International Journal of Sustainable Energy and Environmental Research
2014 Vol. 3, No. 3, pp. 145-154
ISSN(e): 2306-6253
ISSN(p): 2312-5764
© 2014 Conscientia Beam. All Rights Reserved

NUMERICAL MODELING OF WIRES INCORPORATION RESPONSE APPLIED TO A CONCEALED CABLE

Chouairi Asmâa[1] --- El Ghorba Mohamed[2] --- Benali Abdelkader[3] --- Boudlal El Mostapha[4] --- El Had Khalid[5]

[1,2,3]*Laboratory of Control and Mechanical Characterization of Materials and Structures, National School of electrical and mechanical, Hassan II University, Casablanca, Morocco*

[4,5]*Higher Institute of Maritime Studies, Department of Machinery, Hassan II University, Casablanca, Morocco*

ABSTRACT

In recent years hoisting ropes have been increasingly used for construction of complex structures: tall buildings, bridges and far-reaching platform for oil drilling, nuclear plants, etc. These structures have complex geometry and subjected to environmental loads, and operation which can cause to material many conditions beyond its elastic limit, and created a need to better understand of metal-based cables behavior. For these situations, conventional methods of calculation or those given the current regulations are not sufficient to give a reliable representation of load-displacement relationship, state of deterioration, resistance and failure mode of structures. The quantification of these phenomena aims to design and build those equipments in safe, economic, sustainable methods and must be made by means of numerical methods, including the finite element one. Although it is possible to establish a model without considering the effects which can allow a microscopic level, however, they are many determinants of mechanical response of cable factors. That is why their knowledge will be of great interest for modeling the behavior of materials. We therefore mention mechanical behavior of cables with the fundamental relation of damage which will be used for modeling the stress-strain relationship. The present work falls within this context, our goal is to develop a behavior model for the lifting cables, designed for the calculation of structures by numerical methods in trying to incorporate most of the factors with their non- response linear behavior.

Keywords: Hoisting ropes, Metal based, Elastic limit, Load-displacement, Failure mode, Finite element, Non-response linear.

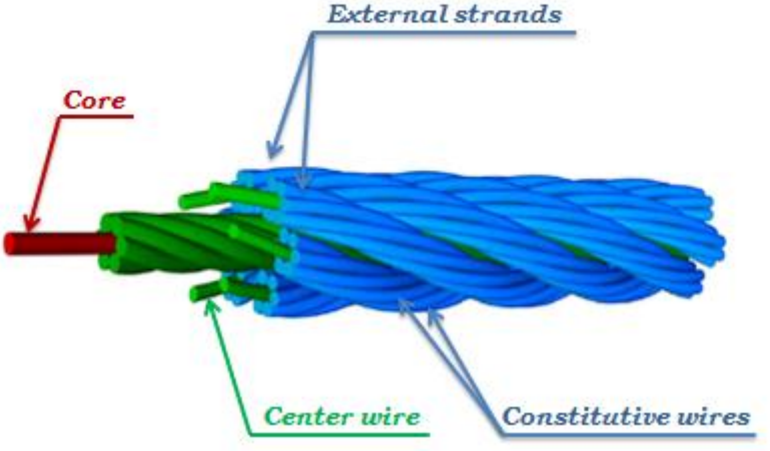
1. INTRODUCTION

Wire ropes combine two very useful properties: high axial strength and flexibility in bending. These properties convert wire ropes into indispensable load transmission elements for many industrial applications. For instance, wire ropes are widely used in cranes, mine hoisting, and lifts. These mechanical properties of the ropes are dependent on their construction and the properties of cables itself, because the wires are wound into strands, which are then wound around a central

© 2014 Conscientia Beam. All Rights Reserved

core to form the wire rope, as shown in Figure 1. The properties of the rope depend on the number, size and arrangement of wires in the strands.

Figure-1. Component parts of a metallic wire rope



The breaking cables by artificial damage are the process of cumulative damage caused by loads of varying and repeated intensity. The fatigue damage occurs only in regions of the cable which deform plastically under a load of varying intensity. After a number of fluctuations, causing cumulative damage initiation and propagation of cracks in plastically damaged regions.

