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ADVANCES IN 3D WIRE ROPE MODELING AND NUMERICAL ANALYSIS

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Key words: wire rope model generation, finite element analysis, independent wire rope core.

Abstract:
Wire ropes are used in variety of important application areas such as electrical transmission lines, bridges, cranes, elevators, mines and ocean engineering, etc. Due to its complex geometry, a wire in rope is subjected to the combined effects of tension, shear, bending, torsion, contact friction, and possible local plastic yielding when loaded. A valid 3D wire rope model generation depends on the mathematical definition of the single and nested helical wire geometries. In this study, a 3D modeling methodology is developed to generate a wire strand (WS) and an independent wire rope core (IWRC). Finite element analysis procedure is validated using a WS model by comparing the numerical results with the available test results. IWRC with varying lay length are analyzed and presented. Moreover, the numerical analyses for IWRCs with different lay direction are compared.

1. Introduction

Wire ropes are mostly analyzed using the analytical solutions of the equilibrium equations of Love [1]. Numerical analyses on wire ropes are started in 1999 by the study of Jiang [2]. A new model for simulating the mechanical response of an IWRC is presented in [3]. A contact model for laying wire rope with the augmented Lagrangian multiplier method in [4].

Wire ropes are composed by wrapping helical wires around other wires. Therefore, the helical wires are the base components while producing a wire rope. While the modeling a 3D wire rope model this reality have to be taken into account. Wire rope model is complicated due to the inclusion of different type of helical wires within a model. Single and nested helical wires are used to compose a complex wire rope such as independent wire rope core (IWRC). Because of the different helical geometries are included in a wire rope, it needs special treatment while generating the 3D solid models. Wire rope 3D modeling and analysis in wire-by-wire based method is presented in [5,6]. Wire rope modeling issue is explained in [5] based on the control nodes of the single and nested helical wires and uses the HyperMesh to generate the final wire rope model. Each wire is separately taken into account and generated. A GUI code is written to simplify the procedure to implement each wire within a rope and presented in [6]. A new GUI code is underway which will generate the complete meshed model ready for FEA analysis. It is based on the parametric mathematical equations of single and nested helical geometry.

In this study, using the advanced 3D wire rope modeling techniques FE numerical analysis is investigated. Meshed solid wire rope model is generated and numerical analysis using finite element method is conducted under certain loading conditions. Wire rope 3D solid model without length limitation is established and affect of pitch length is analyzed. Different lay types of IWRCs are analyzed and FEA results are presented at the end.

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2. Design and FEA analysis results for a simple straight strand and IWRC

A simple straight strand is the first basic component of an IWRC. It is built up wrapping six single helical wires around a straight wire as known. With the similar way, strands are wrapped around a simple straight strand to establish an IWRC model as depicted in *Fig. 1*. Differences between inner and outer strands are the helix types used while construction. Inner strand is composed by using a straight wire and single helical wires while the outer strand uses both single and nested helical wires. Here first of all a simple straight wire strand is analyzed and numerical results are compared with theory and available test results. Then IWRCs are considered for varying pitch lengths and von-Mises stress distributions are presented. At the end, IWRCs for different lay types are investigated using FEA and compared.

