Advances in Engineering Software 83 (2015) 45–58

Contents lists available at ScienceDirect

Advances in Engineering Software

journal homepage: www.elsevier.com/locate/advengsoft

Finite element analysis of spiral strands with different shapes subjected to axial loads

Eva Stanova [a], Gabriel Fedorko [b], Stanislav Kmet [a,*], Vieroslav Molnar [b], Michal Fabian [c]

[a] Faculty of Civil Engineering, Technical University of Kosice, Vysokoskolska 4, 042 00 Kosice, Slovak Republic
[b] Faculty of Mining, Ecology, Process Control and Geotechnology, Technical University of Kosice, Park Komenskeho 14, 042 00 Kosice, Slovak Republic
[c] Faculty of Mechanical Engineering, Technical University of Kosice, Letna 9, 042 00 Kosice, Slovak Republic

ARTICLE INFO

Article history:
Received 29 August 2014
Received in revised form 14 December 2014
Accepted 7 January 2015
Available online 14 February 2015

Keywords:
Oval strand
Geometric parametric equations
Round strand
Triangular strand
Computer modelling
Finite element behaviour analysis

ABSTRACT

In this paper a new mathematical geometric model of spiral one or two-layered oval wire strands are proposed and an accurate computational two-layered oval strand 3D solid model, which is used for a finite element analysis, is presented. The three dimensional curve geometry of wires axes in the individual layers of the oval strand consists of straight linear and helical segments. The present geometric model fully considers the spatial configuration of individual wires in the right and left hand lay strand. Derived geometric equations were used for the generation of accurate 3D geometric and computational models for different types of strands. This study develops 3D finite element models of two-layer spiral round, triangular and oval strands subjected to axial loads using ABAQUS/Explicit software. Accurate modelling and understanding of their mechanical behaviour is complicated due to the complex contact interactions and conditions that exist between individual spirally wound wires. Comparisons of predicted responses for the strands with different shapes and constructions are presented. Resultant stress and/or deformation behaviours are discussed.

1. Introduction

Spiral strands and ropes are widely used in engineering applications. In recent years a broad range of specialty cables that meet the exacting specifications for original equipment manufacturers, military, transit offshore, and marine shipboard, nuclear and mining applications have been developed. Cables are usually subjected to large tension loads which are associated with torsion and bending effects. Mining and tunnelling applications expose cables to an abusive environment. Extensive abrasion, impact, vibration, tension, cut-through, and sometimes damage from local wildlife are common causes for cable failure. All mining cables can be tailored to specific needs.

Oval strand steel wire ropes generated from oval strands are applied in vertical mine hoisting and vertical mine excavation (shaft buildings). Cables are manufactured to withstand the kind of extreme conditions common in mining applications such as excessive material strain, extraordinary climatic conditions and risk of explosion. The oval cables with defined physical and mechanical characteristics are resistant to extreme temperatures, sunlight, water, chemicals, oil and abrasion. Oval cables are also suitable for other similar applications such as tunnelling and underground industry, loading trains and ships, and have been performing consistently in these areas since their introduction. New types of oval mining and tunnelling cables provide great lifecycle performance and reliability.

Spiral oval strands have a basically oval cross-section consisting of one or two layers of wires laid helically around parallel core wires. They have a high strength-to-mass ratio and good efficiency of construction, and due to their increased outer-wire surface area, they have good wear properties. The use of such ropes is especially efficient when there is a heavy end load and severe abrasive wear. Oval strand ropes are characterised by high structural stability, high fill factors and large bearing surfaces. The oval strand shape not only provides better resistance to crushing, but also offers a greater exposed surface area for contact with sheaves and drums. This feature distributes the abrasive wear over a greater number and length of wires.

Numerous works have been devoted to the development of mathematical geometric models of round spiral wire strands and ropes as well as the modelling of their behaviour under static and dynamic loads [1–9]. The round wire strands and ropes are treated either as a discrete set of concentric orthotropic cylinders, where individual layers of wires are replaced by equivalent cylindrical orthotropic sheets [1,2] or as a configuration of helically

* Corresponding author. Tel.: +421 55 6022121; fax: +421 55 6332748.
E-mail address: stanislav.kmet@tuke.sk (S. Kmet).

http://dx.doi.org/10.1016/j.advengsoft.2015.01.004
0965-9978/

curved rods, with different assumptions regarding the cable geometry and inter-wire contacts [3–9].

Lee [10] presented a geometrical analysis applicable to any rope with axisymmetric strands. The Cartesian coordinate equations, which describe the helix geometry of wire within a rope, were derived. Elata et al. [11] presented a new model for simulating the mechanical response of a wire rope with an independent wire rope core. In contrast with previous models, the present model fully considers the double-helix configuration of individual wires within the wound strand. Ghoreishi et al. [12,13] analysed synthetic fibre ropes subjected to axial loads. Usabiaga and Pagalday [14] derived parametric equations of double helical wires for the undeformed configuration of the rope. Nawrocki and Labrosse [15] presented a finite element model for simple straight wire rope strands, which allows the study of all possible interwire motions. Labrosse et al. [16] investigated the quantity of energy dissipated through friction due to motions between wires when a cable is loaded.

