Analysis of the Impact of Highway Tunnel Blasting Construction on High Voltage Electric Towers

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Abstract. The highway is aligned with a 110kV high-voltage power tower. Tunnel excavation and blasting operations may cause certain deformation or affect the use of high-voltage electric towers. Using numerical simulation methods, analyze the possible effects of tunnel excavation on the settlement and tilting of high-voltage power towers, and conduct compliance checks with relevant standards and specifications. Using mechanical calculation methods, examine the potential impact of tunnel blasting construction on high-voltage electric towers, and provide recommendations for the maximum amount of explosives used. With the encryption of the highway network, there are more and more cases of collinearity with high-voltage power towers. The relevant methods used in this study are for reference in similar projects.

Keywords: Highway tunnels, blasting vibrations, high-voltage electric towers, safety assessments.

1 Introduction

In recent years, with the intensification of the highway network, there have been frequent occurrences of highways sharing corridors with high-voltage power towers. The highway passes through high-voltage power towers in the form of tunnels, which are affected by standard specifications, tower vibration deformation, tower settlement and inclination. The tunnel excavation process, excavation method, protective parameters, blasting dosage, etc. should be effectively controlled. In order to better study the possible effects of tunnel excavation and blasting on endangered high-voltage power towers, Midas simulation software and mechanical calculation methods were used to predict the deformation and blasting vibration effects of high-voltage power towers, providing effective guidance for excavation depth and blasting dosage [1][2].

The tunnel site area belongs to the low mountain landform area of structural erosion and erosion, with developed gullies and undulating terrain, and a relatively large difference in terrain height. The ground elevation within the center line range of the tunnel is 13.3m to 222.5m, with a natural slope of 15 ° to 30 °. Vegetation is well-developed, and the tunnel entrance and exit are located in the slope area in front of the mountain.

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The current situation of the tunnel entrance is a natural slope with a slope of 20 ° - 35 °. The surface of the slope is mainly forest land, and there are manually excavated slopes in the surrounding mountains with a slope ratio of 1:0.25-1: 0.50. The bedrock of the slope is exposed, the rock mass is broken, and joint fissures are developed. It is covered by a 0.5m residual slope soil layer.

Horizontal distance. After the relocation of the power line, the newly built Tower 1 is about 30.48m away from the right side line of the tunnel; The newly built Tower 2 is approximately 31.3m away from the right tunnel edge, and Tower 3 is 28.97m away from the left tunnel. The new Tower 1 is about 93.6m away from the new Tower 2, and the new Tower 2 is about 43.47m away from the new Tower 3. The relevant positions are shown in the following figure. The horizontal distance between the repositioned tower line and the tunnel is shown in Figure 1.

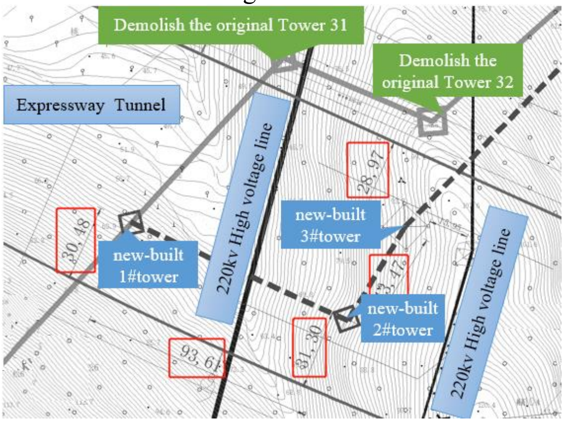

Fig. 1. Map of the relocated tower line and tunnel location.

Vertical distance. From the contour line, it can be seen that the surface elevation of the electric tower location is about 69m, the elevation of the tunnel floor is 43.3m, and the excavation height of the tunnel is 12.54m, that is, the distance from the arch top to the surface is 13.16m. The vertical distance between the repositioned tower line and the tunnel is shown in Figure 2.

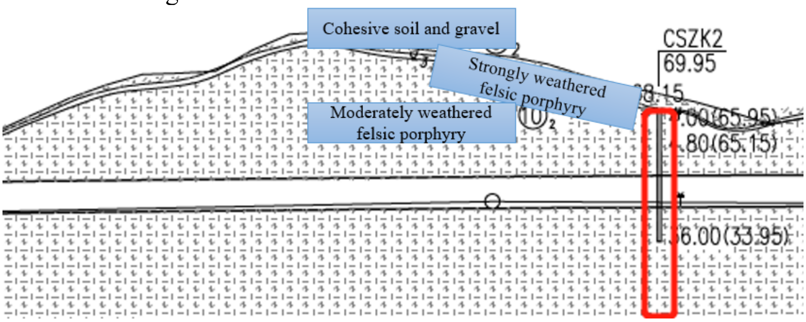

Fig. 2. Vertical section at the intersection of electric tower and tunnel.

