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Dynamic Simulation of Underground Cable Laying for Digital Three-Dimensional Transmission Lines

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Abstract: In light of the issues associated with the laying process of transmission line cables, including concealed security risks and contact collisions between pulleys and cables, which primarily stem from reliance on drawings, this paper introduces a simulation methodology for the cable laying construction process utilizing Building Information Modeling (BIM) technology. Initially, two-dimensional DWG graphic data are employed to develop a model of the target equipment and construction environment using BIM software (Solid works 2020). Subsequently, the cable is accurately modeled by applying ADAMS virtual prototype technology, the bushing force connection method, and the macro command language. This allows for the construction of a three-dimensional real cable laying system for transmission lines, enabling the simulation of the dynamic cable laying process in the field. Subsequently, an error analysis is conducted to compare the axial tension and laying speed of the cable with theoretical calculation values. The study then proceeds to analyze tension fluctuations during the cable laying process and assess the load-bearing capacity of the pulleys, thus facilitating effective control of the construction process and enhancing safety measures. The findings indicate that the proposed method can accurately and efficiently simulate the on-site cable laying construction process, with numerical errors maintained below 5%, thereby validating the integrity of the model. Furthermore, the traction overload safety protection amplification coefficient is determined to be $\alpha = 1.5$. It is highlighted that the bearing capacity of the block must exceed 60% of the load carried by the conductor at constant speed. This research provides a theoretical foundation for addressing safety hazards in cable laying engineering and holds certain engineering value.

Keywords: cable laying; transmission lines; digitization; BIM technology; dynamic simulation

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1. Introduction

With the development of the economy and the improvement of people's living standards, the demand for power facilities and electricity continues to increase, so related power construction is also continuously strengthened [1]. Among them, during the laying of high-voltage cables, if the cables withstand excessive traction or lateral pressure, it may cause deformation and damage to the cables, which will affect their service life and thus affect the safe and stable operation of the power grid [2]. During construction, it is common for cables to be deformed due to excessive stress on the laid cables. There are many factors affecting the safe laying of cables. Due to the limitations of actual conditions, it is impossible to implement specific real model tests, so we can only rely on manual calculations to obtain basic data. The actual construction process often relies more on past experience and judgment.

Because it is common for cables to be deformed due to excessive stress during cable laying, cable laying construction methods have received widespread attention. Guo Sheng and others [3] established a transmission line tension stringing system model through the secondary development of the virtual prototype ADAMS, realizing the real-time dynamic display process of conductors and traction ropes during the tension stringing process. Xiao Qi and others [4] studied the influence of the traction plate on the contact force of the conductor and pulley when passing through the pulley by analyzing the axial speed and tension changes of the conductor and traction rope based on the simulation model of the stringing system. Hu Jinjun and others [5] proposed a laser point cloud-based method for simulating the construction process of tension paying out of transmission lines. Zhang Junyi and others [6] clarified the issues that should be paid attention to in terms of checking driving force and side pressure, traction method, and radius of curvature when hauling cables by the windlass, and improved the traction system to ensure cable laying standards. Using three-dimensional software, Xu et al. [7] established a cable laying model for each interval distribution unit, completed a three-dimensional visualization simulation of cable laying at a station, accurately designed the cable laying path, and formed a cable laying optimization design scheme with smooth cable connection and economic savings.

However, the above studies are all aimed at the simulation research of the tension-stringing system of transmission lines and the calculation and monitoring of traction force during cable laying. In recent years, cable lines have shown a rapid development trend [8], and a dynamic simulation of the cable laying system is currently still missing [9]. Therefore, this paper proposes a digital-based cable-laying construction process simulation method to solve the problem that the cable-laying construction of transmission lines mainly relies on drawings and cannot intuitively feel the safety hazards in the laying process and the contact collision between pulleys and cables. Simulating the dynamic process of cable laying on the construction site, analyzing the error between the axial tension of the cable and the laying speed and the theoretical calculation value, and finally analyzing the axial tension of the cable and the bearing capacity of the pulley to effectively control the construction process and explore safety, provides important data support for accurate cable construction. The mean error between the real value and the simulation value is 2.75%. We find that the method proposed in this paper is accurate and reliable compared with other methods.

2. Modeling of Digital Cable Laying System

The process of modeling cables and cable laying systems using sleeve force with ADAMS software (https://hexagon.com/products/product-groups/computer-aided-engineering-software/adams) is as follows: Firstly, the geometric parameters of the cable material are clarified to ensure the accuracy of the model. Next, ADAMS/View is used to create the geometry of the cable, usually represented by a slender cylinder, and set the constraint relationship between the cable and the supporting structure in the model. Subsequently, reasonable quality and material properties are allocated to the cables, and external loads are applied to reflect actual operating conditions. By constructing a motion path, the dynamic behavior of the cable during the laying process is defined, and simulations are run to observe its stress situation. Finally, the simulation results will be analyzed, and the performance of the cable system will be evaluated and iteratively optimized based on the analysis results to achieve the expected design goals.

2.1. Target Equipment Model Establishment

The modeling does not need to focus on the target equipment components or other information; it is only modeled according to the target equipment specifications, quality, rated load, and other parameters required to reasonably and realistically establish the target of the different components. Then, according to the actual size, assembly occurs to form a three-dimensional model, as shown in Figure 1.