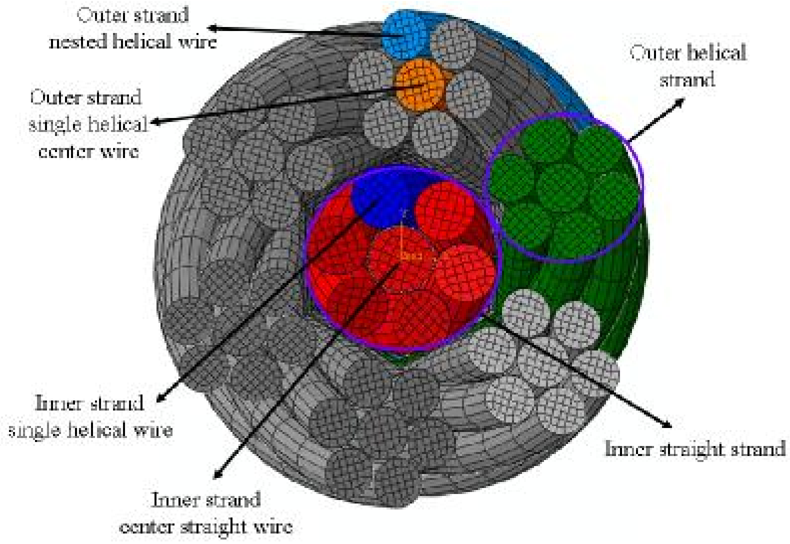


***Fig. 1** An IWRC model with inner and outer strand compositions*

An $14mm$ length (1+6) wires simple straight strand is considered which is defined as a core wire with center wire diameter R_1=3.94*mm,* outer wire diameter R_2=3.73*mm* and pitch length *p*=115*mm* [2]. Numerically obtained FEA results are compared with both Costello's [7] model and test results reported by Utting & Jones [8,9]. Elastic frictionless and elastic-plastic frictional numerical models are developed. Wire material properties are obtained from [10] for elastic and plastic behaviors. Axial loading behavior of a simple straight strand is investigated. An axial strain e of 0.015, was applied in increments of 0.001 in the analysis. Rotation restrained, $\Theta = 0$, constant axial deformation results are illustrated in *Fig. 2* for the straight strand. It can be seen from the figure that the frictionless behavior of both theory of Costello and FEA results are in good agreement. The frictional plastic behavior of the strand is compared with the test results of Utting&Jones [8,9] given in the literature. Plastic behavior of the model is found to be in very good agreement with the available test results. In addition, FEA result of Jiang is compared. It can be seen from the *Fig. 2* that the present numerical FEA result is in good agreement with Jiang's results also.

***Tab. 1:** Helix angle changes for IWRC*

Inner strand single helical wire		Outer strand single center helical wire		Outer strand nested helical wire	
Angle a_2 $(degree)$	Pitch length $[p_2](mm)$	Angle a_2^* $(degree)$	Pitch length $[p_2^*]$ (mm)	Angle a_4 $(degree)$	Pitch length $[p_4]$ (mm)
64.27	50	64.71	137	68.72	50
71.01	70	71.46	193	74.45	70
75.01	90	75.49	250	77.79	90
80.23	140	80.67	394	82.08	140
84.02	230	84.47	669	85.16	230

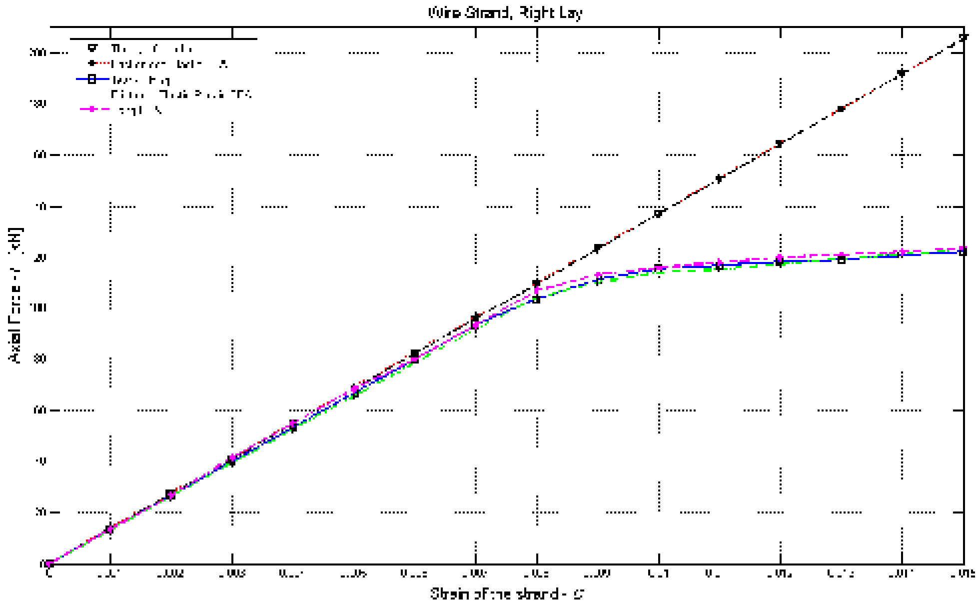
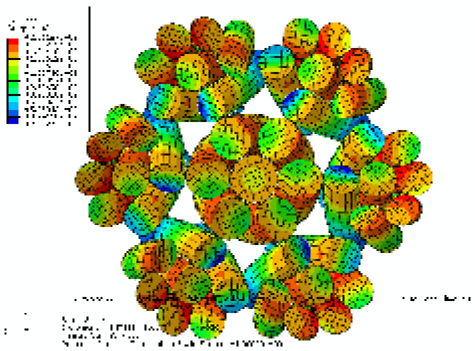
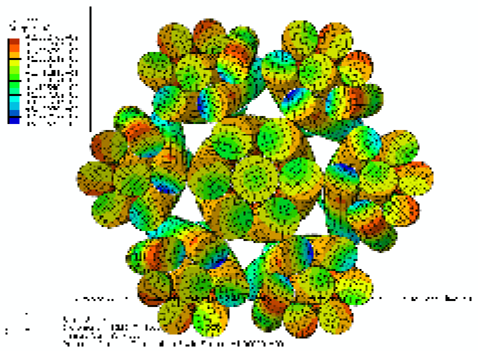


