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RESEARCH ARTICLE

A COMPLEX DISCRETIZED 3D WIRE ROPE MODEL CREATION AND ITS NUMERICAL ANALYSIS: 6X25 FILLER IWRC

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ABSTRACT

6x25 Filler IWRC type ropes belong to 6x19 rope class. It is widely used in 6x19 wire rope class in almost all industrial sectors. Filler type rope has good balance in both wear and fatigue resistance. Drilling lines, cranes, lifting devices, bridges, oil drilling rig, elevators etc. are some of the usage areas. 25 Filler wire strand (1-6-6f-12) consists of two layers of uniform-size wire around a center wire with the inner layer and small filler wires are laid in the holes of the inner layer. In this paper, three-dimensional meshed model of 6x25 Filler IWRC was created by using parametric equations. Using the proposed three-dimensional model, a finite element analysis is conducted by applying displacement boundary condition to one end and encastre boundary condition is applied to the other end of the wire rope. The results of the analysis show that the proposed model can be used in analysis studies under different loading conditions.

Keywords: *6x25 Filler IWRC, Filler Wire Strand, Meshed Model*

KOMPLEKS AYRIKLAŞTIRILMIŞ 3D TEL HALAT MODELİNİN OLUŞTURULMASI VE SAYISAL ANALİZİ: 6X25 FILLER IWRC

ÖZ

6x25 Filler IWRC tipi halatlar 6x19 halat sınıfına aittir. Neredeyse tüm endüstri sektöründe 6x19 tel halat sınıfında yaygın olarak kullanılmaktadır. Filler tipi halat hem aşınma direnci, hemde yorulma direnci açısından iyi bir dengeye sahiptir. Sondaj hatları, vinçler, kaldırma tertibatları, köprüler, petrol sondaj kuleleri, asansörler vb. alanlarda kullanılmaktadırlar. 25 Filler tel demeti (1-6-6f-12), merkez telin etrafına sarılı iki katmanlı tekdüze tellerden oluşturulmuş olup dolgu telleri bu iki katman arasındaki boşluklara yerleştirilmiştir. Bu yazıda, 6x25 Filler IWRC'nin üç boyutlu sayısal örgü modeli, parametrik denklemler kullanılarak oluşturulmuştur. Önerilen üçboyutlu halat modelinin bir ucuna enkastre diğer ucuna ise yer değiştirme sınır koşulları uygulanarak sonlu eleman analizi gerçekleştirilmiştir. Elde edilen analiz sonuçları, önerilen modelin farklı yükleme koşullarında yapılacak analiz çalışmalarında kullanılabileceğini göstermektedir.

Anahtar Kelimeler: *6x25 Filler IWRC, Filler Tel Demet, Sayısal Örgü Modeli*

1. INTRODUCTION

During last decades importance of wire rope usage is increased in wide variety of application area due to its flexible nature and advantages over traditional solutions. With the diversification of the areas of use, the rope manufacturers focus on research and development activities to produce ropes of different characteristics and types to meet the needs in these areas. There is a need to analyze new designs and productions in engineering field and to report their results. For this purpose, it is necessary to design and manufacture test equipments. In addition test samples needed for the analysis and to perform rope tests under different conditions. The time required to make the required tests, as soon as possible, number of staff needed and the creation of the samples is going to result high costs. In addition there can be difficulties in developing remedies for the problems that may arise during production. One of the best solutions is to use high performance computer technology. The existing high-processor PCs and advanced software allow for the three-dimensional modeling and analysis of such structures.

Researches on modeling and analysis of ropes have been investigated comprehensively. A generalized mathematical model that completely describes the geometry of the wires. The specific model for a 33-mm 6×19 Seale, independent wire rope core (IWRC) was presented by showing the paths and the geometric properties of the wires within the given models in [1]. An accurate wire strand (WS) model is generated using the finite element method (FEM) which accounts tension, shear, bending, torsion, contact, friction and possible local plastic yielding and compared the results with available theoretical and test results in [2]. The nested helical structure (NHS) for wire ropes using 3D solid modeling is presented where the mesh problems using CAD softwares are taken into account and a solution procedure is proposed for the solution in [3]. A new technique of modeling IWRC is presented and the numerical results of the IWRC model compared with the literature in [4]. The single-lay wire strands and double-lay wire ropes models are presented using CATIA 5 in [5]. The development of a finite element model for the numerical simulation of the multi-layered strand under tension are represented in [6]. A more difficult complex helical structures in three-dimensional form which is called triple helical structure is presented and then it is generalized to more complex form of n-tuple helical structures in [7]. The response of a multi-strand wire rope, which is called independent wire rope core (IWRC), subjected to axial tension and axial torque is represented and it is showed that the torsion stress of a double-helix wire can be neglected when the rope is subjected to axial tension while axial torsion is restrained in [8]. A beam finite element model (FEM) presented for efficient analysis of the mechanical behavior of a three layered 19-wire strand using two-noded elastic plastic beam elements in [9]. Three-dimensional modeling approach and finite element analysis of wire ropes are explained and wire-by-wire results are gathered by using the proposed modeling and analysis method under various loading conditions in [10]. In addition a lot of study conducted on the experimental analysis. The response of prestressing strands to axial tensile load is investigated both theoretically and experimentally in [11]. Calculation of irregularity of stress distribution between a core and wires of the steel rope in case of different rates of wire twisting is investigated in [12]. Theoretical and experimental determination of bending over sheave fatigue lifetimes of rotation resistant steel wire ropes has been conducted in [13]. Discard lifetimes of 6 × 36 Warrington-Seale steel wire ropes subjected to bending over sheave (BoS) fatigue have been determined theoretically and experimentally and presented in [14]. Characterize the mechanical behavior of the wire rope in service along with monitoring the evolution of its damage in order to facilitate the determination of the conditions of use reliably is presented in [15]. These experimental analysis can be supported and enhanced by the contributions of the numerical analysis results.