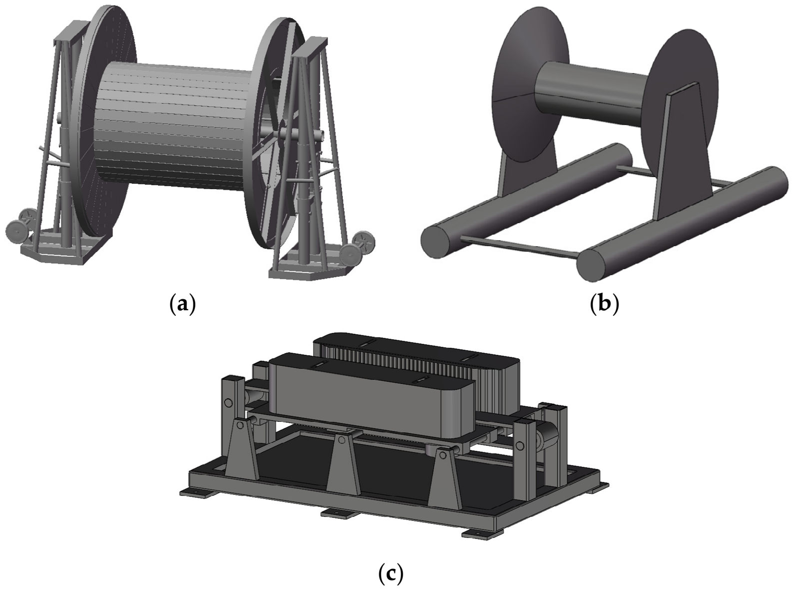

Figure 1. Target device model. (**a**) Cable tray model. (**b**) Pulley model. (**c**) Cable conveyor model.

2.2. Construction Environment Model

SolidWorks was used to model based on the existing two-dimensional DWG drawings of the cable tunnel environment. The model is divided into three parts: a diagonal upward section, a horizontal laying section, and a diagonal downward section, as shown in Figure 2.

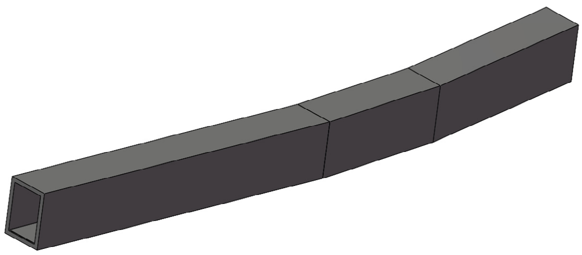

Figure 2. Cable tunnel environment model.

3. Construction of Cable Laying System

3.1. Modeling of Cables and Traction Ropes

Taking full account of the stiffness and physical characteristics of cables and traction ropes, we use the shaft sleeve force Bushing [10] method to establish cables and traction rope models to maximize the actual actions, such as stretching, shearing, twisting, and bending, of the cables and traction ropes themselves during cable laying construction [11]. The specific steps are as follows: first, the micro-element method is used to divide the cable and the traction rope into a number of micro-segment cylinders with different radii according to equal lengths; then, the shaft sleeve force Bushing is used to impart a mutual force to the two micro-segment cylinders; and finally, the macro command of the ADAMS virtual prototype is used to traverse all the micro-segment cylinders and connect them to establish a cable and traction rope model. Figure 3 shows the force model of the micro-section cylinder of the cable and traction rope.

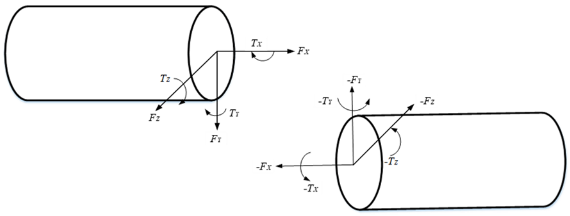

Figure 3. Cylindrical force model of cable and traction rope.

The bushing force Bushing connection method adds a flexible connection force to the two by defining six components of force and moment between two micro-sections of cylinders. The calculation formula for the bushing force is [12]:

$$\begin{bmatrix} F_z \\ F_y \\ F_z \\ T_x \\ T_y \\ T_x \end{bmatrix} = \begin{bmatrix} K_{11} & 0 & 0 & 0 & 0 & 0 \\ 0 & K_{22} & 0 & 0 & 0 & 0 \\ 0 & 0 & K_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & K_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & K_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & K_{66} \end{bmatrix} \begin{bmatrix} R_x \\ R_y \\ R_z \\ \theta_x \\ \theta_y \\ \theta_z \end{bmatrix} - \begin{bmatrix} C_{11} & 0 & 0 & 0 & 0 & 0 \\ 0 & C_{22} & 0 & 0 & 0 & 0 \\ 0 & 0 & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{bmatrix} \begin{bmatrix} v_x \\ v_y \\ v_x \\ w_x \\ w_y \\ w_z \end{bmatrix} + \begin{bmatrix} F_{x0} \\ F_{y0} \\ F_{z0} \\ T_{x0} \\ T_{y0} \\ T_{z0} \end{bmatrix} \quad (1)$$

In Equation (1), R_i and θ_i are, respectively, the relative linear displacement and relative angular displacement of the I-Marker coordinate system on the first micro-segment cylinder relative to the J-Marker coordinate system on the second micro-segment cylinder; V_i and W_i are, respectively, the relative linear velocity and relative angular velocity of the I-Marker coordinate system on the first micro-segment cylinder relative to the J-Marker coordinate system on the second micro-segment cylinder; F_{i0} and T_{i0} are, respectively, the initial force and moment of the model; K and C are, respectively, the stiffness coefficient and damping coefficient of the model.

