Variation law of equivalent bending stiffness of steel-cored aluminum stranded wire under bending

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Abstract. Steel core aluminum stranded wire, its abbreviation is ACSR, is a classic multi-stranded wire composed of different materials. Many scholars have used static experiments to study the mechanical properties of steel wire rope structures\textsuperscript{1}. In this paper the author use the finite element software ANSYS to carry out numerical simulation on the aluminum-scored steel-cored wire of model LGJ/JL/G1A-300/25, gain a more in-depth understanding of the bending rigidity of the aluminum-steel wire the numerical change law and internal reasons of the bending stiffness of the wire structure.

1. Steel core aluminum stranded wire mechanical model

Under the action of external force, the bending stiffness of the wire will change significantly, that is, the effective bending stiffness is closely related to the external force of the strand, such as stretching, torsion and bending (axial force, torque, bending moment). McConnell\textsuperscript{2} designed an experimental model of steel-cored aluminum stranded wire bending based on force deformation on the basis of Hruska\textsuperscript{3}, which can give the effective bending stiffness of the stranded wire under different stress conditions. As shown in Figure 1, the left end of the wire under test is set as a fixed end, which is used to constrain the axial displacement and rotation angle of its end in different directions. The right end applies a load $F_x$ along the axis of the wire, while restraining other differences except the axial direction. The degree of freedom of rotation and translation. The span length of the wire is $l$, the position perpendicular to the wire axis and in the middle of the span is selected, and the vertical load $F_y$ is applied.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{(a)}
\end{figure}
The deformation of the measured wire can be represented by a curved beam that is pulled along the axial direction. The external force analysis of the wire is shown in Figure 1. According to the balance condition, the curve equation corresponding to the bending of the steel core aluminum strand is:

$$\gamma(x) = \frac{F_y}{16EI\lambda^2} \left[ \frac{1 - \cosh \lambda}{\sinh \lambda} \right] \left[ 1 - \cosh (\lambda x) + (\lambda x - \sinh \lambda x) \right]$$

among them, $$b^2 = \frac{F_y}{EI}$$, $$\lambda^2 = \frac{F_y l^2}{EI}$$

Here, suppose the displacement in the span is, and substituting into equation (1), it can be simplified to:

$$\frac{4F_y \Delta}{F_y l} = 1 + \frac{2(1 - \cosh \lambda)}{\lambda \sinh \lambda}$$

The parameters on the left side of the formula, namely the length of the wire, the axial load of the wire and the vertical load of the wire, can be set by ANSYS, and the midpoint displacement of the wire can be calculated by ANSYS simulation, so the determined value can be calculated by numerical methods. Then

$$EI = \frac{F_y l^2}{4\lambda^2}$$

It is the equivalent bending stiffness value of the steel-cored aluminum stranded wire under the corresponding stress state.

2. Finite element modeling

Select the solid unit SOLID45 to create steel strands and aluminum strands. The contact between the twisted wires also uses the contact unit CONTA173 and its counterpart unit TARGE170.

Steel core aluminum stranded wire is a composite material, which is made up of layers of inner steel core and outer aluminum stranded wire. According to related data \(^5\), in engineering, $$E_s$$=201GPa is usually selected as the elastic modulus of the steel core, and $$E_{al}$$=62.3GPa is selected as the elastic modulus of the aluminum stranded wire. The steel and aluminum in the established ANSYS model are set according to this data and defined as ideal linear elasticity. According to Lanteigne \(^4\) theory, the friction coefficient between strands is set as $$f = 0.7$$. The basic parameters of LGJ/JL/G1A-300/25 steel core aluminum stranded wire model are as follows:

| Number of layers | Number of ACSR | Pitch diameter ratio | Wiggle /° | diameter /mm |
|------------------|----------------|----------------------|------------|--------------|
| 1                | 6              | 15                   | 8.12       | 2.22         |
| 2                | 10             | 14                   | 10.04      | 2.85         |
| 3                | 16             | 13                   | 11.50      | 2.85         |
| 4                | 22             | 12.67                | 12.30      | 2.85         |

The schematic diagram of the finally established ACSR model is as follows:
3. Comparison of calculation examples

In order to verify the accuracy of the model used in this chapter, for the wire bending experiment case in literature\cite{4}, the ANSYS simulation software is used to simulate this model, and the relevant data is extracted to calculate the equivalent bending stiffness and compare the experimental results. The literature experiment refers to McConnell\cite{2}'s steel core aluminum stranded wire bending experiment model design, using LGJ/JL/G1A-300/25 type steel core aluminum stranded wire, and the schematic diagram of the bending experiment device is as follows:

Table 1 shows part of the data record value of the test condition span $l = 1020\text{mm}$ and axial force in literature\cite{4}. According to its value, the model in this chapter is used for simulation in ANSYS to obtain the axial displacement, combined with the equivalent bending stiffness expression based on the force deformation:

$$EI = \frac{F_y l^2}{4 \lambda^2}$$

and

$$\frac{4F_y \Delta}{F_y l} = 1 + \frac{2(1 - \cosh \lambda)}{\lambda \sinh \lambda}$$

The equivalent bending stiffness under different working conditions is calculated and compared with the data in literature [5], as shown in Table 2, to judge the accuracy and applicability of this model.

| $F_y / \text{N}$ | Literature data | ANSYS | deviation |
|------------------|-----------------|-------|-----------|
|                  | $\Delta / \text{mm}$ | $EI/\text{N} \cdot \text{m}^2$ | $\Delta / \text{mm}$ | $EI/\text{N} \cdot \text{m}^2$ | Experiment/simulation |
| 49               | 0.25            | 644   | 0.24      | 661   | 2.7%               |
It can be seen from the above table that the calculated value of the mid-span displacement obtained from the simulation using the model in this paper has a small gap with the value calculated from the experimental record data of literature [6]. In view of the fact that there may be measurement errors or instrument accuracy effects in the experimental process of the literature, such deviations can be considered to be within the allowable range, so the calculation results obtained from the ACSR simulation model in this chapter are in good agreement with the literature experiments. It shows that the model has good applicability and accuracy.

4. Analysis of the law of change

4.1. Influence of vertical load

In order to explore the influence of vertical load on the equivalent bending stiffness, when the span is 1000mm, the change curve of the vertical load at the same span and the equivalent bending stiffness is drawn, as shown in the figure below:

![Graph of mid-span displacement and vertical load](image)

Fig. 4 $l = 1000mm$, Load displacement stiffness variation diagram

From Fig. 4, it can be observed that when $l=1000mm$ and $F_x=3KN$ and the vertical load is the same, the mid-span vertical displacement of the wire model decreases with the increase of the axial load. At the same time, when the axial load increases, the increase in the mid-span vertical displacement will decrease, indicating that the mid-span vertical displacement is more sensitive to changes in the vertical load under the condition of lower axial force.
4.2. Influence of axial load

In the above analysis of the influence of the vertical load, it can be found that the equivalent bending stiffness of the ACSR is not only affected by the change of the vertical load, but also changes with the change of the axial tension. It can be seen from Figure 4 that when the vertical load is small, the corresponding equivalent bending stiffness is large, and when the vertical load increases, its value will be greatly reduced, which is not easy to compare. In order to accurately ascertain the relationship between equivalent bending stiffness and axial load, five working conditions of vertical load of 60N~200N are selected for analysis.

When the span is \( l = 1000\, \text{mm} \), the equivalent bending stiffness of the steel-cored aluminum stranded wire varies with the axial load, as shown in the figure below:

![Graph showing the change of equivalent bending stiffness with axial load](image)

**Fig.5** \( l = 1000\, \text{mm} \), Relative sliding of the outermost layer

![Graph showing the change of load displacement stiffness variation](image)

**Fig.6** \( l = 1000\, \text{mm} \), Load displacement stiffness variation diagram

Figure 5 shows the change curve of the relative slip of the outermost strands under different vertical and axial loads under the same span. Make a straight line perpendicular to the vertical load of 60N, and then intersect the four curves at four points A-D. It can be observed that the ordinate of these four intersection points decreases in sequence, while the axial load on the corresponding curve increases in sequence. As shown in Figure 6, when the vertical load is constant, the axial load The larger the value, the weaker the relative slip between the outermost layer and the secondary outer layer, and the greater the equivalent bending stiffness at this time.

5. Conclusion

(1) The flexural rigidity experimental model of the wire proposed by McConnell was used, and the ANSYS simulation model considering Poisson effect, friction, and radial contact was used to simulate the LGJ300/25. The calculation results are very close to the data recorded in the literature. This model has high accuracy and applicability.

(2) Carry out the parameter analysis of the bending stiffness, the analysis shows that when the axial
load is constant, the equivalent bending stiffness of the wire decreases with the increase of the vertical load;

(3) Carry out the parameter analysis of the bending stiffness. The analysis shows that when the vertical load is the same, the equivalent bending stiffness of the wire increases with the increase of the axial load.

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