Evans et al. [17] investigated wire strain variations in tension–tension fatigue for two six-strand rope constructions under normal and overloaded conditions. Bradon et al. [18] presented a theoretical model of the torsional characteristics of parallel multi-part rope systems. Erdonmez and Imrak [19] proposed a computational model of a wire strand for its numerical analysis. Paczelt and Beleznai [20] developed the p-extension concept in the finite element method for a simple straight two-layered wire rope strand which considers all possible inter-wire motions, contact and dry friction amongst the wires. Argatov [21] developed a refined discrete mathematical model of a simple helical wire rope strand, which takes into account both the Poisson's ratio effect and the effect of contact deformation. Erdonmez and Imrak [22] proposed new methodology of defining and modelling the nested helical structure of wire ropes, and presented accurate wire rope 3D solid modelling, which can be used for finite element analysis. Both single and nested helical wire parametric equations are presented. Prawoto and Mazlan [23] presented computational, mechanical, and metallurgical properties of wire ropes under tension loading. Wang et al. [24] presented the finite element analysis of a hoisting rope and three-layered strand to explore fretting fatigue parameters and stress distributions of the cross-section. Frikha et al. [25] presented an asymptotic expansion method which has been applied to helical structures subjected to axial loads (traction and torsion) at its end sections. Stanova et al. [26,27] presented parametric equations to generate arbitrary multi-layered strand ropes with circular wires and their finite element-based applications.

Jiang [28] presented a concise finite element model for a simple wire strand subjected to pure bending. An accurate bending symmetric boundary condition was developed and applied to the periodic artificial cross-sectional end boundaries of the wire strand finite element model. To achieve better analysis accuracy, full three-dimensional solid elements were used for structural discretization. For the global behaviour of the wire strand, i.e. bending moment versus bending curvature, the finite element results showed a good agreement with the analytical elastic strand model of Costello [6] in an elastic loading regime. Furthermore, the finite element model can predict the detailed progressive nonlinear plastic behaviour of the wire strand. Noyan et al. [29] presented the neutron diffraction method to measure elastic strains induced in the constituent wires of parallel wire strands under tensile loading. The elastic strains carried by the individual wires depended very strongly on the boundary conditions at the grips and on radial clamping forces. The friction forces between the wires were quite significant and should not be neglected in analytical or numerical formulations of strain partitioning in parallel wire cables. Zhou and Tian [30] investigated a new finite element model for single-layered strands for an accurate and efficient mechanical behaviour analysis. A mathematical model was created by sectional path-nodes sweeping and dynamic node-beam mapping. Geometric relations between nodes in centre core wire and helical wires were deduced in tension and bending incorporating material elasticity theory and deformation geometrical compatibility. Based on Timoshenko beam theory, a strand of a pitch length was modelled with specific material and geometric parameters, and predetermined load cases were performed. The results obtained showed that discrepancies between the suggested method and Costello theory [6] do not exceed 1.51% in tension and 6.21% in bending.

Although triangular and other types of cable cross-sections were mentioned in some previous theoretical works [31,32], little investigation of these types of steel wire ropes has been conducted. This paper aims to contribute to the development of an oval strand computational model that will be able to theoretically analyse and predict the behaviour of spiral oval strands subjected to various load effects. Studies of oval cables, as presented in this paper, are rare.

In contrast with earlier references in which geometric models for round spiral strands were built, the contribution of this paper is to propose a 3D mathematical geometric model for oval spiral strands and confirm its applicability. Derived geometric equations are used for the generation of accurate 3D geometric and computational models for different types of strands. Results of finite element analyses of four spiral strands with different shapes are presented in this paper. Responses of two types of round spiral strands, triangular and oval strands subjected to axial loads are compared and discussed.

2. Geometric model of oval strands

The cables considered in this section are spiral oval strands made of one or two layers of circular wires helically laid over central circular straight core wires arranged in parallel (Fig. 1). The right (left) hand lay strand is a strand in which the cover wires are laid in a helix having a right (left) hand pitch.

2.1. Basic assumptions and problem formulation

A spiral oval strand that is created from n_0 parallel-lay straight wires in the core of the strand and n_j wires in the layer j (that is n_1 wires in the first layer and n_2 wires in the second layer) is considered in this study. An approach is based on the assumption that points of wires axes in the core of the cross section of the strand lie in one line. Denotations of the wires diameters in the corresponding layer are δ_j (where $j = 0$ for the core, $j = 1$ for the first layer and $j = 2$ for the second layer) and the gaps between the wires in the corresponding layer j are Δ_j. The gaps between the wires in the core are Δ_0. Gaps between wires of the adjacent layers are not considered. The lay angle of wires in the layer j of the strand is α_j. We assume that the wires of both layers are laid in the right hand direction. The structure of a cross-section of the oval strand which consists of for example 4 straight core wires, 10 wires in the first layer and 14 wires in the second layer is shown in Fig. 1.

A derivation of the mathematical expressions for the individual wires axes is based on the described geometric configuration of structural members of the strand and is similar to that published in [32] for triangular strands.

One of the options, when creating a geometric model of oval strands made of one or two layers of circular wires laid helically over a central circular straight core wires is presented in the following section of this paper. Subsequently, a proposed geometric model will be transformed into a finite element computational model and a behaviour simulation of an oval strand subjected to axial loads will be performed.