The calculation formula for the rigidity coefficient matrix (tension, shear, torsion, and bending) of the shaft sleeve force Bushing is:

$$\begin{array}{l} K_{11} = \frac{EA}{L} \\ K_{22} = K_{33} = \frac{GA}{L} \\ K_{44} = \frac{G\pi d^4}{32L} \\ K_{55} = K_{66} = \frac{EI}{L} = \frac{E\pi d^4}{64L} \end{array} \quad (2)$$

where E is the elastic modulus of the cable and the traction rope; G is the shear modulus of the cable and the traction rope; A is the cross-sectional area of the cable and the traction rope; L is the length of the small cylindrical micro-section of the cable and the traction rope; I and d are the moment of inertia and diameter of the cable and the traction rope, respectively. The Poisson's ratio of cables and traction ropes is 0.3.

A cable model of 64/110 kV-YJQ03 -800 mm^2 was selected and simplified based on the research issues. Because the tensile damping factor has little impact on the operating stability of the entire system, no adjustment was made. The torsional damping factor has a great influence on the change of motion and was selected between 1 and 10 according to the actual needs of the site. Because there were too many parts in the model, the ADAMS/View command language was used to model cables and traction ropes.

3.2. Application of Contact Force and Tension

During the cable laying process, the cable and the laying reel will be partially entangled and will contact and collide with pulleys, cable conveyors, and other equipment. Therefore, relevant contact force needs to be added to the cable and traction ropes to truly simulate the cable laying process. However, suppose contact force is applied to all cables and traction rope micro-sections due to the large number of pulleys and excessive contact force. In that case, this will seriously affect the cable laying simulation speed and even cause simulation failure [13]. The higher the accuracy and the more micro-sections the cables are divided into in the micro-element method, the more truly the dynamic characteristics of the cable can be reflected. However, in the cable laying system, if the number of micro-segments of traction ropes and cables is greater, the higher the conditions of hardware facilities required for simulation, the lower the success rate of the simulation, which may even cause the termination of the simulation. Therefore, when adding contact force to the traction rope and cable, the positional status of the traction rope and cable micro-segment columns should be estimated according to the simulation time so as to minimize the number of contact forces and improve the success rate of the simulation [14].

The contact force of a cable laying system is mainly composed of components such as friction and collision forces, where the friction force is the contact friction generated by the cable and the traction rope as they pass over the pulley several times [15]. The collision force is the positive pressure generated by the mutual collision between the pulley and the cable, which is usually defined using the IMPACT function [16]. The tension mechanism consists of the combined force of part of the cable's own gravity and a STEP function force, which ensures that the tension of the tension mechanism of the cable release disk remains constant [17,18].

4. Engineering Examples and Analysis of Results

The article adopts the cable tunnel path diagram in the civil engineering project of Huangjiahu. The total length of the cable tunnel line is about 879.61 m, of which a 58.5 m tunnel is selected for modeling and analysis in this article. Figure 4 shows the cable tunnel transmission line construction engineering diagram.

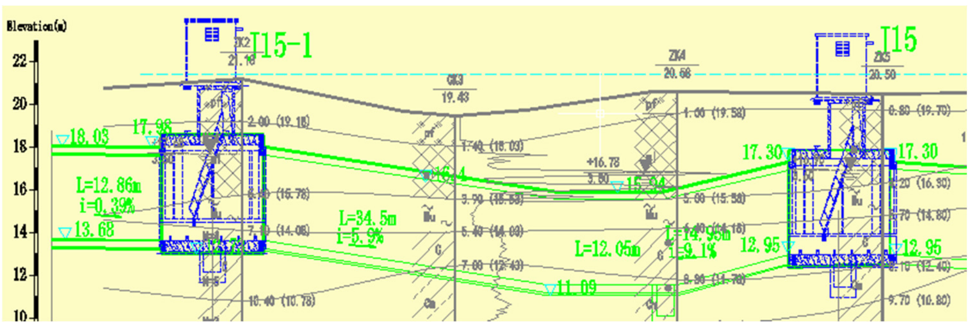

Figure 4. Drawing of the cable tunnel environment.

The construction environment model is built based on the existing 2D DWG graphics of the project tunnel. Then, the existing target equipment model is put into the tunnel environment model. Due to a large number of cable model components, manual modeling is almost impossible to complete, so the ADAMS-VIEW command language is used to complete the modeling of the cable laying system. Finally, the target equipment and construction environment models are fused according to the actual situation to form a three-dimensional transmission line reality model.

The basic parameters of the cables and tow ropes are shown in Table 1. A total of 305 cable micro-segments and 65 tow rope micro-segments of different specifications with a length of 500 mm were established in the three-dimensional construction model, and 401 bushing forces Bushings, 1795 contact forces, and 2 external tensions were applied to the model to establish the "one towing one" cable laying system, as shown in Figure 5 [19,20].

Table 1. Basic parameters of cable and traction rope.

Name	Modulus of Elasticity E/GPa	Shear Modulus G/GPa	Caliber d/mm	Cross-Sectional Area A/mm^2
electric cable	115.0	41.5	87.3	5982.7
tow rope	181.4	69.8	14	86.69

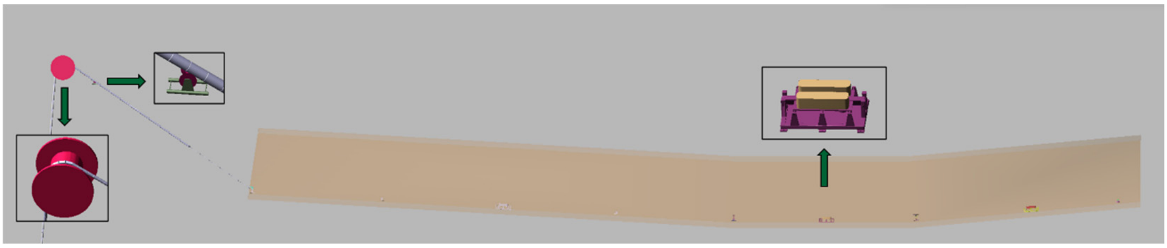

Figure 5. Cable laying system model.

