Distributions of stress and deformation in a braided wire rope subjected to tensile loading

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Abstract. Braided wire rope is vital for stringing conductors with tension in overhead transmission lines. Its structure and characteristics determine the safety and reliability of the stringing construction. Tensile loading is the main load-bearing form of the steel wire rope in this process. This study analyzes distributions of stress and deformation in braided wire rope subjected to tensile loading. A geometric model for YS9-8 × 19 braided wire rope was established, and the finite element simulation of the tensile process was carried out using explicit dynamics. The simulation results are analyzed to reveal the distribution laws of stress and deformation on whole rope and intermediate cross section.

1. Introduction

A braided wire rope is crossed and braided in a spiral path by groups of single-stranded wire ropes, which are braided together symmetrically, with equal numbers of left- and right-hand lays. Owing to the anti-twist characteristics of the special structures in braided wire ropes, they are widely used as a guide and traction rope for the tension stringing of transmission lines. Braided wire rope mainly bears tensile loading in the actual working condition. In order to discuss the failure of the wire rope and improve equipment related to power construction, it is necessary to study the distribution laws of stress and deformation of braided wire ropes subjected to tensile loading.

With advancements in computer technology, the analysis of the complex structures of a wire rope using finite element methods has become an important research subject. Some scholars studied the mechanical properties of wire ropes subjected to tensile loading using finite element software. Prawoto et al. [1] studied the mechanical and metallurgical properties of lay non-rotating steel wire rope under tensile load, and modeled and simulated it. Stanova [2] proposed a new geometric model of spiral single-layer or double-layer elliptical strands. Finite element model of three-dimensional spiral circles, triangles and elliptical strands subjected to axial loads were developed using ABAQUS/Explicit software. Kastratović [3] established a wire rope finite element model of 6 × 7 IWRC with different contact conditions in ANSYS Workbench to obtain the mechanical behavior of the whole rope subjected to axial tensile force. Later, he performed finite element analysis on the 1 × 19 and 7 × 19 IWS lay ropes in ANSYS Workbench [4]. Fontanari et al. [5] studied the mechanical behavior of the Warrington-Seale wire rope subjected to axial loading through the finite element numerical simulation in ANSYS. Currently, only a few studies related to braided wire ropes have been conducted. The above studies were largely on lay wire ropes. Nevertheless, the above results serve as a reference for studying braided wire ropes.

YS9-8 × 19 braided wire rope is used as the research subject in this study. The three-dimensional solid model of it is established by 3D modeling software, and a finite element method is used to study
the stress and deformation distribution laws of the wires in the rope subjected to tensile loading. This study can lay a foundation for the friction wear analysis, failure mechanism analysis, and life prediction of this type of braided wire rope and provide a theoretical basis for its design and manufacturing process and for the structural optimization and design improvement of related equipment.

2. Geometric model of braided wire rope
Considering the symmetry and periodicity of the braided wire rope structure, a half of the pitch YS9-8 × 19 braided wire rope is selected as the research subject. The scanning function of Solidworks 3D software is used to establish the geometric model of braided wire rope according to the relevant parameters in literature [6]. The geometrical model of the YS9-8 × 19 braided wire rope is established using a parametric modeling method, as shown in Figure 1 (the right-lay and left-lay strands are indicated in green and gray, respectively).

![Figure 1. Geometrical model of YS9-8 × 19 braided wire rope](image)

3. Finite element simulation of braided wire rope subjected to tensile loading

3.1. Selection of solution methods for nonlinear and multi-contact problems
The implicit solution method is employed in conventional static analyses. In this method, the stiffness matrix needs to be transposed, and an incremental iteration method is used. Moreover, a series of linear approximations (Newton-Raphson) is made for the solution. As the implicit algorithm needs to invert the stiffness matrix, the overall stiffness matrix may not be singular during the calculation process. Therefore, the convergence cannot be guaranteed for some highly nonlinear contact problems. The explicit dynamics module in ANSYS Workbench uses an explicit center-difference method to replace the differential iteration method and thereby facilitate the convergence. This method is more suitable for solving nonlinear, multi-contact, and large deformation problems. Therefore, the explicit dynamics method is used to study the torsion problem in braided wire ropes.

3.2. Setting of boundary condition
To solve the high-nonlinearity problem in braided wire ropes, the material nonlinearity is realized by setting the wire rope material to structural steel NL. Considering the numerous frictional contacts between the wires in the braided wire rope, the contact method of body interaction is used to realize automatic contact. This contact setting can automatically reflect all contact surfaces, and the contact setting process is simplified. The friction coefficient between the wires is set to 0.1 to consider the material property of the wires.