Fig. 2 *Force-Strain results for the straight strand; theory of Costello, test of Utting&Jones, frictionless elastic & frictional elastic-plastic FEA*

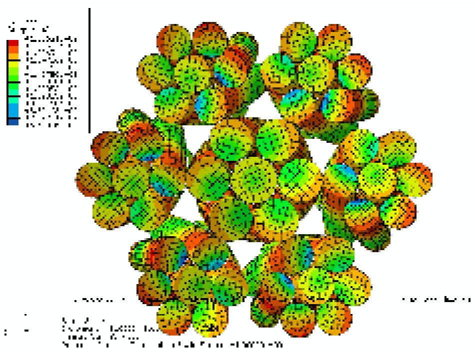
Fig. 3 shows the 3-D structure of the IWRC with the contour plots of the stress distribution over different helix pitch lengths. For the core strand; center wire diameter R_1=3.94*mm,* outer wire diameter R_2=3.73*mm* and for the outer strand; center wire diameter R_3=3.2*mm,* outer wire diameter R_4=3*mm*. The helix pitch lengths are defined in *Tab. 1*. From the figure close fitting of the outer nested helical wires over the outer single center wires can be easily seen for p_2=50*mm*. While the helix length increases the close fitting nature of the outer wires are changed and when the helix length increases to p_2=140*mm*, center strand single helical wires are nearly parallel to the center straight wire. This situation affects the behavior of the IWRC and center wire strand behaves like parallel rods, which reflects to the whole solution of the IWRC.



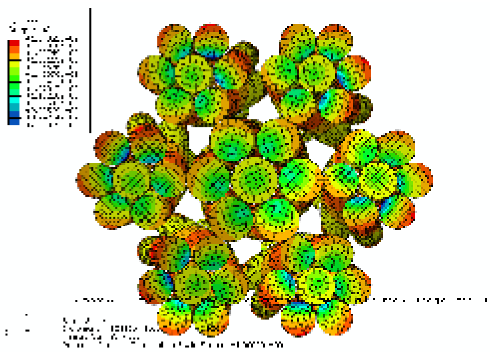
Pitch length; p_2, p_2^*, p_4; *50, 137, 50*