4.1. Cable Laying System Reliability Verification

In the cable laying digital model [21], the segmented calculation is carried out according to the cable laying path, and the total traction force is equal to the sum of the traction force of each segment. According to the simplified schematic diagram of the cable laying path in Figure 6, the traction force required for cable laying is calculated [22].

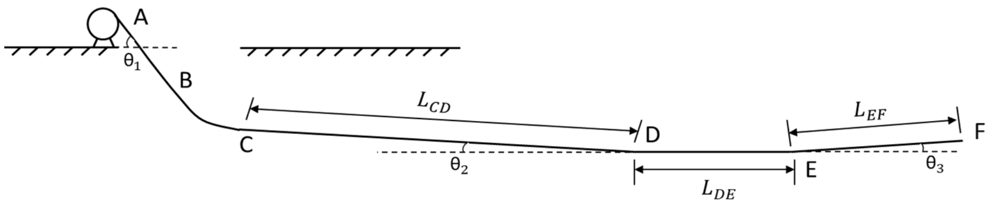

Figure 6. Simplified diagram of cable laying path.

(1) The cable is led from the cable tray. According to the basic principle of the traction force calculation, the friction force of the cable tray hole and the shaft can be converted into the gravity calculation of about 15 m length of the laid cable:

$$F_{\text{Cable reel}} = 15 \times 9.8W \tag{3}$$

(2) Traction of the cable from A $\to$ B:

$$F_1 = 9.8W\left\{h_1 - R_1\left[1 - \sin\left(\frac{\pi}{2} - \theta_1\right)\right]\right\} \times \csc\theta_1(\mu\cos\theta_1 - \sin\theta_1) \tag{4}$$

(3) Traction of the cable from B $\to$ C:

$$F_2 = 9.8\mu W R_1 \cos\left(\frac{\pi}{2} - \theta_1\right) - 9.8WR_1 + 9.8W\sqrt{R_1^2 - \left[R_1\cos\left(\frac{\pi}{2} - \theta_1\right)\right]^2} \tag{5}$$

(4) Traction of the cable from C $\to$ D:

$$F_3 = 9.8WL_{CD}(\mu\cos\theta_2 + \sin\theta_2) \tag{6}$$

(5) Traction of the cable from D $\rightarrow$ E:

$$F_4 = 9.8\mu W L_{DE} \tag{7}$$

(6) Traction of the cable from E $\rightarrow$ F:

$$F_5 = 9.8 W L_{EF}(\mu \cos\theta_3 - \sin\theta_3) \tag{8}$$

(7) When calculating the traction force required for cable laying, it is also necessary to take into account the traction rope, which is usually converted into 5 m of cable self-weight:

$$F_6 = 5 \times 9.8W \tag{9}$$

(8) The traction force required for cable laying is the sum of the above-segmented forces:

$$F_{\text{total}} = F_{\text{Cable reel}} + F_1 + F_2 + F_3 + F_4 + F_5 + F_6 \tag{10}$$

After the end of the construction simulation, in the virtual prototype, ADAMS post-processes the random extraction of the cable and traction rope micro-segment axial velocity to verify that its axial motion speed meets the engineering requirements. Figure 7 shows the axial velocity of a micro-segment of the cable and hauling rope. The cable and hauling rope extract in the stationary state under the action of the traction force to produce acceleration; then, axial velocity suddenly increases, gradually stabilizes at 6 m/min after 13 s, and the traction speed of the traction machine is consistent with the actual requirements of the project.

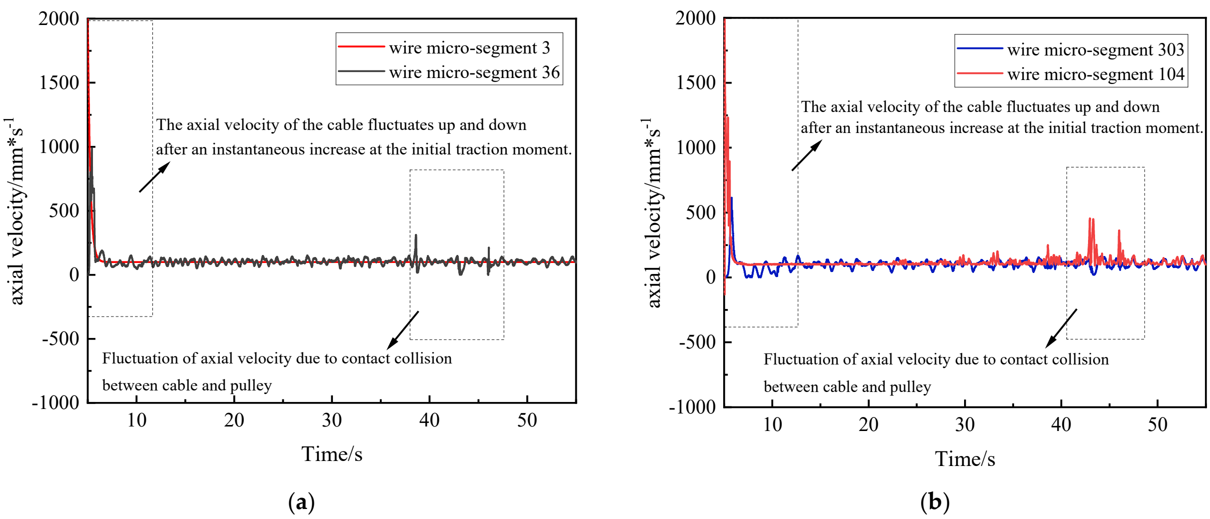

Figure 7. Dynamic speed change of cable laying. (**a**) Tow rope axial velocity. (**b**) Axial velocity of cable micro-segments.

