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Numerical Model and a Methodology on the Analysis of Complicated Wire Rope Structures

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Abstract: Wire ropes have complicated structures. Its core is assembled using six wire strands around a simple straight wire strand and called as Independent Wire Rope Core (IWRC). IWRCs are used as the core for most complex structured wire ropes as Seale IWRC. In this paper as a complex wire rope structure the construction of Seale IWRC is described and its finite element analysis (FEA) is mentioned. The proposed methodology gives wire by wire results and as a result gives necessary information about the wire behavior within a wire rope.

Keywords: Wire rope, Independent Wire Rope Core, Seale IWRC.

1 Introduction

A well-known treatise of Love, '*A treatise on the mathematical theory of elasticity*' gives very important theoretical information about the theory of wire ropes, see Love (1944). At first stages of the researches most people studied the analytical theory of wire ropes using the equilibrium equations defined over a helical rod, see Phillips and Costello (1973). Costello investigated different aspects of wire rope theory and presented them in a monograph, see Costello (1990).

Taking advantage of geometric considerations explicit expressions for the determination of axial force, bending and twisting moments in the helical wires, and for the axial force and twisting moment in the core of a 7-wire strand subjected to axial and torsional displacements are defined and the analytical expressions for axial force, bending moment, twisting moment and contact forces between wires are presented by Machida and Durelli (1973). Static behavior of wire rope with a frictionless theory is presented by Costello and Sinha (1977). The solution shows that it is valid for complex cross sections that are usually found in practice. Velinsky (1981) and Velinsky et.al. (1984) presents a theory that will predict the axial static response of a wire rope with complex cross sections such as a 6x19 scale IWRC. The results

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show that, if the rope is not allowed to rotate, the maximum tensile stress occurs in the center wire.

A general nonlinear theory has been developed to analyze complex wire ropes by Velinsky (1985). The nonlinear equations of equilibrium for bending and twisting of thin rods are applied to a 6x19 Seale wire rope with an IWRC. The results of the nonlinear theory are compared to the recently developed linear theory and found to be nearly identical in the load range in which the most wire ropes are used.

These earlier studies are general theoretical considerations on wire rope theory and Seale IWRC's are not studied much using numerical methods. Lately model generation and numerical analysis are investigated in a number of papers by Erdönmez and İmrak (2011), İmrak and Erdönmez (2010). In this paper our aim is to model and investigate wire by wire behaviour of Seale type IWRCs. Indeed, the theory is difficult to apply to complex problems such as contact analysis and behaviour of wires within a composition of Seale IWRC. Six equilibrium equations for wire ropes can be solved by linearization process and this lacks to consider the nonlinear behaviour and material characteristics of wire ropes. Due to this, numerical analyses of wire ropes are necessary. To accomplish this aim, first of all the composition of wire ropes is described briefly. Soon afterward the numerical analysis of Seale IWRC is mentioned in this paper.

2 Basics for construction a Seale IWRC

The main difficulty of finite element analysis (FEA) is model generation and its mesh. A valid mesh is mandatory part of the solution for a FEA analysis. General parametric equation for a helix can be defined as,

$$\begin{aligned} x_s &= r_s \cos(\theta_s), \\ y_s &= r_s \sin(\theta_s), \\ z_s &= r_s \tan(\alpha_s)\theta_s, \end{aligned} \tag{1}$$

where r_s is the radius of the single helix, α_s is the single helix laying angle and θ_s defines the location of the wire around the centerline of the wire strand. To form the outer strand of an IWRC, the centerline of the outer single helical wire is used as mentioned in detail by Erdönmez and İmrak (2011). The common form of the outer nested helical wire parametric definition is as follows,

$$\begin{aligned} x_d &= x_s(\theta_s) + r_d \cos(\theta_d)\cos(\theta_s) - r_d \sin(\theta_d)\sin(\theta_s)\sin(\alpha_s), \\ y_d &= y_s(\theta_s) + r_d \cos(\theta_d)\sin(\theta_s) + r_d \sin(\theta_d)\cos(\theta_s)\sin(\alpha_s), \\ z_d &= z_s - r_d \sin(\theta_d)\cos(\alpha_s), \end{aligned} \tag{2}$$

where θ_d is the helix turning angle around the outer centerline and r_d is the radius of the outer helix while α_s and θ_s are the same quantities as defined previously.

Eq.1 and Eq.2 are used to construct the single helical wire where as equation (2) is used to construct the Seale part of the Seale IWRC. As it can be concluded from these parametric equations it is mandatory to construct each wire in the outer strand of the IWRC where as in the Seale part of the whole assembly. After this process is accomplished one can assembly these wires to model the Seale IWRC. A general meshed form of Seale IWRC is given in Fig. 1.

