Study on Risk Analysis and Structural Safety Performance of Material Ropeway Construction of Transmission Line

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Abstract. Material ropeway transport runs through the whole construction process of transmission line. It is operated frequently with long working period and its structural components are easy to produce fatigue, wear, deformation and other defects. The result is to form safety risks and cause personal and property losses, which is the focus of construction safety. This paper first summarizes the common construction safety risk factors of material ropeway and analyzes the causes of the risk points. Then, safety assessment method of material ropeway of transmission line is proposed. The method considers with the coupling dynamic factor of working ropes and running car and the states of carrying rope, pulling rope, trestle, saddle, anchor underground, etc. is analysed in whole process of transportation. The safety evaluation method is suitable for different topographic conditions and structural types of material ropeway, which provides technical means for the construction check and evaluation of material ropeway.

1. Introduction

With the development of power grid construction, due to line contour restrictions and environmental protection issues, the route of line paths often pass through areas with complex and harsh terrain, the transportation of large tower materials, conductor, equipment and other materials has become an urgent problem to be solved.

The material ropeway for the construction of transmission line has the advantages of easy route selection, excellent transportation performance, high work efficiency, and low impact on the weather and external environment, etc., which can effectively solve the problem of mountain transportation of materials [1-3]. With the wide application of material ropeway in engineering, the structural components of ropeway are affected by various human factors and natural factors in the operation process, which inevitably lead to the defects such as fatigue, wear, deformation, corrosion and fracture, easily causing safety hazards and safety accidents.

This paper summarizes and analyzes the common safety risk factors of material ropeway of transmission line construction, and builds the checking and evaluation software based on the mechanical calculation method of ropeway components. Aiming at the safety risk of material ropeway, the safety assessment method is put forward in order to provide practical technical guidance for the safe operation of material ropeway construction.
2. Safety Accident Risk Analysis

The main structural components of material ropeway includes working rope (carrying rope, pulling rope), saddle, trestle, running car, steering pulley, ropeway driving device and anchor underground. The main causes of material ropeway safety accidents include the following aspects.

2.1. Collapse of Trestle

The trestle of material ropeway bears the force exerted by the working rope. Simple material ropeways often use non-standard support structures or even wooden trestle (as shown in figure 1), which have uneven carrying capacity, may cause greater safety risks such as collapse of trestle.

![Figure 1. Wooden trestle of material ropeway.](image)

2.2. Damage of Anchor Underground

The anchor underground is connected to the carrying rope and provides a fixed fulcrum for the carrying rope. When the anchor is located in soft soil or the buried depth of the anchor is insufficient, the anchor will loosen, causing safety accidents such as the collapse of the trestle, the overturning of the driving device, and the falling of the carrying rope.

2.3. Fracture of Pulling Rope

In the operation process of the ropeway, the pulling rope bears heavy load when it passes through the saddle roller, steering pulley and driving device for many times. After repeated bending, it is easy to break the strand.

2.4. Fracture of Saddle Shaft

The trestle provides support for the pulling rope through the saddle. When the pulling rope has a large load, the saddle receives a great downward load, and the saddle shaft is subjected to shearing force. When the bearing performance does not meet the requirements, the saddle shaft will break, causing the pulling rope to fall. As shown in figure 2.

![Figure 2. Fracture of saddle shaft.](image)

2.5. Damage of Ropeway Driving Device

Ropeway driving device is the power supply equipment of material ropeway. When the manufacturing quality of the structural parts of the driving device does not meet the design requirements, the driving
device may have problems such as bearing damage, gear fracture, controller failure under the long-term operation environment, which may easily lead to accidents, as shown in figure 3.

Figure 3. Gear damage of ropeway driving device.

3. Theoretical Calculation and Analysis
The analysis of safety accident of material ropeway shows that the structural performance of ropeway is an important safety risk point in engineering transportation. Therefore, the precise structural analysis and calculation method of material ropeway of transmission line should be studied to make it an effective means of engineering safety analysis and the basis of construction safety assessment method.

3.1. Calculation Method
The calculation method of the working rope of the material ropeway of transmission line is based on the catenary equation of the elastic suspension rope. According to the characteristics of fixed and sliding multi-span material ropeway, the nonlinear equations of multi-span material ropeway system are established from two aspects of structure conservation and force balance relationship. The single span and multi-span analysis methods of carrying rope system are proposed. At the same time, based on the calculation method of the working rope, the calculation method of the bearing capacity of the saddle, trestle, running car, steering pulley, ropeway driving device is proposed, forming the overall design and analysis method of the material ropeway [4-7]. In this method, the stress state changes of components of material ropeway are considered in the operation process, and the refined analysis and calculation of material ropeway are presented.

The elastic catenary equation can be used to express the segments of carrying rope and pulling rope. The span and height difference of the segment of the elastic catenary only affected by gravity can be expressed as follows:

\[
\begin{align*}
L &= q \left[ \frac{q s}{E A_0} + \text{asinh} \left( \frac{V_B}{H} - \text{asinh} \left( \frac{V_A}{H} \right) \right) \right] \\
L &= \frac{V_A^2 - V_B^2}{2q E A_0} + H \left( \frac{1 + \frac{V_A^2}{H^2}}{1 + \frac{V_B^2}{H^2}} \right)
\end{align*}
\]

Where: \( q \), the unit gravity of rope; \( E A_0 \), the product of sectional area and elastic modulus; \( S \), the initial length of rope section; \( h \), the horizontal tension of rope section; \( V_A \), the vertical tension of point A; \( V_B \), the vertical tension of point B.