It is necessary to verify not only the axial velocity of the cable but also to check whether the axial force of the cable in the cable laying system meets the engineering requirements. After the end of the cable laying simulation, the axial sleeve force of the cable and traction rope micro-segments are randomly extracted in the virtual prototype ADAMS post-processing and compared with the theoretical axial sleeve force in the numerical model to verify the reliability of the cable laying system. Figure 8 shows the dynamic axial tensile force diagram of the cable and traction rope in the cable laying simulation.

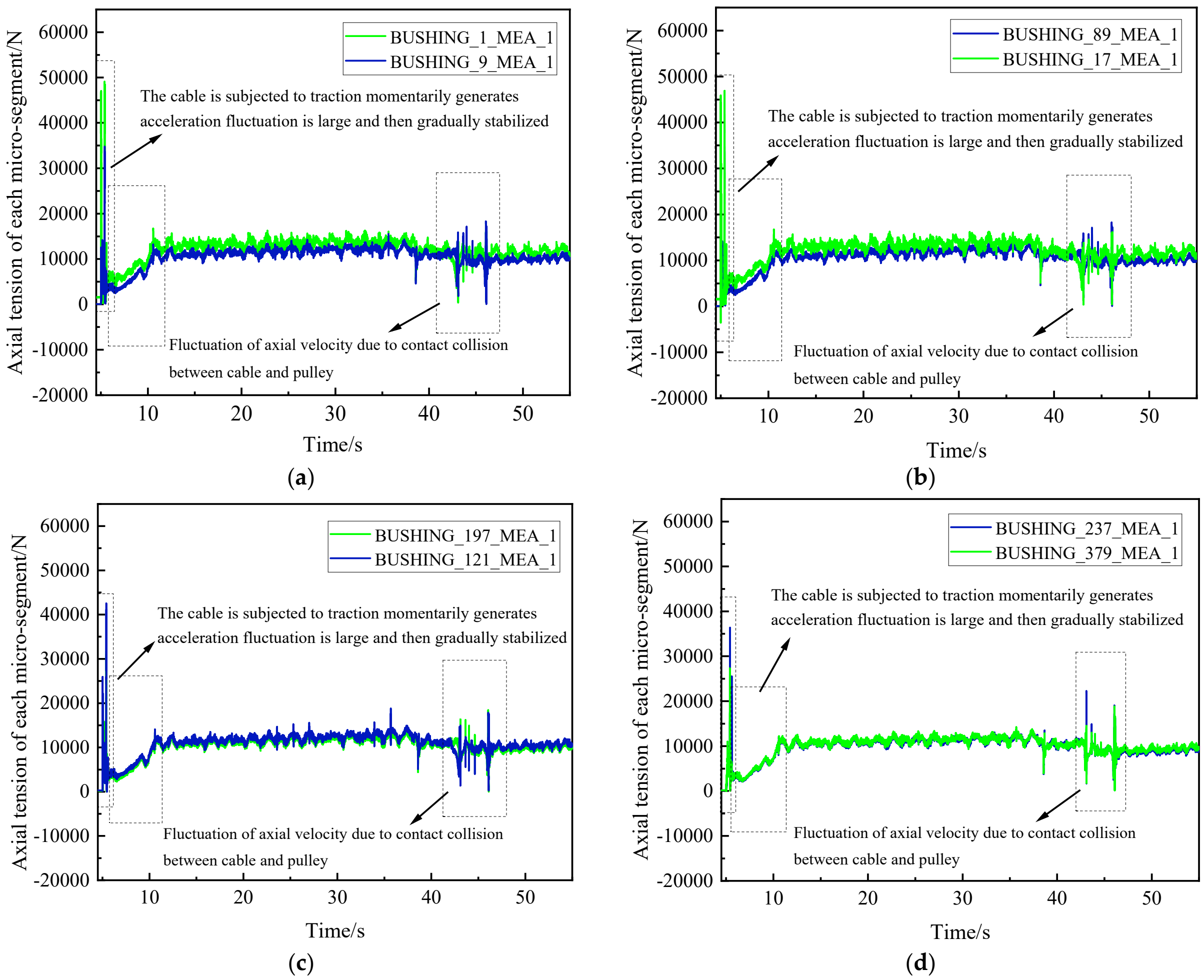

Figure 8. Changes in dynamic axial tension of cable laying. (**a**) Axial traction of micro-segments of haul rope. (**b**) Axial tension in micro-segments of diagonal upstream cables. (**c**) Axial tension in micro-segments of horizontal section cables. (**d**) Axial tension in micro-segments of diagonal downstream cables.

The axial tension at each position of the cable and traction rope in the cable laying system is compared with its numerical model, and the error coefficients at each position of the cable and traction rope in the cable laying system are calculated. Figure 9 shows the axial traction tension error diagram for the cable micro-section.

