Impulse Load Analysis of Breakdown of Overhead Transmission Line

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Abstract: The movement of track rope which was impacted by broken line was relatively complicated, it was difficult to get accurate analytical expression. In this paper, the simulation model of track rope was established by LS-dyna, the model analyzed the impact dynamic response of track rope and accurately determined the tension and sag of track rope. The expression of impact load was established based on the collision theory, and the impact dynamic process was analyzed based on a specific case, the results were compared with engineering calculation results. The results show that tension and sag of track rope which was calculated by the LS-dyna all meet the requirements. Compared with engineering calculation results, the error value within the scope of the permit, the simulation analysis was feasible and it could improve the level of safety construction.

1. Introduction
With the development of our the social economy in our country, the cross-over between new transmission lines is often encountered in power grid construction [1-4]. The traditional power cut across construction methods has a long power outage period, and it is difficult to achieve the demand for high-quality and reliable power supply from customers [5-7]. Therefore, power construction units usually adopt live-leap-forward construction methods, which can reduce the economic losses caused by blackouts, and significantly improve social and economic benefits. Closure network crossing is a commonly used electrified span construction technology. The temporary holding poles are installed on the crossbars in the newly built railway towers, and the crossover electrification devices are used to cross the livelines [8-10].

2. Load bearing cable tension and sag calculation methods in engineering applications
In the engineering application, the tension and sag of the load-bearing cable subjected to the impact under the broken line accident are calculated as follows:

(1) Load bearing cable tension calculation
The conditions for the load cable can be divided into installation conditions and accident conditions. The installation condition can also be referred as the no-load condition. At this time, the tension value of the load-bearing wire can be taken into account by the engineering experience and the maximum breaking force of the load-bearing wire can be taken as 1/50[11,12] according to the requirements on the installation wire.

Accident conditions refer to the conditions under which the conductors all fall on the screen-sealing
device and the load-bearing cable is subjected to impact load during the line-breaking process.\textsuperscript{[13,14]} From the tension of the load-bearing cable under the known installation conditions, the tension value under accident conditions is deduced from the state equation. The state equation is as follows:

\[ H_2 - \frac{l_1^2 \omega \phi}{24H_1} \cos \phi = H_1 - \frac{l_1^2 \omega \phi}{24H_1} \cos \phi \]  

(1)

In the formula: \( l \) represents the span (m) and \( \phi \) represents the height difference angle (°) between hanging points; \( H_1, H_2 \) respectively represents tension of the load-carrying cable under installation conditions and accident conditions (N); \( E, A \) respectively represents the elastic modulus of load-carrying cable (N/mm\(^2\)) and cross-sectional area of load-carrying rope (mm\(^2\)); \( \omega_1 \) represents the weight of the load-bearing cable unit under installation conditions (N/m), including the net-closing device and the attachment weight; \( \omega_2 \) represents the weight per unit length of the load-carrying cable under the broken condition (N/m).

Impact coefficient \( k_d \) is the coefficient that calculating the weight per unit length of the load-bearing cable under accident conditions. The value is the indicator that the load-bearing cable will not touch the straddle under accident conditions. The value is determined by engineering experience and usually takes 1.0~1.7. The weight per unit length of the load-carrying wire under accident conditions is:

\[ \omega_2 = k_d (\omega_1 + \omega_1) \]  

(2)

From formula (1) and formula (2), the tension value of load-bearing cable under impact load can be calculated.

(2) Carrier cable arc sag calculation

From the above tension values, In accident conditions, the sag of the load-carrying cable at the crossing point under impact load \( f_x \) is:

\[ f_x = \frac{\omega_x A x (l - x)}{2H_2 \cos \phi} \]  

(3)

In the engineering calculation, the tension value of the load cable and the sag value at the crossing point are calculated under the impact load, and then they are compared with the maximum tension allowable value and the safety sag value of the load bearing cable. If the requirements are satisfied, the payoff is indicated. It is safe and effective to cover the net across construction.

3. Broken impact load calculation based on collision theory

During the line laying process, if a wire breakage accident occurs, and the wire impacts the closure net device. Its movement trajectory is similar to the free fall motion. When the wire contacts the closure net device, the load-carrying wire will move in an approximate trajectory under the impact load of the wire. With the energy conversion and loss, the final load cable and wire will be in a static state. The entire process is shown in Figure 1.
As shown in Fig. 1, during the impact process, the trajectory of the load-bearing cord is a back-and-forth motion at a static load position. Considering that the weight of the load-bearing cable is much smaller than its quality, the following assumptions can be made for the entire impact process\cite{15,16}:

1) The collision between the two is a non-elastic collision; 2) The impacted object (loading cable) is lighter, and its quality can be ignored with respect to the quality of the wire. Therefore, the impact load caused by wire breakage will spread throughout the entire load wire at the impact moment. 3) The entire system complies with the law of conservation of energy. After the load cable is impacted, the conductor will attach to the load cable and the conductor will not spring back again.

Based on the above-mentioned assumptions, combined with the collision theory, the impact load can be derived as:

\[ F = k x = k \sqrt{\frac{g\Delta h}{\omega}} \sin \omega t + k x_0 \cos \omega t \]  

Where \( \omega = \sqrt{\frac{k}{m}} \) is the natural frequency of the spring system.

\( x_0 \) in the above equation can be determined by the position of the load cable before and after the impact (static position).

4. Load-bearing cable LS-dyna simulation under impact load

4.1 Unit type selection

Multiple unit types are available in the LS-dyna simulation software cell library, where LINK167 and LINK10 simulate a three-dimensional stretchable cord\cite{17}. The final unit type is determined by comparing the dynamics characteristics of the LINK167 unit and the LINK10 unit.