As a result of the literature review, it has been observed that finite element analysis (FEA) of the wire ropes are increased in last decade. Many studies have focused on modeling simple wire rope strands. Recently, more efforts have been focused on IWRC type rope models. Generalization of the rope structures to the n-tuple wire rope structures in focused in [7]. In addition, SEALE type rope model is included in a few studies. However, Filler type wire rope model is not mentioned. For this reason, in this article the design and analysis of a common type of 6x25 Filler type wire rope model is discussed.

2. FILLER IWRC WIRE ROPE STRUCTURE

Filler wire rope is one of the most used rope type in the industry. Most common identification of this class of wire ropes are known under the name of 6x19 class wire ropes. Beyond this class of wire ropes 6x25 Filler IWRC is analyzed in this paper. The core is an 7x7 IWRC which is surrounded by 6 Filler strand which is composed by using (1-6-6f-12) wires. In Figure 1 the general structure of the 6x19 Filler IWRC is presented.

The construction of the Filler IWRC, shown in Figure 1, done by using the parametric mathematical equations of both single and double helical wires as mentioned in the literature [1,3,4,7]. The wire radiuses are labeled as R1-R4 for IWRC in Figure 1. The core inner wire strand of the IWRC is composed by using a straight wire which is nested by 6 simple helical wires. But the outer strands of the IWRC includes both single and double helical wires. The single helix geometry centerline (x_s, y_s, z_s) of the outer strand of the IWRC is obtained by the following formula,

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

where r_s shows the radius of the center wire of the outer strand and α_s shows the helix angle of the outer strand. The outer strand single helical of the IWRC is surrounded by six double helical wires and its centerline (x_d, y_d, z_d) is defined in parametric form as,

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

where r_d shows the radius of the double helical wire and θ_d is the rotation angle of the double helical wire around the single helical wire. The relation between the rotation angles given in [7]. Using the Equations (1) and (2) centerlines of the single and double helical geometries can be obtained.

The next step is to construct the 25 wire Filler Strand and to wound it around the IWRC. The 25 wire Filler strand is composed by a single helical wire as a core and two lays of outer double helical wires. Wire radiuses for the Filler strand is labeled as R5-R8 in Figure 2. First layer has 6 double helical wires while the second layer has 12 double helical wires. There exists 6 double helical wires between the first and the second layers. Figure 2 shows one of the Filler strand which is wound helically around the IWRC. A sector of this Filler strand is defined in Figure 2. Two new important lengths to properly define the centerline of each double helical wires within the Filler IWRC is represented by r_7 and r_8 in this sector view. Using these lengths, r_7 and r_8, one can find the centerline of each double helical structure within the Filler strand in the similar way of double helical wires defined for IWRC in Equation 2. The wire radiuses and pitch lengths are given for the 6x25 Filler IWRC in Table 1.