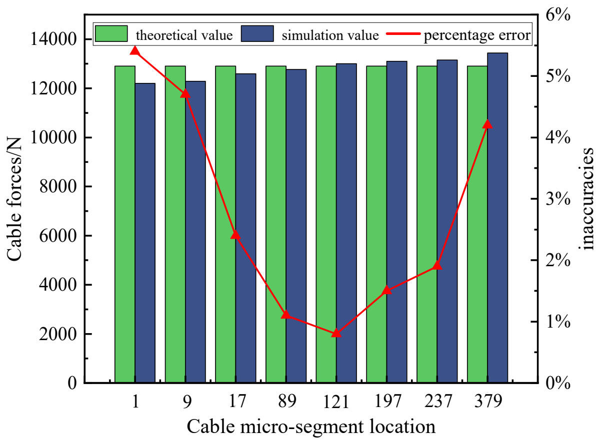

Figure 9. Errors between calculated and simulated tension values at each position.

From the result, it can be seen that the max error between the real value and simulation value is 5.4%, the mean error is 2.75%, and the min error is 0.8% (Table 2), which indicates that the model is correct and the results have a certain degree of reliability. It can provide a certain reference value for the actual engineering cable laying construction. Compared to references [4,5,7], we can find that the method proposed in this paper has smaller average and max errors. It shows that the proposed method is accurate and reliable, as shown in Table 3.

Table 2. The error between the real value and simulation value.

Cable Location	Real Value/N	Simulation Value/N	Error
1	12,903.21	12,200.36	5.4%
9		12,290.10	4.7%
17		12,590.64	2.4%
89		12,770.32	1.1%
121		13,000.25	0.8%
197		13,100.22	1.5%
237		13,150.98	1.9%
379		13,440.74	4.2%

Table 3. Comparison of error in the paper and Refs. [4,5,7].

Method	Mean Error	Max Error
Reference [4]	3.89%	——
Reference [5]	3.21%	8.9%
Reference [7]	3.18%	6.3%
This paper	2.75%	5.4%

4.2. Safety Survey and Hazard Analysis

4.2.1. Analysis of Axial Tension During the Initial Traction Period

The maximum permissible traction cable is generally based on the cable-bearing steel tensile strength of one-quarter of the determination, that is, according to the tensile strength multiplied by the cross-sectional area of the steel for the maximum traction. However, due to the differences in traction, the general cable maximum allowable traction is calculated as follows:

$$T_m = K\delta S \quad (11)$$

where K is the correction factor, the power cable takes 1, the control cable takes 0.6; δ is the allowable tensile strength of the material, N/mm^2 (specific values refer to Table 4); S is the cross-sectional area of the material, mm^2.

Table 4. Maximum allowable traction strength of power cable.

Stressed Material	Tensile Strength/ (N/mm^2)	Applicable Traction Methods
Copper conductor	70	traction head
Aluminum conductor	40	traction head
Polyethylene sheath	7	hauling net cover
Cross-linked polyethylene sheath	6	hauling net cover

Taking the cable laying system shown in Figure 8 as an example, the maximum allowable cable traction force is calculated to be 56 kN. The following figure shows the axial traction force of the cable micro-section during cable laying.

Figure 10 presents that in the initial traction cable, the cable axial tension increases instantaneously and then slowly fluctuates to a stable value of about 13 s. The cable laying process of axial tension gradually stabilized at about 13 kN in the cable within the maximum permissible traction force, which is in line with the requirements of construction safety.

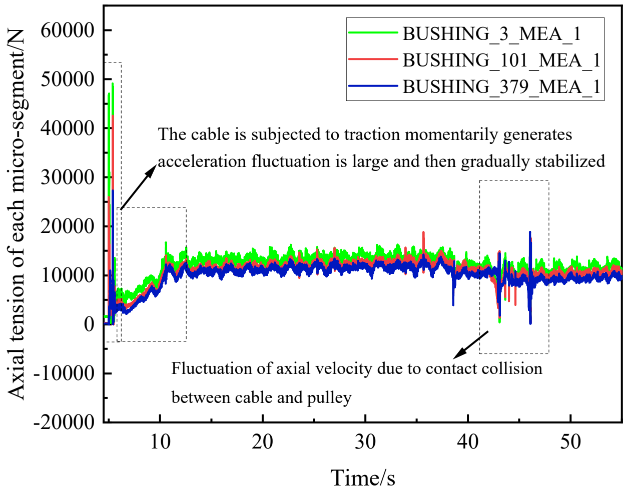

Figure 10. Axial tension of cable microsegment.

In the initial stage of the traction axial force, changes in movement make the cable axial tension suddenly increase, followed by a gradual stabilization of its axial tension up to 49 kN. The cable can withstand a maximum of 56 kN; therefore, at the beginning of the laying of the cable, the traction speed should be controlled, and the traction force should gradually be increased, minimizing the transient tension to ensure the safety of construction.

4.2.2. Analysis of the Axial Tension of the Cable over the Pulley Moment

The axial tension at the moment the cable micro-segment moves over the pulley is shown in Figure 11. When the cable passes through the pulley, there will be a large fluctuation in the axial tension of the cable. This fluctuation is mainly due to the friction between the cable and the pulley and the cable's own inertia. The entire cable laying system will be affected by the impact of the cable on the pulley in the process, resulting in a short period of large tension fluctuations. The axial tension of the cable passing through the pulley is extracted, and the axial tension value of each cylindrical micro-segment of the cable passing through the pulley is compared with the calculated value of the theoretical formula. The maximum value of axial tension is calculated using theoretical methods (as shown in Figure 12), and the following axial tension amplification factor is proposed:

$$\alpha = \frac{T_{i\max}}{T_i} \tag{12}$$

where $T_{i\max}$ is the maximum value of axial tension at position i, N; T_i is the theoretically calculated value of axial tension at position i, N.