The main cause of failure is associated to the wire of interfiled friction between strands along the cables, due to continued aggression of environment (effects of rain, wind) and changes in random loads. When these movements are caused by stress variables, it concerns interfiled friction or friction induced by small displacements. This is exacerbated in areas of stress concentration by phenomena of wear, fatigue or corrosion, which are direct consequences of the modifications strong geometrical and mechanical characteristics of components.

Indeed, the detection of damage in broken internal or external wires, is of extreme importance. However the situation may be complicated by multiple cuts that occur along the wire, especially in the presence of interfiled friction.

2. NUMERICAL MODELING OF WIRE ROPES

Helical structures are widely used in mechanical and civil engineering applications. These structures are usually subjected to large loads which can lead to material degradations and cracks, associated with corrosion and mechanical fatigue. In this framework, non-destructive testing is a crucial tool for detection, localization and measurement of material discontinuities. The choice of appropriate technique depends on dimensions and accessibility of the structure.

Numerous works have been devoted to the modeling of static behavior of helical structures as springs and multi-wire cables under axial loads. For helical springs, an analytical model was proposed among others in (Ancker and Goodier, 1958) and (Wahl, 1963) considering the spring

© 2014 Conscientia Beam. All Rights Reserved

as an Euler–Bernoulli beam with pitch and curvature corrections. Numerical approaches describing the static behavior of helical springs have been also developed.

Among these works, a finite element model of half of a spring slice has been proposed in (Jiang and Henshall, 2000). The static behavior of seven-wire strands has been widely studied in literature. Various analytical models based on different assumptions have been proposed, such as the model of (Costello, 1977) which is one of the most popular. These models are reviewed compared in (Jolicoeur and Cardou, 1991) and (Ghoreishi *et al.*, 2007). Besides, numerical models relying on the finite element method were developed.

Some of them are based on beam elements (Durville, 1998), (Nawrocki and Labrosse, 2000), (Páczelt and Beleznai, 2011), also (Nemov *et al.*, 2010) and (Bajas *et al.*, 2010) in which superconducting cables composed of a large number of strands are studied.

But most of the time, 3D models are used, works of (Boso *et al.*, 2006), (Ghoreishi *et al.*, 2007), (Imrak and Erdönmez, 2010), (Nemov *et al.*, 2010), (Stanova *et al.*, 2011a; 2011b) and (Erdönmez and Imrak, 2011). In order to obtain a good representation of the geometry as well as the displacement solution, which may involve bending phenomena, quadratic elements are employed. This leads to models which can be computationally expensive, when the model axial length is about the pitch length. Therefore, as soon as the loading fulfills helical symmetry, one can take benefit of this property to reduce the model size. This has been achieved in (Jiang *et al.*, 1999) and (Jiang *et al.*, 2008) in which the computational domain is restricted to a basic sector of a helical slice. Helical symmetry may also be accounted for within the framework of homogenization theory. This has been proposed first in (Cartraud and Messager, 2006) using axial periodicity, and then improved in (Messager and Cartraud, 2008), in which helical symmetry enables to consider one slice of a strand. The derivation of the slice model is different in (Jiang *et al.*, 1999), (Jiang *et al.*, 2008) and (Messager and Cartraud, 2008). However, in both cases, helical symmetry yields displacement constraints between the two faces of the slice, with a loading under the form of an axial strain and a twist rate.

This work further advances (Cartraud and Messager, 2006) and (Messager and Cartraud, 2008), taking advantage of the translational invariance. Helical symmetry can be actually considered more efficiently. Thus the model can be reduced to a 2D one, i.e. a cross-section model. This requires formulating the homogenization theory in a twisted coordinate system. This technique then allows the computation of the static prestressed state of helical structures (single wire and multi-wire) from the solution of a 2D problem. Let us mention that an advanced analytical 2D model has been proposed in (Argatov, 2011). This model takes into account Poisson's effect, contact deformation and allows obtaining the overall strand stiffness as well as local contact stresses. In this reference, plane strain was assumed to formulate the 2D problem while in the present work helical symmetry is used.