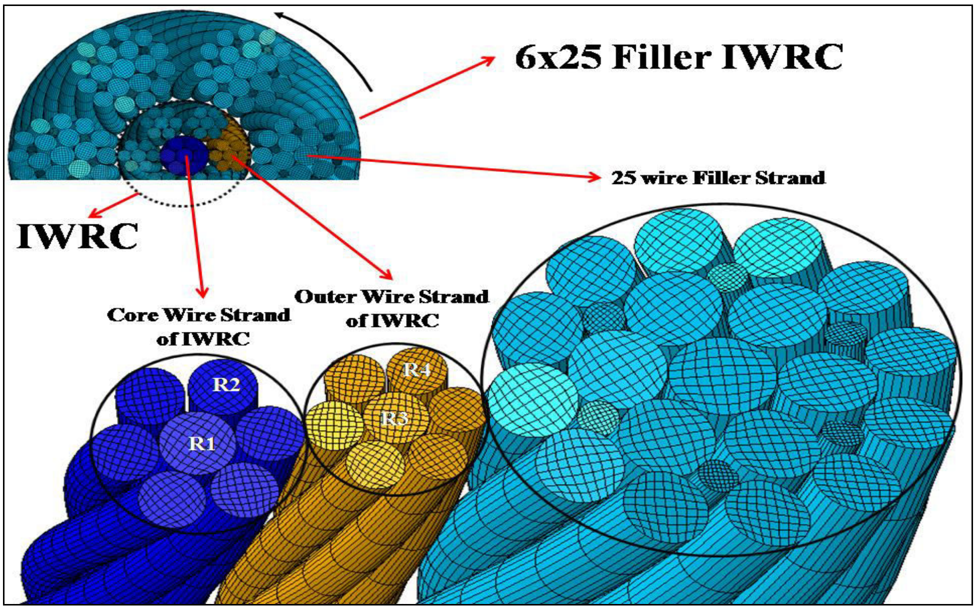

Figure 1. Composition of the 6X25 Filler IWRC Structure

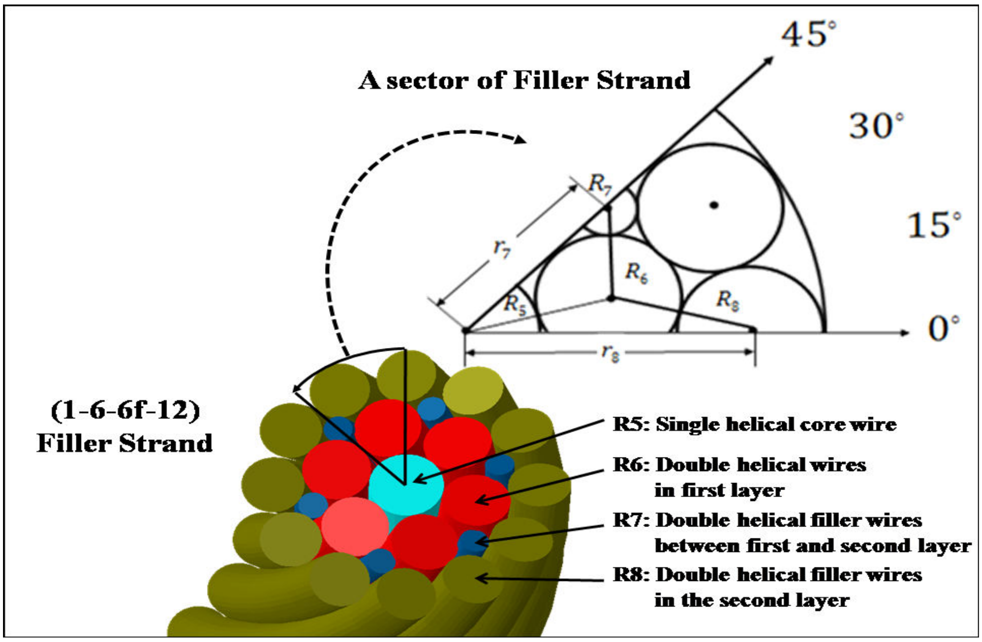

Figure 2. (1-6-6f-12) Wire Filler Strand Radiuses and a Sector of Filler Strand

Table 1. Wire Radiuses and Pitch Lengths for 6x26 Filler IWRC

Labels	Radiuses	Pitch lengths
R1	0.343*mm*	-
R2	0.305*mm*	35.74*mm*
R3	0.292*mm*	88.48*mm*
R4	0.267*mm*	35.82*mm*
R5	0.483*mm*	82.89*mm*
R6	0.445*mm*	33.07*mm*
R7	0.191*mm*	33.18*mm*
R8	0.406*mm*	45.88*mm*

3. THREE-DIMENSIONAL MESHED MODEL AND STRESS ANALYSIS

Using the Equations (1) and (2) double helical geometries are prescribed for each wire within the IWRCs and Filler Strands. It has been presented in [3] that the discretized meshed model of wire ropes are very difficult most of the time. For this reason a Matlab code is developed to model which uses the proposed parametrical equations to generate meshed model of each wire within 6x25 Filler IWRC. This code generates 199 wires which constructs the whole model of the 6x25 Filler IWRC in 3D and gives a text output. This output file can be imported by using Abaqus/CAE and the FEA is run on this 3D meshed model. The benefit of this code is that it only takes a few minute, depending on the length of the wire rope you need to generate, to produce the meshed model of the wire rope. So any changes on the wire radiuses or the helix angles can be re-meshed within a few minutes again.