The braided wire rope 3D solid model was imported into ANSYS Workbench software to mesh and generate a finite element model. Considering the actual working conditions of the braided wire rope subjected to tensile loading, the corresponding boundary conditions are imposed on the finite element model, as shown in Figure 2. Dynamic tensile load is applied to the end face A using the remote displacement command to apply a maximum displacement of 2 mm for stretching the end face A about the axis of the wire rope. A fixed constraint is imposed on the end face B of the wire rope using the fixed support command.
3.3. Simulation results and analysis of braided wire rope subjected to tensile loading

The default solver of the explicit dynamics module is used to solve the problem, and the result is obtained after completing the solution. Figure 3 shows the variation in the maximum equivalent stress with respect to axial displacement of YS9-8 × 19 braided wire rope. When the axial loading displacement is 0~0.1 mm, the maximum equivalent stress of the wire rope increases sharply, and the initial preload of the wire rope is realized. After the loading displacement continues to increase, the maximum equivalent stress of the wire rope increases slowly. The equivalent stress value is maximum until the loading displacement is 2 mm.

![Figure 3. Variation in the maximum equivalent stress with respect to axial displacement](image)

In order to obtain the evolution law of stress and deformation during the stretching process of braided wire rope, the mechanical properties of the braided wire rope under tensile load were investigated by finite element analysis. The axial displacement of 0.1, 0.5, 1, 1.5, 2 mm were taken. The cloud pictures of stress distributions on whole rope and intermediate cross section were comparatively analyzed, as shown in Figure 4-8.

The results can be seen from the cloud pictures. When the axial displacement is 0.1 mm, the tensile force is transmitted to the middle position of the wire rope, and the wire rope is not significantly deformed due to the small load. When the axial displacement is 0.5 mm, the stress distribution of the whole wire rope is even, the wire rope is slightly deformed, and the stress at the core wire of the rope is larger than that of the outer wire. When the axial displacement is 1 mm, the wire rope is obviously deformed. The maximum equivalent stress appears at both ends and middle positions of the wire rope, and the core wire and inner layer wire of the right twist strand 2 and 4 appear stress concentration. With further loading, the stress concentration gradually moves towards the center of the section. When the axial displacement is 1.5 mm, the internal clearance of the wire rope is minimized, all the strands are gathered together, and the stress concentration position is close to the contact side wire. When the axial displacement is 2 mm, the right twist strand 1 and 3 are staggered. The stress concentration of the outer wires and core wires at the contact position of the right twist strand 2 and 4 is significant. The location is dangerous. It provides a basis for the wire rope to break preferentially during the service.
Figure 4. Equivalent stress on whole rope and intermediate cross section when the axial displacement is 0.1 mm

Figure 5. Equivalent stress on whole rope and intermediate cross section when the axial displacement is 0.5 mm

Figure 6. Equivalent stress on whole rope and intermediate cross section when the axial displacement is 1 mm

Figure 7. Equivalent stress on whole rope and intermediate cross section when the axial displacement is 1.5 mm
Figure 8. Equivalent stress on whole rope and intermediate cross section when the axial displacement is 2 mm

In conclusion, the strands of the braided wire rope are deformed and gradually move closer to the center, and the stress on the strands changes from a uniform distribution to a stress concentration and moves toward the center of the strand section. There is a significant stress concentration between the inner strands of the wire rope due to the pressing force, which may cause the failure of the wire rope during long-term service.

4. Conclusions

In this paper, the distributions of stress and deformation in YS9-8 × 19 braided wire rope subjected to tensile loading are reported. Following are the conclusions drawn from the research results:

(1) The explicit center difference method of the explicit dynamics module in ANSYS Workbench was used to solve the nonlinear tensile problem of the braided wire rope. The simulation results were obtained on the premise of ensuring convergence.

(2) At the initial stage of tension, the stress distribution on the steel wire is relatively uniform. With the increase of tensile load, the internal clearances of the braided wire rope are gradually eliminated. The significant stress concentration happened between the rope strands caused by extrusion pressure, which can lead to the failure of the wire rope.

(3) The positions of the maximum stress obtained by the simulation are consistent with the position of the broken wire in the actual project, which provides a reference for the improvement of the wire rope structure.

Acknowledgments

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