2 Analysis of the impact of tunnel excavation on the deformation of electric towers

2.1 Impact mechanism

The iron tower is adjacent to the right tunnel, and the excavation of the left tunnel may have a greater impact on the iron tower than the right tunnel. Moreover, the foundations are independent of each other and the external load is asymmetric. Therefore, the tower foundation is prone to uneven settlement, causing the iron tower to tilt, causing deformation or local damage to the tower. Excessive tilting may lead to the overall overturning of the iron tower.

When the disturbance caused by the excavation of the dangerous road causes the overall sinking of the iron tower to be too large, the condition of other elements of the transmission line will change, resulting in the inability to transmit electricity safely.

Under the influence of tunnel excavation, iron towers may experience local instability and damage due to their own design, materials, construction quality, as well as destructive factors such as strong storms, ice and snow, and vibration loads.

2.2 Control standards

According to the power industry standard " Operating code for overhead transmission line " (DL/T 741-2019) [3], the inclination of 110KV iron towers below 50m shall not exceed 1%.

According to the " Code for design of building foundation " (GB 50007-2011) [4], due to factors such as uneven building foundations, significant load differences, and complex shapes, the deformation of the foundation should be controlled by the inclination value for multi-story or high-rise buildings and high-rise structures. If necessary, the average settlement should be controlled. The allowable values are: the inclination should not exceed 0.006 and the settlement should not exceed 400mm.

According to Article 7.3.1 of Code for design of foundation of overhead transmission line (DL/T 5219-2017) [5], for certain tower foundations with special deformation requirements, the maximum inclination rate of the foundation shall be determined δ (Excluding the basic pre bias value) shall not exceed 0.006.

Based on the above three specifications and considering that the maximum height of the high-voltage iron tower is 36 meters, the foundation inclination shall not exceed 0.6% as the control standard.

2.3 Numerical simulation analysis and results

The geological data of the simulation points are shown in the table 1 below.

Table 1. Soil layer parameters table.

Solum	Thickness (m)	Unit weight (KN/m³)	Compression Modulus(MPa)	Poisson's ratio	C(KN/m²)	φ(°)
gravels	2	17.5	7	0.35	20	20
Moderately weathered felsite	-	20.5	100	0.25	200	30

Simulate using MIDAS/GTS software. The numerical model adopts a three-dimensional model with hexahedral elements, which are obtained by extending two-dimensional elements [6]. In order to simplify calculations and simulate the excavation unloading process based on construction characteristics. In order to balance computational efficiency and accuracy, the soil and rock mesh between the interface and the tunnel is denser, while the soil and rock mesh further away from the tunnel is sparser, as shown in the figure 3.

Simulated working conditions: Simulate the settlement and deformation law of the electric tower position caused by tunnel excavation.

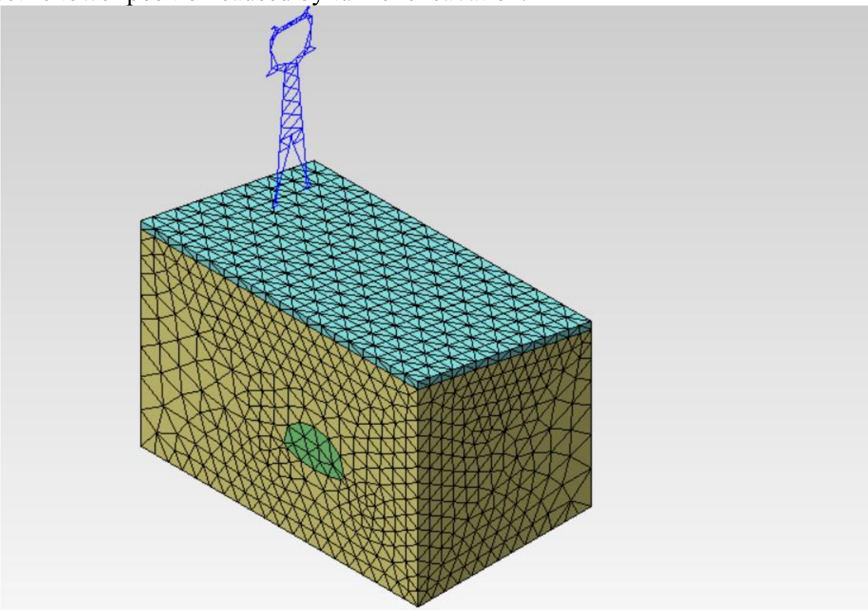

Fig. 3. Tunnel excavation model.

Settlement calculation model is shown in the figure 4. From the calculation results, the maximum settlement is 0.13mm, as shown in the figure 5.