The last step is the FEA of the proposed model of the 6x25 Filler IWRC. The numerical analysis of the proposed model is conducted using Abaqus/CAE. The length of the model is 20*mm*. Encastre boundary condition is applied to one end while the displacement boundary condition is applied to the other end. Only 0.43125*mm* displacement is applied for the analysis. In the proposed model total number of nodes, Total number of elements and number of linear hexahedral elements of type C3D8R are used as 360855, 272384 and 272384 respectively. Von-misses stress and strain distribution on the 6x25 Filler IWRC are represented in Figure 3 and Figure 4 respectively. The results are represented for selected strands and wires along the model to see the distributions over the wires inside the 6x25 Filler IWRC. From the Figure 4 and Figure 5 it can be observed that the stress and strain distributions along the wires on the model shows the general characteristics of the wire ropes. Meanwhile it can be obtained that the stress and strain values are increasing at the contact areas as expected. At the same time due to contact center wires of each strand becomes more important for the whole model.

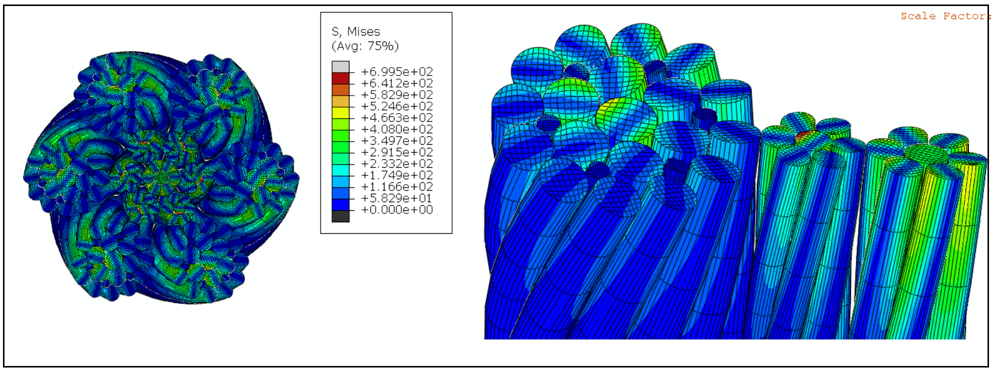

Figure 3. Von-Misses Stress Distribution Along Filler IWRC

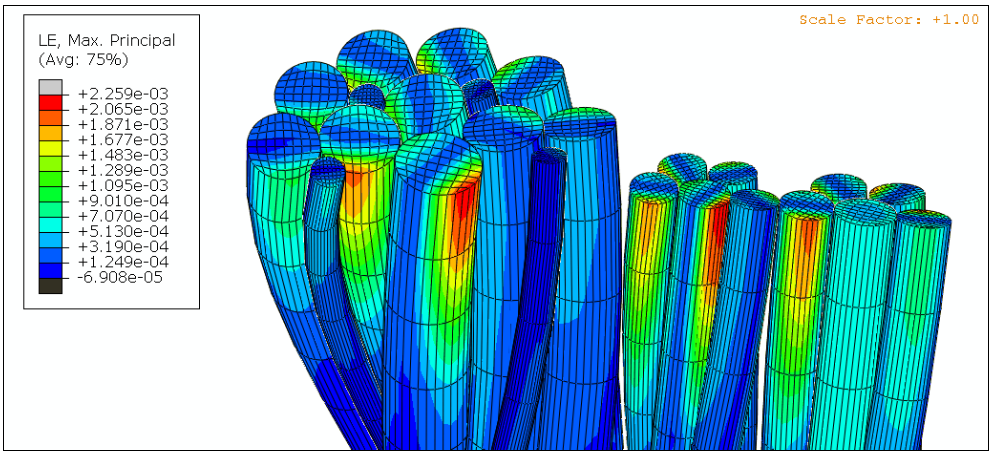

Figure 4. Logarithmic Strain Components Along Filler IWRC on Selected Wires

4. CONCLUSION

6x25 Filler IWRC is one of the most popular design along the class of 6x19 wire ropes in the industry. The most important issue that manufacturers work on is undoubtedly to produce more durable wire ropes which can work under the desired conditions. One of the way to achieve this is to do research and development on the design of wire ropes. Instead of expensive and long-term testing, it is possible to improve the products through numerical analysis studies in the industry. For this purpose three-dimensional modelling and analysis of 6x25 Filler IWRC ropes are discussed in this paper. The parametric mathematical model of the rope has been converted into a ready-made design by means of an intermediate program code written using Matlab. Then the finite element analysis of this meshed model performed under the displacement boundary conditions. The results show that the core wires of the strands are important for the rope and the elongation and stress distribution are increasing towards the center of each IWRCs and Filler strands. This study shows that the three-dimensional model of the 6x25 Filler IWRC can be build easily using the proposed Matlab code correctly and gives expected FEA results. It is thought that the present study will guide the other researchers to do more complicated analysis in the future.

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