3. GEOMETRIC PROBLEMS RELATED TO CABLES

© 2014 Conscientia Beam. All Rights Reserved

The geometry of some cables is so complex that the definition of areas interfilaire contact, or bends and twists in the wires before loading, require lengthy mathematical developments. Several authors have tried to solve this purely geometrical problem. Thus, in their study, (Karamchett and Yuen, 1979) were interested in research of interfilaire contact points in a multi-strands cable. They presented many results of numerical applications of their model, which they varied the arrangement of wires in cable section. They also noted that loading of the cable changes the number and distribution of contact areas.

Lee *et al.* (1987) are attached to express geometric curvature and torsion, before loading in any constituent cables of an optionally complex cable section, when wound around a drum or pulley. The objective is to calculate stresses in the wires.

(Out and Vonmorgen, 1997) treated sliding wound on a cylinder in bending wire. The subject of their model is considered as flexible tube consisting of several layers which have a helical obvious analogy with cables, although the winding angle is much larger than wires in a cable. The approach chosen by authors is essentially geometric. When the tube is bent, they define the maximum shift between two successive layers as the difference between the initial distorted helix and the geodesic line on the cylinder down (geodesic is the shortest line between two points remaining on a surface curve). Their theory is designed to calculate the landslide responsible for fatigue phenomena in this category of cables.

4. NUMERICAL ANALYSIS MODELS

4.1. Models of Curved Beams

In these styles of cables, wires constituent are considered as helical beams and their bending stiffness are in torsion behavior. Many studies have been conducted using this approach. Thus (Costello, 1997) presented his synthesis of several previous studies under his direction that the basic idea is to work with the equilibrium equations of curved beams in case of a single-strand cable; the only contacts are treated radial contact between outer wire and soul.

(Vélinsky and Teissier, 1998) developed a model for complex cable section and took into account the change in diameter due to Poisson effect. Equations are linearized, which can greatly simplify the theory and apply results to other types of sections. However, for a cable or textile plastic soul, an exact solution is difficult to obtain. It becomes necessary to study radial behavior of such a cable. To simplify this problem, (Kollros, 1973) introduced a very simple equation with two constants that depend only on geometric structure of cable and which can be determined by experimental tests.

4.2. Semi –Continuous Modèles

Semi -continuous patterns are based on a technique similar to that used for the example composite materials homogenization. When a system is composed of a large number of identical elements, they may in fact replace the system by a discrete continuous material whose characteristics are determined properly.

© 2014 Conscientia Beam. All Rights Reserved

This approach was proposed by Hobbs and Raoof (1994) who modeled a layer wire in a cable as an elastic orthotropic cylindrical sheet. The entire cable is then analyzed as the sum of different concentric elastic layers. Results given by this method are of course even better as the number of wires in each layer is important. Therefore, the model is particularly intended for multilayered wiring. Within same layer, linear contact with slippage and friction between two adjacent wires is studied using the results given by the contact mechanics for two straight and parallel cylinders. This particular model allows calculating the stiffness in tension and torsion of a multilayer cable.

4.3. Finite Elements Models

The first finite element model cables were built from existing elements in the NASTRAN code (code calculation of NASA). The description of the geometry and efforts was very rude. For example, (Cardou and Jolicoeur, 1997) modeled the wire cable form bars. For (Cutchins *et al.*, 1987), wires of cable are modeled by eight-node elements heptaedriques but connections between wires are treated as springs.

(Chiang, 1996) used ANSYS code (trademark of Swanson Analysis Systems, Houston, USA) and hexahedral elements to eight nodes to discretized a small length of a strand (1 +6) in axial loading.

The study conducted is only statistical in nature and determine the influence of six parameters on axial stiffness and stress distribution between the outer and wire purpose. These parameters are the winding angle wire, the boundary conditions in rotation, length of strand, conditions interfilaire contact, core radius and external radius wires.

In a different context, (Durville, 1997) developed a beam FE model which allows it to take into account the large disturbances, interfilaires friction and warping sections wires.

(Nawrocki, 1997) has developed a FE model helical wire, adapted to the study of a strand where each wire is discretized by a beam element. Wire sections remain plane during deformation. The Poisson effect is neglected, as well as local deformations due to interfilaire contacts, but force in the section wire is taken into account. Internal frictions are neglected, but all possible interfilaire movements (sliding, rolling and rotation) are modeled. Contact conditions are introduced through Lagrange multipliers for their consideration at the exact nodes. Furthermore, the possible local separation of wires is treated with a suitable algorithm. Finite element is created elements based on a Cartesian isoperimetric approach. They have four nodes and six degrees of freedom per node. These nodes have three translations and three possible rotations of a node, expressed in the global coordinate system.

