Improved Method of Determining Bending Stiffness of Underground Cables

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ABSTRACT

An improved method for the characterization of underground cable bending is presented. The test protocol proposed in [1] has been modified and a more precise analytical model for the interpretation of the test results based on a second-order calculation has been developed. It has been demonstrated that the second-order calculation results in an increased bending stiffness modulus EI of 25 to 35%, depending on the type of cable being tested. The paper presents the models that were developed and their applications for interpreting the test results.

KEYWORDS

Underground cables, bending stiffness, experimental method.

INTRODUCTION

It is important to be able to quantify the mechanical forces on the cable, the cleats and the support structures, such as when the cable is being installed by pulling in a duct or during thermal cycling, at the underground line design stage. This ensures that the mechanical forces do not exceed the maximum strength of the accessories and that of the materials of the various cable components. To estimate these forces in a realistic manner, it is imperative that the parameters used in the calculations be reliable.

One of the parameters that affects cable behaviour is its bending stiffness, which is usually expressed by the bending stiffness modulus *EI*. Unfortunately, this parameter is generally difficult to estimate, which is due to the fact that the cables are made up of layers of various materials. In addition, the mechanical properties of these materials generally vary based on temperature, time and the deformation curvature of the cable. In this situation, the only approach that allows the modulus *EI* to be estimated in a realistic manner is to perform characterization tests.

The paper [1] describes a methodology, proposed as an international standard, of tests aimed at characterizing the bending stiffness of underground cables. The methodology consists in applying a progressive displacement at the mid-point between two roller-type supports. The displacement and the resulting force that is generated are simultaneously measured. Based on these measurements, the parameters characterizing the elasticity of the cable and the bending moment corresponding to the maximum sag are calculated using analytical formulas. However, these formulas are too approximate as they are based on a simplified first-order equation. They underestimate the bending stiffness and lead to an unsafe assessment of the associated forces. Also, the test procedure described in this publication does not implicitly provide the bending stiffness modulus *EI* or cable relaxation parameters that are usable from an analytical standpoint.

TEST PROTOCOL

To improve the characterization of cable bending stiffness, we therefore had to modify the test protocol presented in the publication [1] and develop more precise analytical models for interpreting the test results. The proposed protocol includes two separate test stages (Figure 1), namely:

1. *Progressive bending*: the displacement imposed at the mid-point of the cable section increases with constant and controlled speed, until a maximum predefined value has been attained (Figure 1a). Force *F* and angle *θ* of the cable rotation on the support, induced by the progression of the imposed sag *f*, are simultaneously recorded as a function of time (Figure 1b). This stage, similar to the one in the paper [1], uses a calculation to assess the parameters that characterize cable bending stiffness.
2. *Relaxation*: once the bending stage has been completed, the cable is then maintained for a certain time under constant maximum sag. The decrease in load is recorded as a function of time. This stage uses a calculation to assess the cable relaxation parameters.

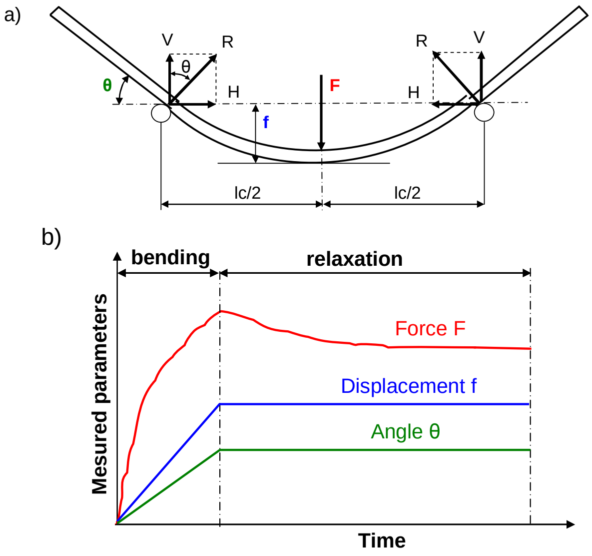

Fig. 1: Bending test; a) Cable bending over two supports; b) Parameters recorded during the test

Each of these two test stages requires its own analytical model to interpret the measurement results.

BENDING MODELS

The bending analytical models for the first stage of the test were developed based on two simplifications, namely:

- The actual variations on the cable span of bending moment *M*, bending stiffness modulus *EI* and also the