Pitch length; p_2, p_2^*, p_4; *70, 193, 70*



Pitch length; p_2, p_2^*, p_4; *90, 250, 90*



Pitch length; p_2, p_2^*, p_4; *140, 394, 140*

Fig. 3 *von-Mises stress distribution over a right regular lay IWRC*

A 300*mm* fixed end reaction force comparison for RLL, LLL, RRL and LRL type IWRCs are presented in this example. Total reaction force comparisons, given in *Fig. 4*, for fixed end condition shows that the maximum reaction force is obtained at the LRL IWRC while the minimum reaction force is obtained at the RLL IWRC. When the LRL and RLL types IWRC are considered, it can be seen that the differences of the lay directions are important while force distributions within a rope. In LRL IWRC, wires in the strands are laid to the right while the strands are laid to the left. The nested helical wires for lang lay compositions are smoother than the regular lay wires. The wires in the strands are laid to the right, while the strands are laid to the left to form the LRL IWRC. In this lay, each step of fabrication is exactly opposite from the right regular lay. For this reason, considering the geometry of the LRL IWRC the axial force distribution given in *Fig. 4* is clearly understood.

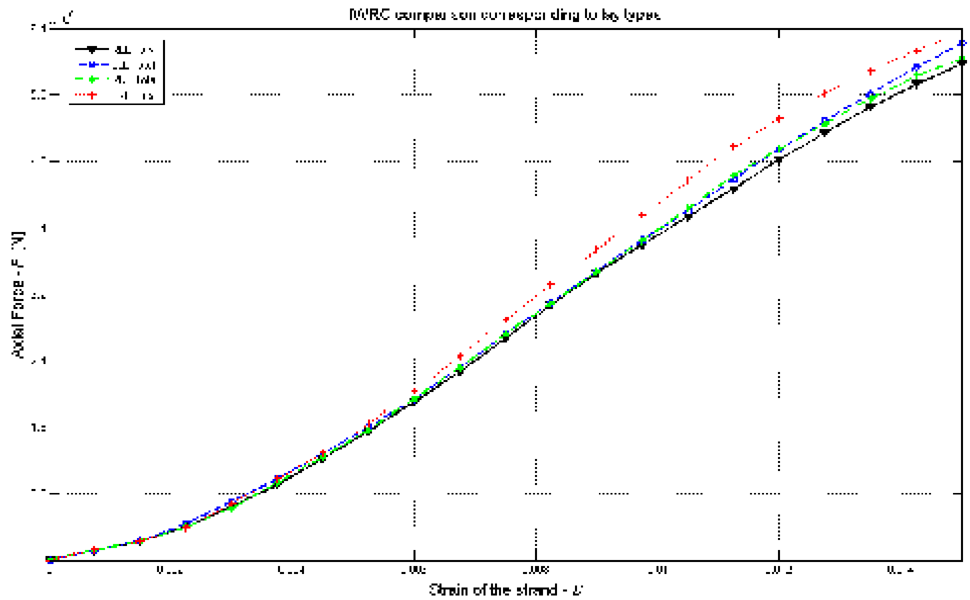


Fig. 4 *A 300mm fixed end total reaction force comparison for RLL, LLL, RRL and LRL type IWRCs*