5. DESCRIPTION AND CHARACTERIZATION OF WIRES GEOMETRIES

It is well known that solution by mechanical problems finite element interactional contact, which generally uses implicit integration schemes, is often affected by numerical problems due to poor convergence.

The deformation of cables is an example of problems with multiple contacts interaction wires, especially if the number of strands in cable is high enough. In this context, several finite element

© 2014 Conscientia Beam. All Rights Reserved

codes were used to solve this problem the majority incorporates temporal integration schemes. However, (MSC Marc, 2006) used an efficient code to solve problems of cables by a general purpose with implicit solver. One way to overcome several difficulties is to use a dynamic language that guarantees absence of convergence problems.

Code with explicit finite element solvers has been applied to problems of cables as ABAQUS / Explicit. One of difficulties in applying the Finite element codes is to find optimal loading speed is slow enough to take into account dynamic effects.

Our numerical simulation is performed using computer code Abaqus. This program aims to provide a computational tool easy to handle for recessed cables for analysis, taking into account the lagged effects of applied force and displacement.

5.1. Geometry-Setting

In the first stage of our study, this analysis will focus on a triplet consisting of three cable strands (6 mm diameter) (Figure 2).

Figure-2. Representation triplet cable (6 mm diameter)

The geometrical and mechanical characteristics considered for triplet are summarized in table 1.

Table-1. Geometrical and mechanical characteristics of triplet

Diameter of cable	6 mm
Height of torsion	45 mm
Young's modulus	117 GPa
Poisson's ratio	0,3
Wire diameter of strand	1,6 mm
Mass per unit length	0,143 kg/m

5.2. Maillage and Boundary Conditions

In order to obtain equations governing motion of triplet, we have developed a numerical approach, using Abaqus software.

If we consider the triplet as a single spiral beam, its mechanical behavior is governed by the system of equations.

Finite element method, adopted in this study, is calibrated by a suitable calculation of mechanical response applied to cables. Mesh elements are finely refined elements including special wires.

For all models, symmetry properties are used when it's available. Thus, for 3D geometries, we have two planes of symmetry: the plane containing elements of beam and the perpendicular plane passing through axis of revolution.

© 2014 Conscientia Beam. All Rights Reserved

The strands are discretized with 3D linear triangular elements. The model has 7450 nodes distributed in prismatic elements.

All models developed reflect large deformations, large displacements and contact interaction between strands. Both models of elastic and elastic-plastic materials were considered.

5.3. Charge-Displacement

The simulated load is a tensile along longitudinal axis of the wires. To avoid bending or twisting of parasite we ensure an aligned tensile stress.

