Improved method of determining bending stiffness of underground cables

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The improved method for determining the mechanical bending properties of underground cables presented in this paper is based on the methodology described by H.J. Jorgensen et al. in "Measurement of the rigidity of polymeric cables" (Jicable 2003), proposed as an international standard. This method consists in bending a cable progressively by applying known displacements at the mid-point between two roller-type supports, and recording the corresponding vertical forces at that location (Figure 1a).

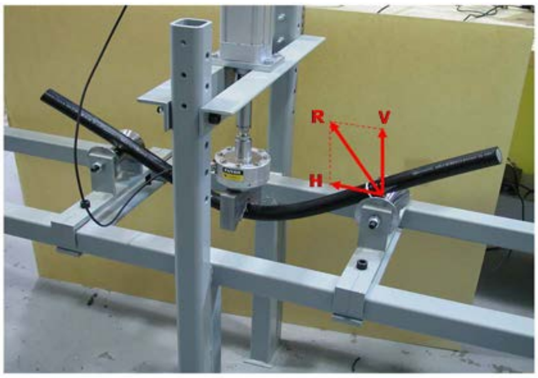

Fig. 1a Cable bending test

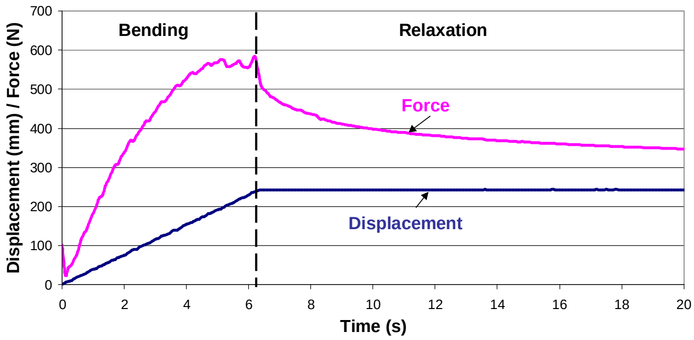

Fig. 1b Cable displacement and corresponding bending force as a function of time

However, the analytical models recommended by Jorgensen et al. for the interpretation of the test results provide only an approximation, as they are based on a simplified first-order equation. The cable bending stiffness values obtained in this manner are underestimates and lead to an unsafe assessment of associated forces—for example, the pulling forces or the thermo-mechanical forces. Additionally, the test procedure described in this publication does not provide usable data on the relaxation of the cable after bending.

In order to improve the characterization of cable bending properties, the test protocol was modified and more accurate analytical models have been developed for the interpretation of the test results. The revised protocol features two distinct steps for each test (Figure 1b):

- *Bending*: stiffness parameters of the cable are assessed
- *Relaxation:* relaxation parameters are assessed

Each of these steps requires its own analytical model for data analysis and interpretation. Since the cable is compressed axially during bending by the horizontal component *H* of reactions *R* at the supports (Figure 1a), the analytical models were developed based on the second-order equation for axially loaded beams. Additionally, the horizontal force H induces a bending moment, calculated relative to the deformed position of the cable. We have demonstrated that this effect, not accounted for in the first-order calculation, increases the bending stiffness modulus *EI* by 15 to 30%, depending on the type of cable tested.

The model for the relaxation of the bending moment in the cable, maintained at a constant curvature, is expressed as an exponential curve, which is dependent on a single parameter characterizing this relaxation over time. This parameter can be interpreted as the time t for which the ratio of measured moments at time t and at the beginning of the relaxation stage is $1/e$. A more accurate relaxation model with two parameters is also proposed. The paper describes the models developed and their application in experimental determining of the bending properties of underground cables.