis results, especially with regards to the bend radius resulting from dynamic loading. It is therefore of importance that the stiffness applied in the analysis is reasonable and that the range and uncertainties in the applied values are understood and evaluated from a sensitivity point of view. Performing full-scale tests to measure the bend stiffness of submarine cable during different loading conditions is therefore of high interest. The results from the measurements can be used as input for the installation analysis to ensure that the cable behaviour is accurately captured. The full-scale test results can also be used to develop and calibrate numerical models for calculation of the bend stiffness.

There exists no standard or recommendation specifying specific test methods that should be applied when measuring the bend stiffness of submarine cables. CIGRE TB669 [1] describes the three most common test principles that can be used for land cables; the three-point bend method (also termed single-point load method), four-point bend method (termed two-point load method) or moment method. There are different advantages and drawbacks with each of the methods as described in [1]. These three test methods can also be applied on submarine cables.

The bend stiffness of submarine cables has been experimentally studied in ref [2] and [3]. In both cases the three-point bend method was applied, and the bend stiffness was investigated as a function of bending radius, temperature and bending rate. Both paper shows that the bend stiffness of a submarine cable is highly non-linear and affected by temperature.

This paper describes a set of full-scale experimental tests that have been performed to further study the non-linear bend stiffness of submarine cables. For the test program, a specially designed rig has been developed which is based on the four-point bend method. Bending tests have been performed on different cable designs and for various temperature conditions and the results from these tests will be presented.

To predict the bend stiffness of a submarine cable it is necessary to calculate the resulting stress in the armour wires during cable bending. The mechanics of helical components without bitumen during bending has been extensively studied in the literature, see for instance [5], [6] and [7]. With armour wires covered in bitumen, the wire stress during cable bending will depend on the shear deformation of the bitumen layer. Methods to account for this effect has for instance been studied in [8], [9], [10] and [11].

A numerical model, based on [9], has been used to calculate the bend moment curvature relationship for the experimentally investigated submarine cable designs. The model predictions are compared with the measurement results from the full-scale bend tests.

STUDIED CABLE DESIGN

The basis for this paper is the result and analysis of bend stiffness tests performed on two different cable designs; a single core HVDC submarine cable and a three core HVAC submarine cables.

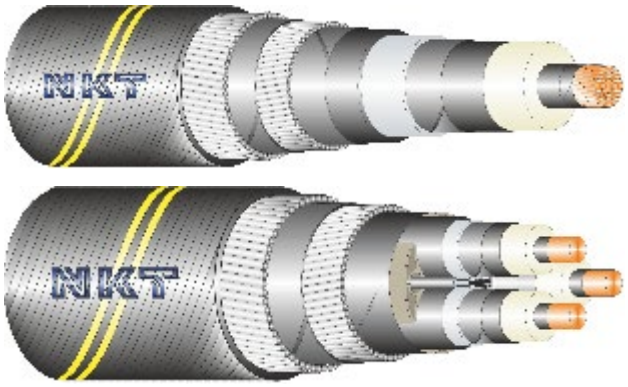

Fig. 1: Design of HVDC and HVAC submarine cables that have undergone bend stiffness testing

The designs of the HVDC and HVAC cables are illustrated in Fig. 1. In both designs, the cables are protected by two layers of steel armouring wires laid in opposing directions, covered by an outer serving made of polypropylene yarn.