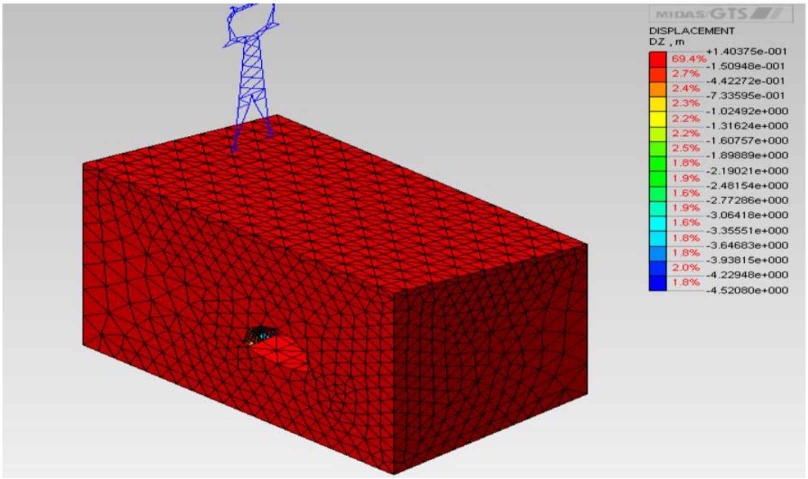

Fig. 4. Settlement during tunnel excavation process.

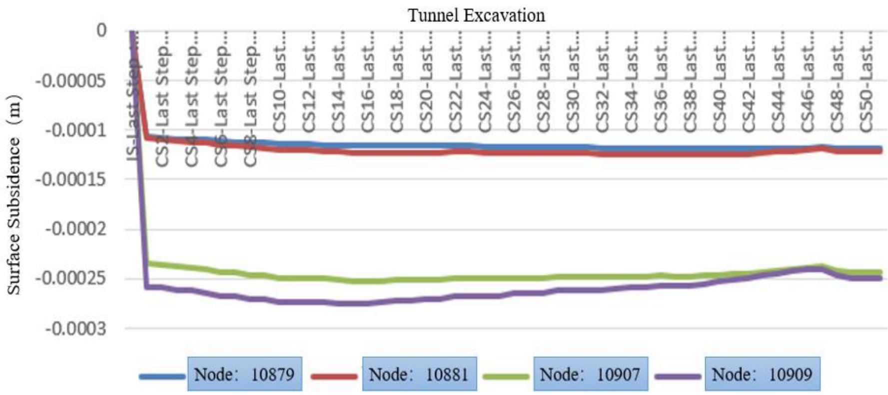

Fig. 5. Settlement values of four nodes.

The maximum settlement difference is 0.000112m, and according to the height of Tower 31 of 27m, the maximum inclination rate is 0.0004%.

According to the calculation results, the settlement value and inclination rate both meet the relevant requirements of the specifications.

3 Analysis of the Impact of Tunnel Blasting Operations on Electric Towers

3.1 Impact mechanism

When explosives explode in rock and soil media, the explosion energy generated by them breaks, loosens, and moves some of the rock and soil media outside the body, and a portion of the energy propagates outward in the form of waves, causing elastic deformation and vibration of rock and soil media particles in the far blasting area. This elastic wave that causes vibration of rock and soil media particles is called seismic wave.

The seismic motion caused by different types of engineering blasting at different distances from the blasting center is complex and diverse. Its damage to buildings includes both high-frequency impact wave damage in the near area and vibration damage similar to natural earthquakes in the mid to long range. The degree and characteristics of seismic damage to buildings are mainly caused by different damage processes and mechanisms of seismic motion. Analysis shows that the blasting seismic damage mechanism of buildings can generally be divided into the following three types.

(1) Shockwave damage

In the vicinity of the explosion source, the seismic effects on buildings are generally caused by a combination of explosion stress waves, high-frequency seismic waves, and blast wind shocks. The explosive stress waves propagating in the subsoil of the structure collide with the foundation of the structure and then turn into brick and stone masonry. The main vibration frequency of this high-frequency seismic wave is far from the natural vibration frequency of the structure, so the dynamic response of the structure is not significant. However, they reflect, refract or diffract on the surface of the building, as well as at the doors, windows, chimneys or other openings, generating tensile waves in the masonry, leading to cracking of the masonry plaster layer Falling off and cracks appearing at the opening, in addition, the contact positions of various components are also prone to contact failure and damage.

(2) Vibration damage

In the mid to long range of extensive blasting, buildings are subjected to low-frequency, long-period seismic waves. Due to its main vibration frequency being close to the natural frequency of the structure, and its wavelength being equal to or greater than the planar characteristic size of the structure, local and global vibration effects will occur in the structure. The failure of the structure is mainly caused by the shear force generated by seismic inertia acting on the wall, which is called the vibration (shear) failure mechanism.