When the same axial acceleration is applied to both units at the same time, the displacement values are similar, which means that the dynamic characteristics in the axial direction are similar for both units. However, in the tangential direction, the displacement value of the LINK167 unit is larger, meaning that the LINK167 unit has better dynamic characteristics in the tangential direction. Therefore, this paper selects the LINK167 unit.

4.2 Load cable form-finding and meshing

After finding a suitable unit type, conduct form-finding calculations on the wire and the load-bearing cable\cite{18}, draw a geometric model, specify the material properties, and then mesh it to obtain the corresponding finite element model.

4.3 Applying impact load

When using LS-dyna for explicit dynamic analysis, the load changes with time. Before loading, a load-time history curve needs to be defined. The load usually defines its parameters in an array. One
element in the array defines time and the other defines the load. From equation (4), the impact load value that the load cable should apply can be calculated.

4.4 Solving and post-processing
The established model is solved in the solver and the resulting calculations can be visualized and analyzed by the processor.

5. Example analysis
The voltage level in a new line is 500kV. A certain line must span two 220kV lines with a span of 369m. The line is located in the typical meteorological zone III. The specific parameters are as follows.

5.1 Line parameters

| Type       | Cross-sectional area (mm²) | Unit length mass (kg/km) | Density (kg/mm³) |
|------------|----------------------------|--------------------------|------------------|
| LGJ-500/45 | 531.68                     | 1688                     | 3.17×10⁻⁶        |
| Length (m) | No-load horizontal stress (MPa) | Span point 1 wire landing length (m) | Span point 2 wire landing length (m) |
| 369.46     | 19.5                       | 70                       | 100              |

5.2 Engineering Calculation Results
The load-bearing cable model during construction is φ16 Dyneema rope. The specific parameters are shown in Table 2.

| Nominal diameter (mm) | Calculation cross-sectional area (mm²) | Unit length mass (kg/km) | Minimum broken force (N) | The pressure across the device is converted to the Dyneema rope pressure (N) |
|-----------------------|----------------------------------------|--------------------------|--------------------------|-------------------------------------------------------------------------|
| 16                    | 156.512                                | 195.78                   | 198400                   | 1507.25                                                                  |

The calculation results of the load bearing cable are shown in Table 3.

| Sag under normal line condition (m) | Dead load static sag (m) | Dynamic load sag under breaking condition (m) | Crossing point 1 sag at breaking condition (m) | Crossing point 1 sag permission |
|-------------------------------------|--------------------------|-----------------------------------------------|-----------------------------------------------|-------------------------------|
| 6.55                                | 8.25                     | 9.06                                          | 7.15                                          | 11.52                         |
| Crossing point 2 sag at breakage condition (m) | 7.45                     | 12.25                                         | 9844.5                                        | 29597.82                      | 33032.82                     |

5.3 LS-dyna simulation calculation results
Through simulation calculations, the results are shown in Figure 2.
It can be seen from Fig. 2 that the displacement values of the load cables are different at different times and they are in a fluctuating state. After converting the displacement value to the sag value, it can be seen that the sag value of the load-carrying cable first gradually increases, and after reaching the maximum value, it gradually becomes smaller until it is stable.

At the second crossing positions, nodes 130 and 360 are selected for analysis. The positions of the two nodes are shown in Figure 3.

As shown in Figure 4, the load-carrying cable sag reaches its maximum at 0.24 s. At this point, the position value of the nodes at both crossing points is 2132.6mm. The sag value converted from the load bearing cable is shown in Table 5.
Table 5 Comparison between simulation calculations and engineering application calculations

| Sag at node 130 (m) | Engineering calculation sag (m) | Error | Crossing point 1 permission sag (m) |
|---------------------|---------------------------------|-------|-----------------------------------|
| 6.92                | 7.15                            | 3.32% | 11.52                             |
| Sag at node 360 (m) | Engineering calculation sag (m) | Error | Crossing point 1 permission sag (m) |
| 7.24                | 7.45                            | 2.91% | 12.25                             |

From the data analysis in Table 5, the following conclusions can be drawn:

1) In both spanning positions, the load-carrying cable sag is less than the permission sag, which can ensure construction safety.

2) The sag value obtained by engineering application calculation method is slightly larger than the sag value calculated by simulation, but the error value for both is within the permission range.

Use LS-dyna to calculate the impact load on the load-carrying wire when the wire breaks. Through calculations, it can be seen that at 0.24s, the load cable has the largest tension value.

![Figure 5 Tension time-distance curve](image)

Table 6 Comparison between simulation calculations and engineering application calculations

| Simulation value (N) | Engineering calculation (N) | Error | Load line permission tension (N) |
|----------------------|------------------------------|-------|---------------------------------|
| 33761.6              | 33032.82                     | 2.15% | 198400                          |

From the data analysis in Table 6, the following conclusions can be drawn:

1) The maximum tension values of the load cables calculated by the two methods are far less than the minimum permission breakage force and meet the requirements.

2) The engineering calculation value is slightly smaller than the simulation result value, but the error value of both is within the allowable range of engineering calculation.

6. Conclusion

In this paper, LS-dyna is used to analyze the impact load during site construction. Through the above analysis, the following conclusions can be drawn:

1) Compared with the LINK10 unit, the finite element model of the load-carrying line established using the LINK167 unit has better dynamic characteristics.

2) The finite element simulation method is used to simulate the load-carrying cable. Compared with the calculation result of the engineering application, its error is smaller, and the simulation analysis method is more effective and feasible.

3) The calculation method in this paper can provide new calculation ideas for constructing the enclosure network and provide theoretical support for implementation across construction safety.
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