In the simulation study of cable laying, it can be seen that the tension fluctuation of the cable is significant during the initial traction period and when the cable passes through the pulley. This fluctuation shows that the actual tension value exceeds the theoretically calculated value, and the amplification of tension is in the range of 1.2~1.5, from which it can be concluded that the amplification coefficient of the overload safety value of the traction force α is 1.5.

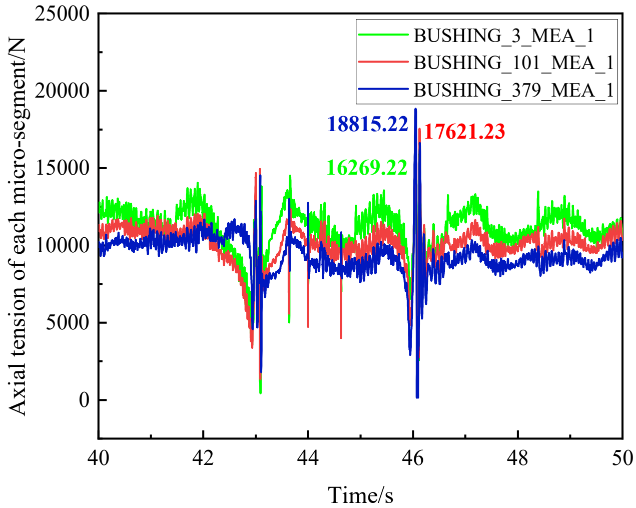

Figure 11. Axial tension at the moment when the cable micro-section crosses the pulley.

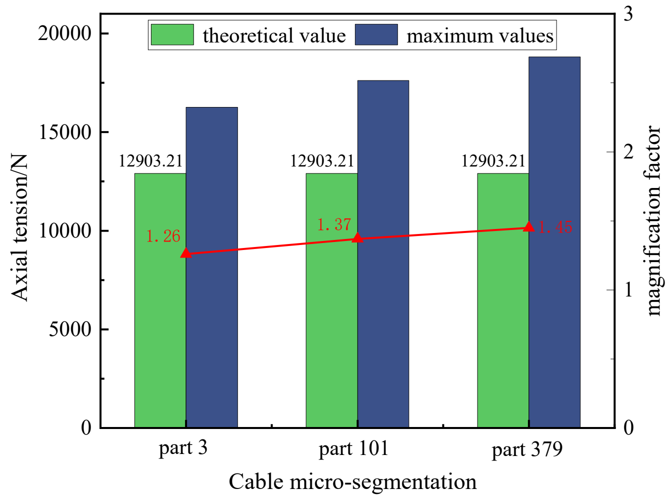

Figure 12. Ratio of maximum axial tension to theoretical calculation value.

4.2.3. Pulley Load Capacity Analysis

In order to investigate the variation of loads borne by the pulleys during cable laying, the values of loads suffered by the pulleys during the passage of cables are extracted. Through the simulation results, potential risks and problems are identified, thus reducing the incidence of problems in the actual construction. For the actual construction, the selection of the maximum load-bearing capacity of the pulley provides a theoretical basis. In the cable laying system, the load data of pulleys No. 1, 2, 3, and 4 are extracted from right to left in sequence.

Figure 13 illustrates that when the cable passes through the end pulley, the first pulley, second pulley, third pulley, and fourth pulley experience sudden loads due to the collision and contact between the cable and pulleys. The first pulley experiences a momentary load fluctuation of approximately 2.8 kN; the peak load on this pulley is about 56% higher than the load during uniform motion. The second pulley is subjected to an instantaneous increase of 2 kN; the peak load on this pulley is about 40% higher than the load during uniform motion. The third pulley experiences a momentary increase of 1 kN; the peak load on this pulley is about 20% higher than the load during uniform motion. The fourth pulley is almost unaffected.