Figure-3. Comparison of displacement results as a function of applied force

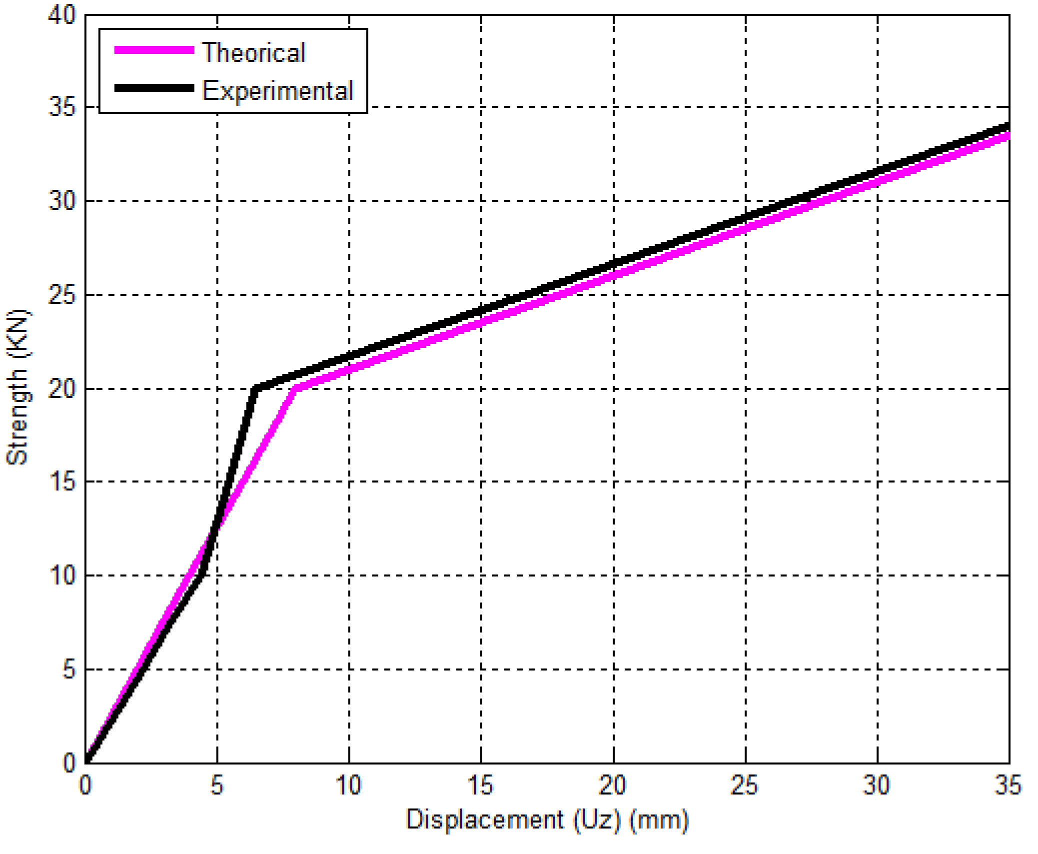


Figure 3 explicit the comparison of displacement results in response to tensile force applied in uniaxial continuous pattern of curved beams elemnts.

Simulation results prove that continuous pattern elements of curved beams are very close to each other, particularly in the elastic portion of the curve (up to 20 kN).

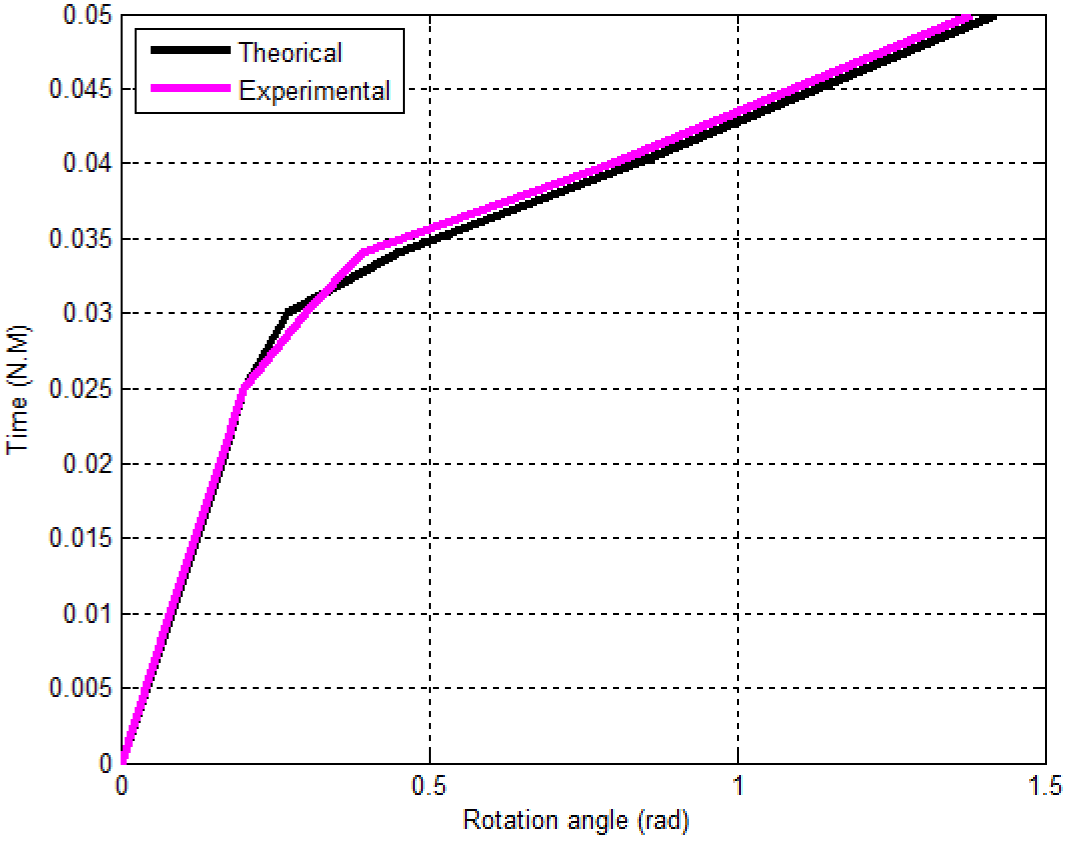
From the value 20 kN force the two curves confirms the stagnation of displacement (Uz) to the breaking force which corresponds to 35 kN.

