Anelasticity Influence of Wire Rope on the Calculation of Freight Ropeway Bearing Cable

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Abstract. The force-displacement data during loading and unloading process is obtained by wire rope stretch experiment, which includes 7 different diameters ropes. Based on the data, deformation curves of elastic extension are established. It is shown that the loading and unloading curves compose of the elastic hysteresis loop because the wire rope during unloading shows obvious anelasticity. Analysing the elastic deformation curve characteristics, the values of loading and unloading curve parameters are provided by fitting the experimental data. The loading elastic modulus is constant independent of initial load, and the unloading elastic modulus is non-linear which is related with the maximum load. The elastic modulus is applied to the calculation of freight ropeway bearing cable. Compared the result with the actual project data, it shows that the method considering the wire rope anelasticity can improve the precision of bearing cable calculation.

1. Introduction

Wire rope is a flexible bearing carrier which is widely used in various industry fields for its light quality, high tensile strength and high impact strength [1-3]. However, due to the particularity of wire rope space structure, its elastic modulus is greatly affected by stress level, diameter size and force change tendency. Therefore, it is difficult to calculate the elastic elongation of wire rope accurately in practical engineering applications. According to the test and related literature, the initial elastic modulus of the wire rope is small. With the increase of loading and unloading cycles, the structural elongation is gradually eliminated [4-5].

![Figure 1. Unsmooth Pass of Load Carrier.](image)

The wire rope is used as the bearing cable in the freight ropeway, and it supports the reciprocating movement of the load carrier. The tension and shape of bearing cable are greatly influenced by the elastic elongation. Frequently, due to the inaccuracy of elastic elongation, the bearing cable selection is not reasonable, or load carrier passes through unsmooth, which can cause the accident [6].
In this paper, by tension test of several types wire rope, the elastic modulus calculation formula in the process of loading and unloading is obtained which can help to analysis the freight ropeway.

2. Tension test of wire rope

2.1. Wire rope selection

The 6×36+FC wire rope with line contact or surface contact is suitable for the freight ropeway, and the nominal tensile strength of steel wire is not less than 1670MPa. The test wire rope’s nominal tensile strength is 1670MPa, the diameters of rope are 18mm, 20mm, 22mm, 24mm, 26mm, 28mm and 30mm respectively. The length of wire rope samples is 4800mm.

2.2. Test load

The tensile safety factor of the wire rope in the freight ropeway is 2.6~2.8, so the design load is 35%~38% of the breaking force usually. In order to cover the main bearing interval and have a certain load margin, the main tensile load in the test is 30%, 40% and 50% of the breaking force. The initial pretension of the test is 5% of the breaking force. The test load of every specification wire rope is shown in table 1.

| No. | Size /mm | Breaking force /kN | Initial force /kN | Breading force 30% /kN | Breading force 40% /kN | Breading force 50% /kN |
|-----|----------|------------------|-----------------|---------------------|---------------------|---------------------|
| 1   | φ 18     | 178              | 8.9             | 53.4                | 71.2                | 89                  |
| 2   | φ 20     | 220              | 11.0            | 66                  | 88                  | 110                 |
| 3   | φ 22     | 266              | 13.3            | 79.8                | 106.4               | 133                 |
| 4   | φ 24     | 317              | 15.85           | 95.1                | 126.8               | 158.5               |
| 5   | φ 26     | 372              | 18.6            | 111.6               | 148.8               | 186                 |
| 6   | φ 28     | 432              | 21.6            | 129.6               | 172.8               | 216                 |
| 7   | φ 30     | 495              | 24.75           | 148.5               | 198                 | 247.5               |

2.3. Tensile test

The devices of wire rope tension test consist of 2000kN hydraulic servo horizontal tension testing machine, wire rope clamp and line displacement sensor.

The bonding head of clamp is locked with the wire rope chuck and connected by the connecting piece to the tension machine. The connection diagram is shown in figure 2. The overall layout of the test is shown in figure 3.

Figure 2. Connection diagram of tensile test.
2.4. Test data
In each test, elastic deformation curves of the wire rope are measured and recorded under different load conditions. Taking 22mm wire rope as an example, the deformation-load curve of different maximum load is shown in figure 4(a). When the maximum load is 40% breaking force, the test curve of loading and unloading for 3 consecutive times is shown in figure 4(b).

(a) Test of the different maximum load  (b) Test of the 40% breaking force load

Figure 4. Deformation-load curve of 22mm wire rope.