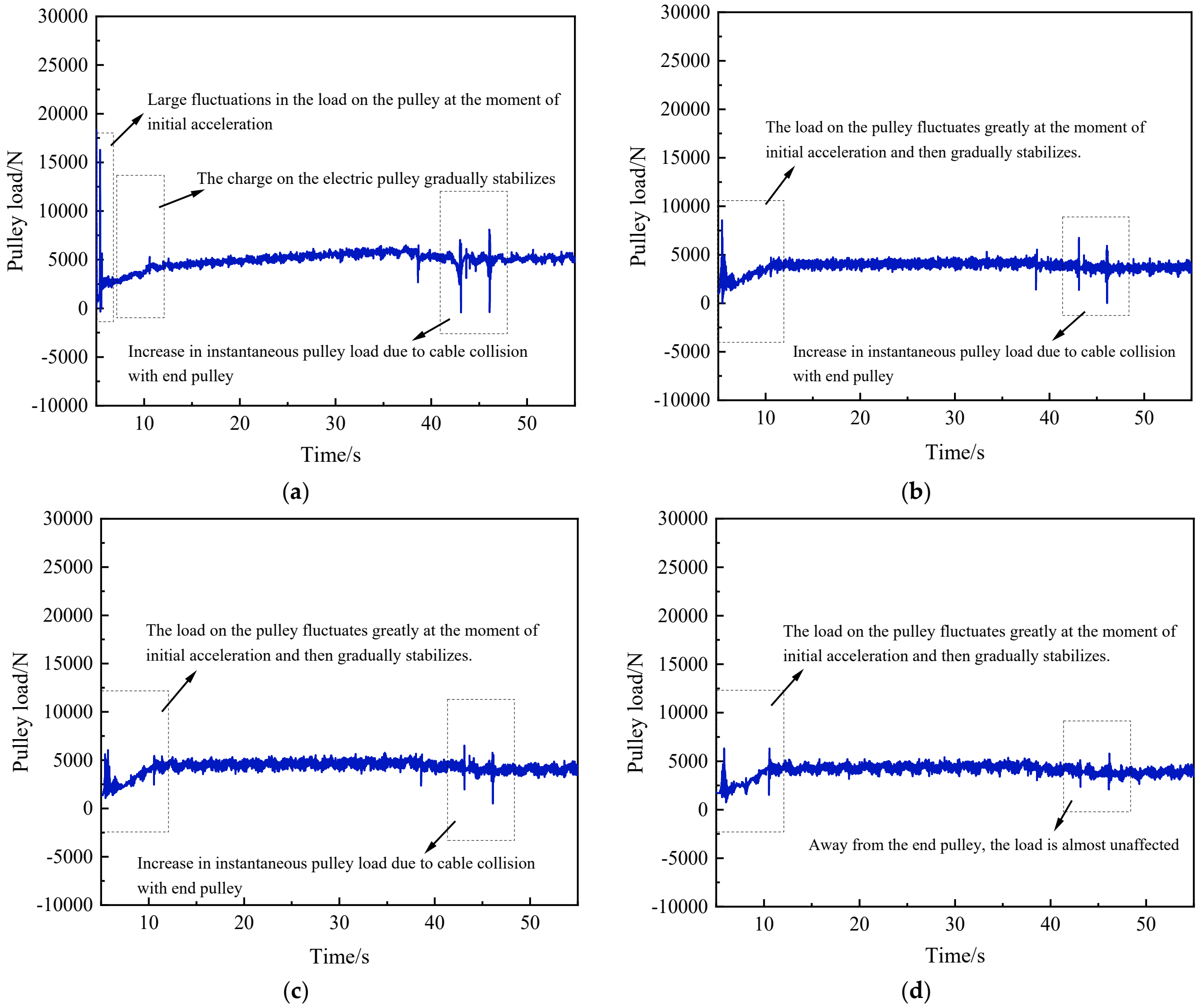

Figure 13. Data diagram of load borne by the pulley. (**a**) Load on pulley 1. (**b**) Load on pulley 2. (**c**) Load on pulley 3. (**d**) Load on pulley 4.

In this study, the selected pulleys have a rated load capacity of 160 kN. Through simulation, it was verified that the maximum load experienced by the pulleys during operation does not exceed their rated value, confirming that these pulleys can meet the demands of actual applications. However, in practical construction, factors such as improper operation by workers can lead to impact loads that may cause the load increment on the pulleys to exceed their rated load, potentially resulting in permanent deformation or displacement, causing the cable to slip off and lay on the pulleys.

Considering these factors, in-field installations require that the selected pulleys have a load-bearing capacity exceeding 60% of the load experienced by the pulleys during uniform movement of the cable, providing a sufficient safety margin to prevent phenomena such as plastic deformation of the pulleys.

In summary, the digital cable laying system model for the Huangjia Lake civil engineering cable tunnel construction site has been validated as correct and feasible. It demonstrates the dynamic variations in cable speed, axial tension, and traction force during the pulling process, leading to an overload safety factor for traction force, $\alpha = 1.5$. Furthermore, it allows for reasonable pulley selection based on the load-bearing capacity, providing a certain reference value for eliminating safety hazards such as collisions during actual construction and ensuring the safety of the cables.

5. Discussion

To demonstrate the reliability of this article, we first model the target equipment and construction environment using BIM software. We utilize ADAMS virtual prototype technology to implement cable modeling through the Bushing force connection method and macro command language, establishing a three-dimensional realistic cable laying system for the transmission line. This dynamic simulation method has been applied in overhead line construction; however, there are currently insufficient dynamic simulations for cable laying operations. Therefore, this article proposes a simulation method for the transmission line cable laying construction process based on BIM technology. After the simulation is completed, we perform error analysis by comparing the cable axial tension and laying speed with theoretical calculation values to verify the consistency between the model and theory. Finally, by analyzing the tension fluctuations during cable laying and the pulley load-bearing capacity, we achieve control over the construction process and safety reconnaissance. From the result, it can be seen that the max error between the real value and simulation value is 5.4%, the mean error is 2.75%, and the min error is 0.8%, which indicates that the model is correct and the results have a certain degree of reliability. This research can provide a theoretical basis for practically eliminating safety hazards in cable laying projects and holds certain engineering value.

6. Conclusions

After in-depth research on the secondary development of ADAMS, we have chosen the Bushing force connection method as the most suitable modeling approach for the cables in this model. After analyzing the time-varying characteristics of cable laying tension and other properties and validating the reliability and effectiveness of the model through comparisons with computational data from actual construction, we can draw the following three conclusions:

(1) Compared to the traditional information processing of two-dimensional DWG drawings, this paper utilizes BIM technology and virtual prototype technology to transform two-dimensional representations into three-dimensional models, proposing a comprehensive set of methods for dynamically simulating the three-dimensional cable laying process within tunnels.

(2) The cable laying system model can comprehensively simulate the dynamic characteristics during the cable laying process and accurately calculate the axial tension values and their positions for each time segment. This model not only enhances the design efficiency of cable laying projects but also provides strong guidance for actual construction.

(3) This paper proposes a cable-laying construction method based on BIM technology. According to the actual construction requirements, when facing the characteristics of various transmission equipment and environments, it allows for a more precise selection of pulleys, thereby eliminating safety hazards and improving the safety of the cable laying process.

(4) Compared to other references, we can find that the method proposed in this paper has smaller average and max errors. However, it should be noted that this work does not take into account actual complex working conditions. Therefore, it is necessary for future research to implement optimal modeling in complex environments.

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