© 2014 Conscientia Beam. All Rights Reserved

5.4. Moment Angle of Rotation

The comparison between the values of angle rotation variation according to the triplet of time shows good agreement between the two models (Figure 4).

Figure-4. Comparison of angle of rotation results depending on the time between the model of curved beams and the model of continuous elements



Analysis of the two curves (Figure 4) shows that the rotation angle increases to 0.3 rad in the angle of rotation value of the model curves beams, which are slightly above the continuous model.

6. CONCLUSION

In order to predict the lifetime of metal wires, it is necessary to select the appropriate numerical model to describe samples lifetimes cables.

Two models are typically used for description of service life of cables which are curved beam distribution pattern and continuous elements. The intended effect of these models is to predict median life span by using existing experimental data or laboratory results. We used these models in comparison with others to represent the stiffness and strength of cables.

Wire rope hoist must be maintained regularly and the type of maintenance depends on the class of the lifting device used, and the type of cable.

© 2014 Conscientia Beam. All Rights Reserved

It should be noted that regular maintenance greatly increases the lifespan of a wire rope hoist.

REFERENCES

Ancker, C.J. and J.N. Goodier, 1958. Pitch and curvature corrections for helical springs. Journal of Applied Mechanics, 80: 466–470.

Argatov, I., 2011. Response of a wire rope strand to axial and torsional loads: Asymptotic modeling of the effect of interwire contact deformations. International Journal of Solids and Structures, 48(10): 1413–1423.

Bajas, H., D. Durville, D. Ciazynski and A. Devred, 2010. Numerical simulation of the mechanical behavior of iter cable-in-conduit conductors. IEEE Transactions on Applied Superconductivity, 20(3): 1467–1470.

Boso, D.P., M. Lefik and B.A. Schrefler, 2006. Homogenisation methods for the thermomechanical analysis of nb3sn strand. Cryogenics, 46(7-8): 569–580.

Cardou, A. and C. Jolicoeur, 1997. Mechanical models of helical strands. Applied Mechanics Review, 50(1): 1-14.

Cartraud, P. and T. Messager, 2006. Computational homogenization of periodic beamlike structures. International Journal of Solids and Structures, 43(3-4): 686–696.

Chiang, Y.J., 1996. Characterizing simple-stranded wire cables under axial loading. Finite Elements in Analysis and Design, 24(2): 49-66.

Costello, G.A., 1977. Theory of wire rope. Springer Book.

Costello, G.A., 1997. Theory of wire rope. Edition Springer Verlag.

Cutchins, M.A., J.E. Cochran, S. Guest, N.G. Fitz-Coy and M.L. Tinker, 1987. An investigation of the damping phenomena in wire rope isolators, in the role of damping in vibration and noise control, (Boston, Massachusetts). Proceedings of the 1987 ASME Design Technology Conference. pp: 197-204.

Durville, D., 1997. Modélisation du comportement mécanique des câbles métalliques. Troisième Colloque National En Calculs Des Struc¬tures, Presses Académiques de l'Ouest. pp: 139-144.

Durville, D., 1998. Modélisation du comportement mécanique de câbles métalliques. Revue Européenne Des Eléments Finis: 9–22.