3. Elastic deformation curve of wire rope
From the deformation-load curve of test, it can be seen that the load and deformation of loading process are linearly dependent, and the loading curve does not change with the initial load. The unloading curve does not coincide with the loading curve, and the deformation is obviously hysteresis. The loading and unloading curves form an elastic hysteresis loop.

3.1. Elastic deformation curve
According to the analysis, the force and deformation relationship of the loading process can be established when the initial pre-tightening force is not considered:

\[ F = a\Delta L \]  \hspace{1cm} (1)

And the relationship of unloading process:

\[ F_d = a\Delta L + c \left( \frac{a\Delta L}{F_m} \right)^k - 1 \Delta L = (a - c)\Delta L + c \left( \frac{a}{F_m} \right)^k \Delta L^{k+1} \]  \hspace{1cm} (2)
Here, \( F_i \) and \( F_d \) respectively represent loading load and unloading load. \( \Delta L \) is elastic deformation of wire rope. \( F_m \) is the maximum load of loading (also is the initial load of unloading). The \( a, c, k \) are undetermined parameters.

When \( \Delta L = 0, F_i = F_d = 0 \), and when \( \Delta L = \Delta L_m \) (maximum elastic deformation), \( F_i = F_d = F_m \). It illustrates that the deformation curve above satisfies the mechanical condition.

### 3.2. The value of curve parameters
For linear elastic parameter \( a \), it can be fitted by the tensile test data of different specification, and the corresponding values are obtained as shown in table 2.

By fitting the test data of the unloading condition of the wire rope, it is found that the parameter \( k \) can be viewed as a constant, 0.3. Parameter \( c \) is shown in table 2.

| Specification | Parameter | 18mm | 20mm | 22mm | 24mm | 26mm | 28mm | 30mm |
|---------------|-----------|------|------|------|------|------|------|------|
| \( a \) kN/mm |           | 2.151| 2.865| 3.277| 4.050| 4.603| 5.409| 6.189|
| \( c \) kN/mm |           | 2.965| 3.636| 4.080| 4.872| 5.479| 6.334| 7.016|

Taking the 22mm wire rope as an example, the comparison of loading and unloading fitting curve with the test data is shown as in figure 5. It can be seen that the fitting curve is consistent with the test data, and it is in good conformity.

![Figure 5. Fitting curve of 22mm wire rope.](image)

### 3.3. Loading and unloading elastic modulus

According to the definition of elastic modulus, the elastic modulus of loading process and unloading process can be obtained:

\[
E_i = a \frac{L}{A} \tag{3}
\]
Here, $L$ is distance length measured of wire rope, 4800mm. $A$ is the cross-sectional area, which is the total area of metal cross-sectional area calculated by the single wire nominal diameter of steel wire. The elastic modulus of the wire rope loading process is shown in table 3.

4. Calculation of Freight Ropeway

The accurate algorithm of the single-span ropeway cable system is presented in reference [7]. Based on this algorithm, a case is calculated to analyse the affection of wire rope anelasticity. To simplify the explanation, the algorithm without considering the wire rope anelasticity is called ordinary algorithm, and the algorithm with considering is called accurate algorithm.

Case 1 is the actual project, and the parameters are set as shown in figure 6.

The bearing cable is 6×36+FC twisted wire rope. Its diameter is 22mm, and the nominal tensile strength is 1670MPa. The length of bearing cable is 826.7 m. There is a 450kg mass in the 3rd span, 660kg mass in the 2nd span. The interval between two loads is 297m.

When the 660kg mass moves forward 100m from the 40m of the 2# bracket, record the change value of the tension on the left side of the 3# bracket. The results by the ordinary and accurate algorithms are compared with the measured data, as shown in figure 7. As can be seen from the figure, the calculation tension result using accurate algorithm is smaller than that using ordinary algorithm, which is closer to the measured data. By comparison, the accuracy increases about 3%.

5. Conclusions

The bearing cable is the main carrying member of freight ropeway. Its shape and tension are affected by elastic elongation. In this paper, wire rope with different diameter specifications were tested, and it
is found that the unloading process has obvious anelasticity. By establishing the appropriate mathematical model, the linear elastic modulus of loading process and the nonlinear elastic modulus relations of unloading process are obtained. Applying the test result to modify the calculation method of freight ropeway bearing cable, the result of the tension is closer to the measured data. It can prove that considering anelasticity of unloading process can improve the accuracy of results in the bearing cable calculation of freight ropeway, which can ensure the safe operation of ropeway and reduce the accident risk.

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