(3) Accumulated vibration load

In the vicinity of repeated blasting areas, the seismic damage to buildings is caused by the combined effect of maximum seismic load and repeated cyclic loading. In the non-elastic working stage, even if the load does not reach the ultimate strength value, masonry will lose its bearing capacity due to accumulated energy loss, which is the cumulative failure mechanism.

3.2 Control standards

(1) Judgment basis

There are two forms of energy release in explosive explosions: shock waves and explosive gases. As the propagation distance increases, shock waves attenuate into stress waves and seismic waves, and the ground (near surface) vibration caused by seismic waves is called seismic motion. When analyzing the impact of seismic motion caused by blasting on surface structures, the peak vibration velocity and main vibration frequency of the geological point where the protected object is located are usually used as criteria. The "Blasting Safety Regulations" (GB6722-2014) make corresponding provisions for the safety criteria of buildings (structures) under blasting loads, and the blasting vibration criteria for each protected object, The peak vibration velocity v and main vibration frequency f of the foundation particle at the location of the protected object are adopted [7], and the safety allowable standards are shown in the table below.

(2) Select Analysis

Analyzing the tunnel using shallow hole blasting, it can be seen from the "Blasting Safety Regulations" (GB6722-2014) that the frequency of shallow hole blasting is generally between 60Hz and 300Hz. Refer to the vibration standards for industrial and commercial buildings. The safe allowable particle vibration velocity V in the tower area this time is 4.2-5.0cm/s. For safety reasons, select the lower limit of the safe allowable value of 4.2cm/s.

3.3 Analysis and calculation of blasting impact

(1) Calculation formula

The allowable distance for blasting safety is often calculated using empirical formulas, using The M A. Sadovsky empirical formula[8][9][10] is used to calculate the safe allowable distance for blasting.

The M. A. Sadovsky empirical formula is:

$$R = \left(\frac{K}{V}\right)^{1/\alpha} \cdot Q^{1/3} \tag{1}$$

In the formula: R - safe allowable distance for blasting vibration, m;

Q - explosive quantity, with simultaneous blasting as the total explosive quantity and delayed blasting as the maximum single stage explosive quantity, kg;

V - Safe allowable particle vibration velocity at the location of the protected object, cm/s;

K, α - The coefficient and attenuation index related to the terrain and geological conditions between the blasting point and the protected object.

(2) Selection of calculation parameters

K, α the values are selected through similar engineering according to the "Blasting Safety Regulations" (GB6722-2014) Table 2. Based on the occurrence conditions and physical and mechanical properties of the rock mass, k=150 is selected; α= 1.50.

Table 2. Parameter selection value

Rock character	k	a
hard rock	50～150	1.3～1.5
medium hard rock	150～250	1.5～1.8
soft rock	250～350	1.8～2.0

(3) Safe allowable distance for blasting vibration

According to the dosage of 200kg, the safe distance is:

$$R = \left(\frac{150}{4.2}\right)^{1/1.5} \cdot 200^{1/3} = 10.8 \cdot 5.84 = 63.07\text{m} \tag{2}$$

According to the dosage of 138.6kg, the safe distance is:

$$R = (\frac{150}{4.2})^{1/1.5} \cdot 138.6^{1/3} = 10.8 \cdot 5.17 = 55.8\text{m} \quad (3)$$

According to the dosage of 100kg, the safe distance is:

$$R = (\frac{150}{4.2})^{1/1.5} \cdot 100^{1/3} = 10.8 \cdot 4.64 = 50.112\text{m} \quad (4)$$

4 Conclusion

4.1 Main evaluation conclusions

(1) Regarding settlement and tilt rate. Using Midas GTS for finite element simulation calculation, the absolute settlement value and inclination rate meet the relevant regulatory requirements.

(2) Regarding blasting. If 200kg emulsion explosives are used, a safe distance of 63.07m should be maintained from the center of the tunnel blasting to the foundation of the electric tower.

4.2 Suggestions for measures

To ensure the construction progress of the tunnel and the safety of the power tower, it is recommended to excavate in the following order:

One is to excavate the right tunnel first, at a horizontal distance of 100m from the original 31 # 32 # electric tower, to meet the requirements of full section blasting.

The second step is to complete the relocation of the power tower before excavating the left tunnel. The horizontal distance between the left tunnel and the newly built 3 # power tower is 29 meters, the vertical distance is about 40 meters, and the straight distance is about 50 meters, which basically meets the requirements of the upper and lower step excavation method for medication.

Thirdly, it is recommended to further verify the surrounding rock level in the tunnel site area after tunnel excavation. The K value can be verified through monitoring, in order to more accurately control the dosage of chemicals to protect the power tower [11][12][13].

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