Erdönmez, C. and C.E. Imrak, 2011. New approaches for model generation and analysis for wire rope. In: Murgante, B., Gervasi, O., Iglesias, A., Taniar, D., Apduhan, B. (Eds.), Computational science and its applications - ICCSA 2011, Lecture Notes in Computer Science. Springer. pp: 103–111.

Ghoreishi, S.R., T. Messager, P. Cartraud and P. Davies, 2007. Validity and limitations of linear analytical models for steel wire strands under axial loading, using a 3d fe model. International Journal of Mechanical Sciences, 49(11): 1251–1261.

Hobbs, R.E. and M. Raoof, 1994. Mechanism of fretting in steel cables. Fatigue, 16(4): 273-280.

Imrak, C.E. and C. Erdönmez, 2010. On the problem of wire rope model generation with axial loading. Mathematical and Computational Applications, 15(2): 259–268.

© 2014 Conscientia Beam. All Rights Reserved

Jiang, W.G. and J.L. Henshall, 2000. A novel finite element model for helical springs. Finite Elements in Analysis and Design, 35(4): 363–377.

Jiang, W.G., M.K. Warby and J.L. Henshall, 2008. Statically indeterminate contacts in axially loaded wire strand. European Journal of Mechanics A/Solids, 27(1) : 69–78.

Jiang, W.G., M.S. Yao and J.M. Walton, 1999. A concise finite element model for simple straight wire rope strand. International Journal of Mechanical Sciences, 41(2): 143– 161.

Jolicoeur, C. and A. Cardou, 1991. A numerical comparison of current mathematical models of twisted wire cables under axisymmetric loads. Journal of Energy Resources Technology, 113(4): 241–249.

Karamchett, Y.S.D. and W.Y. Yuen, 1979. Contact problems in wire ropes. Transactions of the ASME: 702-710.

Kollros, W., 1973. Relation entre le moment de torsion, l'effort de traction et la torsion dans le câble. Ing. Dipl. EFP.

Lee, W.K., N.F. Casey and T.G.F. Gray, 1987. Helix geometry in wire rope. Wire Industry: 461-468.

Messager, T. and P. Cartraud, 2008. Homogenization of helical beam-like structures: Application to single-walled carbon nanotubes. Computational Mechanics: 335–346.

MSC Marc, 2006. 2005 r3 help manual. MSC. Software Corporation, USA.

Nawrocki, A., 1997. Contribution à la modélisation des câbles monotorons par éléments finis, Thèse De Doctorat - Spécialité : Génie Mécanique, Université De Nantes - École Centrale De Nantes.

Nawrocki, A. and M. Labrosse, 2000. A finite element model for simple straight wire rope strands. Computers and Structures: 345–359.

Nemov, A.S., D.P. Boso, I.B. Voynov, A.I. Borovkov and B.A. Schrefler, 2010. Generalized stiffness coefficients for iter superconducting cables, direct fe modeling and initial configuration. Cryogenics: 304–313.

Out, J.M. and B.J. Vonmorgen, 1997. Slippage of helical reinforcing on a bent cylinder. Engineering Structures: 507-515.

Páczelt, I. and R. Beleznai, 2011. Nonlinear contact-theory for analysis of wire rope strand using high-order approximation in the fem. Computers and Structures: 1004–1025.

Stanova, E., G. Fedorko, M. Fabian and S. Kmet, 2011a. Computer modelling of wire strands and ropes part i: Theory and computer implementation. Advances in Engineering Software: 305–315.

Stanova, E., G. Fedorko, M. Fabian and S. Kmet, 2011b. Computer modelling of wire strands and ropes part ii: Finite element-based applications. Advances in Engineering Software, pp: 322–331.

Vélinsky, E.R. and J.M. Teissier, 1998. Les caractéristiques de rotation des câbles métalliques, câbles spéciaux, Société Casar, France.

Wahl, A.M., 1963. 2nd Edn., Mechanical springs. New York: Mc Graw-Hill, Inc., 7: 92-102.

Views and opinions expressed in this article are the views and opinions of the author(s), International Journal of Sustainable Energy And Environmental Research shall not be responsible or answerable for any loss, damage or liability etc. caused in relation to/arising out of the use of the content.

© 2014 Conscientia Beam. All Rights Reserved