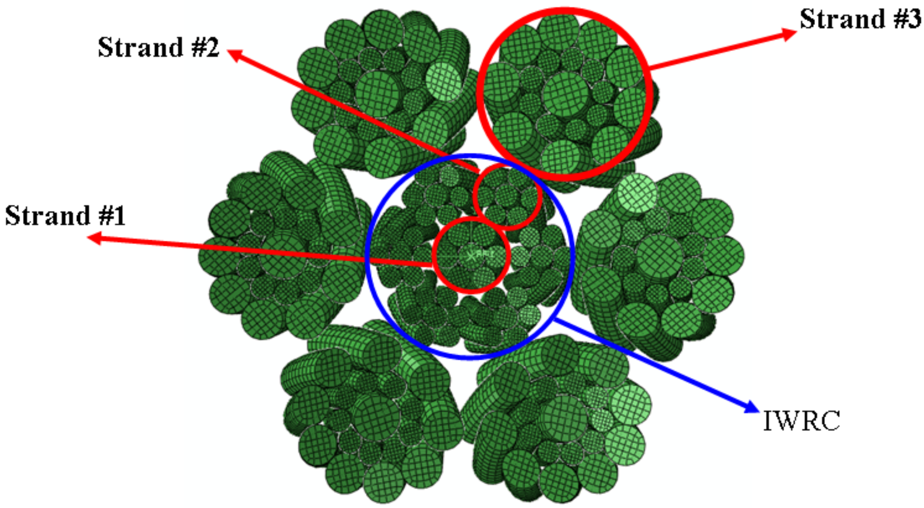

Figure 1: A 6x19 Seale IWRC cross section.

Strand #1 is the core wire strand (WS), strand #2 is the outer strand which wrapped around the core WS to form the IWRC as presented in Fig. 1. Strand #3 is the Seale part of the Seale IWRC as depicted in Fig. 1.

3 Definition of the axial loading problem for Seale IWRC

An axial loading problem is defined over a Seale IWRC. One side of the wire rope is fixed while the other side of the wire rope is displaced with respect to the strain value of 0.001. Material parameters are obtained from the study of Costello (1990) as defined in Table 1.

The reaction force-strain variation is presented over the Seale part of the Seale IWRC is given in Fig. 2.

Table 1: Material properties of a wire within the Seale IWRC.

Young's modulus, E	188000 N/mm^2
Plastic modulus	24600 N/mm^2
Yield stress	1540 N/mm^2
Limit stress	1800 N/mm^2
Poisson's ratio	0.3
Friction coefficient	0.115

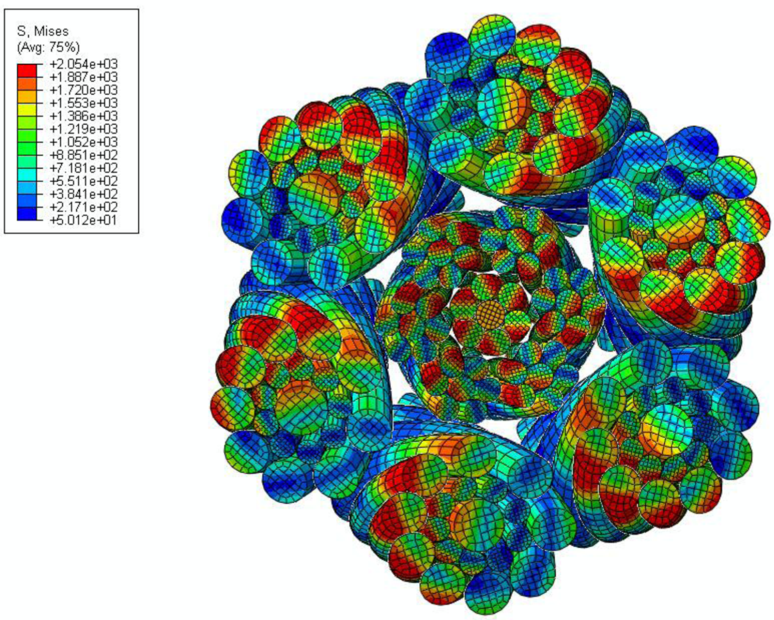

Figure 2: Von-misses stress distribution over Seale IWRC.

4 Conclusion

In this paper a numerical analysis methodology construction for complex wire rope structures is done. As a complex wire rope structure Seale IWRC is selected. It is constructed using the parametric equations of both single and nested helical wires. Main issue of FEA is to construct a correct mesh. To accomplish this, a software code is generated to construct wire rope assembly. Including the material properties FEA of a 6x19 Seale IWRC model is conducted. Wire by wire analysis results of a complex wire rope is presented. This analysis model gives knowledge for the wire behaviors within a wire rope. Using the proposed method one can find solution to different problems over wire ropes. As a future work wire rope bending analysis can be defined and analyzed for various loading conditions.

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