3.2. Verification and Evaluation Software
Based on the design and analysis method of material ropeway, the transmission line material ropeway check and evaluation software is developed by using Visual Studio platform. The software can obtain the maximum bearing capacity and safety factor of each component of the material ropeway by inputting the original data such as erection parameters, working rope parameters, load parameters and so on. The software can generate the evaluation report, the evaluation report includes the original
conditions, calculation results and verification evaluation results, which is convenient for users to view the stress conditions of the selected components of the material ropeway and judge whether the selected components meet the safety performance requirements.

4. Safety Assessment Method

On the basis of the overall design and analysis method of the material ropeway of transmission line, aiming at the risk factors of the transmission line project, safety assessment measures are proposed from the aspects of component information, erection and installation, operation and maintenance, and flow-based safety assessment method for the material ropeway of transmission line is formed and applied in the project.

The safety assessment of material ropeway of transmission line is mainly aimed at evaluating the mechanical properties of structural component and supporting equipment of material ropeway with a load of more than 1t. The evaluation unit conducts on-site inspection on the material ropeway in the project department of the construction unit and the ropeway site. The on-site inspection includes document inspection, appearance inspection and safety check.

4.1. Document Inspection

In order to ensure that the erection of material ropeway meets the engineering requirements, it is necessary to carry out document review.

The document of material ropeway mainly includes material ropeway erection and transportation construction scheme, site installation and acceptance record and report documents of main components of material ropeway. Document inspection requirements are shown in table 1.

| Serial number | Review content                                                   | Conclusion                                                                 |
|---------------|-----------------------------------------------------------------|---------------------------------------------------------------------------|
| 1             | Material ropeway erection and transportation construction scheme | 1. Whether the scheme has been reviewed and approved<br>2. Whether the contents are complete |
|               | Report documents of the components of the material ropeway      | 1. Whether the ropeway driving device, working rope, steering pulley have type test report<br>2. Whether the ropeway driving device, working rope, steering pulley, saddle, trestle, running car have factory test report<br>3. Whether the components that have been out of the factory for more than one year have regular inspection (annual inspection) reports |

The inspection contents of the report documents of the main components of the material ropeway are shown in table 2.

| Serial number | Components                          | Type test report | Factory test report | Regular inspection (annual inspection) reports |
|---------------|-------------------------------------|-----------------|---------------------|-----------------------------------------------|
| 1             | Ropeway driving device              | √               | √                   | √                                             |
|               | Working rope (carrying rope, pulling rope) | √               | √                   | √                                             |
| 2             | Steering pulley                     | √               | √                   | √                                             |
| 3             | Saddle, trestle, running car        | /               | √                   | √                                             |

Note: "√" means document that needs to be provided.
4.2. Appearance Inspection
The appearance inspection mainly includes the erection and layout of the material ropeway and the components of the material ropeway. The material ropeway components include working rope (carrying rope, pulling rope), saddle, trestle, running car, steering pulley, ropeway driving device, etc. The main inspection requirements of each component are shown in Table 3 [8].

| Serial number | Review content | Inspection requirements |
|---------------|----------------|-------------------------|
| 1             | Specification  | The specifications of each component should be consistent with the design scheme |
| 2             | Working rope   | The safety factor meets the requirements of 5.1.4 in Q/GDW 11189 |
| 3             | Trestle        | Metal trestle should not have serious appearance defects, and wooden trestle should not be used |
| 4             | Braided joint of wire rope | The length of the braided joint of the pulling rope should be more than 100 times of the diameter of the wire rope |
| 5             | Driving device | The winding number of the pulling rope on the drum should not be less than 5 |
| 6             | Saddle         | The wheel plate and guide wheel should rotate flexibly without sticking |
| 7             | Running car    | The running car should be marked with rated load or rated capacity |
| 8             | Steering pulley | The bottom diameter of the steering pulley should not be less than 15 times the diameter of the pulling rope |

4.3. Safety Check
According to the results of document inspection and appearance inspection, the evaluation unit used the "transmission line material ropeway check and evaluation software" to check the structural performance of the material ropeway. The safety factors of working rope (carrying rope, pulling rope), saddle, trestle, running car, steering pulley, ropeway driving device and anchor underground are obtained, so as to determine whether each component meets the structural strength requirements.
After the completion of the on-site inspection, the evaluation unit shall summarize and analyze the results of the on-site inspection to form the inspection report.

5. Conclusion
In this paper, the construction safety risk factors of material ropeway of transmission line are analyzed, and the safety assessment method of material ropeway of transmission line is proposed, the conclusions are as follows:
(1) The material ropeway of transmission line is an integral system composed of multiple components. The damage of one of the components can easily cause the overall collapse of the material ropeway and induce safety accidents.
(2) The transmission line material ropeway check and evaluation software is applicable to material ropeway with different terrain conditions and structural types, which provides technical means for checking and evaluation of material ropeway construction.
(3) The on-site inspection of safety assessment for material ropeway of transmission line includes document inspection, appearance inspection and safety check, which provides an effective on-site supervision and inspection method for transmission line construction of material ropeway. The safety assessment method has been applied in a number of UHV projects, which can avoid the use of material ropeway components with insufficient bearing capacity and potential defects in ropeway construction, and can significantly improve the safety of transmission line construction.

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