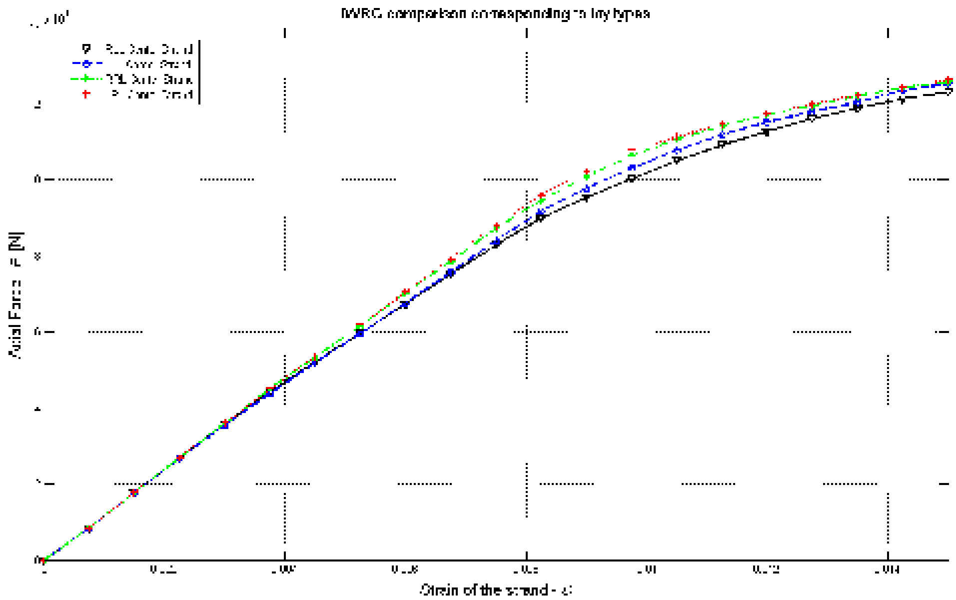


Fig. 5 *A 300mm fixed end center strand reaction force comparison for RLL, LLL, RRL and LRL type IWRCs*

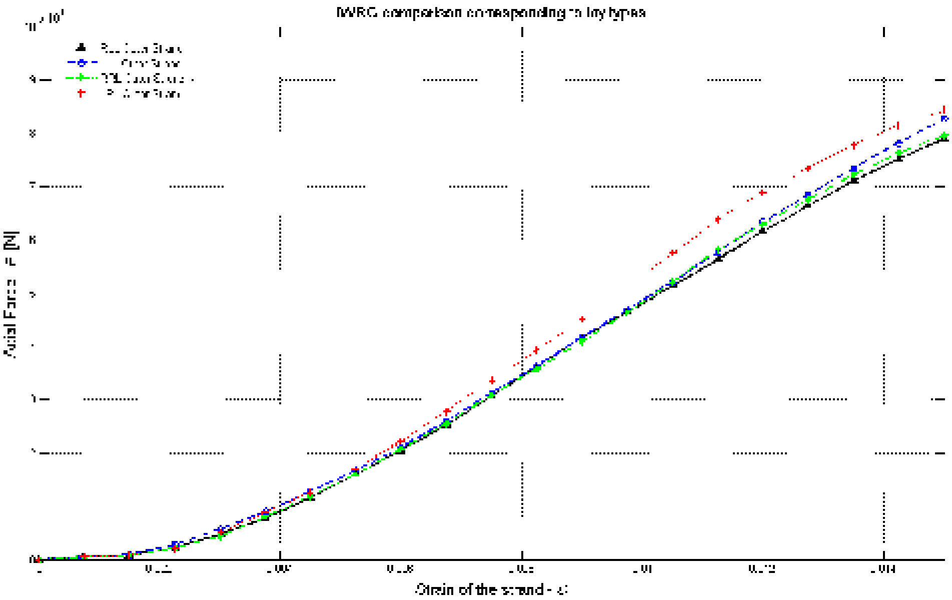


***Fig. 6** A 300mm fixed end outer strand reaction force comparison for RLL, LLL, RRL and LRL type IWRCs*

Strands within an IWRC are compared next. Center strand comparisons for fixed end boundary conditions are shown in *Fig. 5*. It can be concluded that the center strand force distributions are similar with small differences for each lay types. Outer strand comparisons for fixed end conditions are given in *Fig. 6*. LRL takes maximum reaction force while RRL takes minimum reaction force values as depicted in *Fig. 4* due to the geometrical composition of the wires within outer strands of the IWRCs.

3. Conclusion

Wire strand (WS) and independent wire rope core (IWRC) are basic components of wire ropes. In this paper the analysis of WS and IWRCs are investigated by using FEA. First, a simple straight strand is analyzed and FEA results are compared with both theory and test results. It has been observed that the results are in good agreement. IWRC for different pitch lengths are numerically analyzed. At the end RLL, LLL, RRL and LRL type IWRCs are analyzed and FEA results are compared according to the lay types. As a conclusion type of lay direction is an affecting the axial force distribution on IWRCs. This is due to the indentations present on the nested helical wires within the outer strands. It has been observed that the LRC IWRC has the maximum axial force within the other IWRC types.

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