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# Study on Construction Method of High-Voltage Transmission Tower Beneath Shallow-Buried Tunnel

**Junjie Xuan[1], Songhong Yan[2] and Tianming Zhao[3]**

1. School of Civil Engineering, Lanzhou Jiaotong University, Lanzhou, China.
2. Key Laboratory of Road & Bridge and Underground Engineering of Gansu Province, Lanzhou, China.
3. The 2nd Engineering Co., Ltd.of the 17th Bureau Group of China Railway, Taiyuan, Shanxi, China.

Email: 195780793@qq.com

**Abstract.** Wangqiao tunnel of Jiu-jing-qu railway is used as engineering example, based on risk analysis, aim at the construction scheme, comprehensive analysis and calculation has carried on combined monitoring and numerical analysis. Reliability demonstration has conducted on comprehensive construction scheme of" ground surface grunting consolidation & mechanical excavation & improving support measure & settlement monitoring". Practice has proved that the deformation of the tunnel's settlement of the arch and the high-voltage transmission tower were in allowable ranges, and good economic and technical results are obtained, the results can provide a reference for similar projects.
**Keywords:** shallow-buried tunnel; beneath a high-voltage transmission tower; on-site monitoring; numerical analysis.

## 1. Introduction

During the construction process of the mountain tunnel, it will inevitably encounter the situation where the existing building is going down through the mountain surface. For example, there may be houses, diversion canal and high-voltage transmission towers on the top of the mountain. As a high-rise space truss structure, the high-voltage transmission tower is the main bearing carrier in the electric transmission line with the characteristics of small self-rigidity, independent foundation of Tower Foundation and abnormal sensitivity to uneven settlement of foundation. When the tunnel is adjacent to the high-voltage transmission tower construction, the displacement caused by the excavation of the stratum easily leads to uneven settlement of the tower Tower Foundation. In severe cases, the tower may be tilted or collapsed, endangering the normal operation of the national grid and the safety of life and property, and the construction risk is extremely high.

The supporting project of this paper is the Wangqiao tunnel of Jiu-jing-qu railway with the excavation span exceeding 12m, the 220kV high-voltage transmission tower undergoing, and 25.16m of the maximum buried depth of the tunnel. If the tower is removed, it will lead to problems such as high cost, high risk and long construction period. Therefore, under the premise of not changing the tower, how to reduce the impact of tunnel excavation on the force and deformation of the transmission tower and ensure its normal operation is the difficulty of this project.

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## 2. Project Overview [1]

### *2.1. Overview of the Tunnel*

Wangqiao Tunnel is located near Poyang County, crossing the residual hill area, starting mileage DK92+005, ending mileage DK92+233, which is a double-line tunnel with a total length of 228 meters. The maximum buried depth of the tunnel is 27.42m. The surrounding rock is poor overall, with silty clay, sandy slate and metamorphic sandstone. The surface layer of tunnel is the quaternary silty clay with a thickness of about 0.5-1.5m. The subterrane is the sandy slate of the Shuangqiao group of the Proterozoic, all-weak weathering, relatively broken core, and developed joints and fissures of rock mass. The tunnel passes through the 220kV high-voltage tower under the section DK92+097-+103, and the buried depth is 26m. The tunnel body is buried in shallow depth, the rock mass is broken, the joints are developed, and the water is partially localized. There may be risk events such as collapse and deformation during construction.

### *2.2 Overview of High-Voltage Transmission Towers*

According to the site survey, the tower of the high-voltage electric tower above the tunnel is a 220kV double-circuit linear tower with about 33m of the height of the tower, about 15t of the weight of the tower, and 6m×6m of the root of the tower base. The foundation form is an independent pile foundation, the foundation top is 1m×1m square section, and the pile length is 8m. The height difference of the tower foundation in the cross-section of the tunnel is 3.2-3.7m; the relationship between the tunnel and the tower foundation is shown in Figure 1 below.

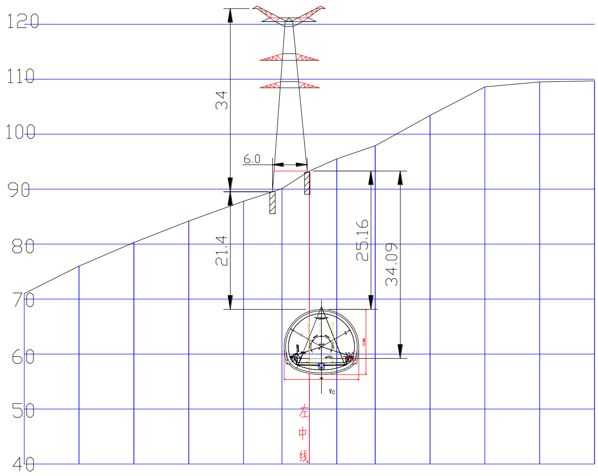


**Figure 1.** Schematic diagram of the cross section of the tunnel and high-voltage tower.

### *2.3. Tunnel Excavation and Support Scheme*

The design advance support measures are Φ89 hole length pipe shed & II type small pipe pre-support, four-step CD method excavation, and 3m radial grouting after excavation. The initial support thickness is 28cm, and the second lining thickness is 50cm. Shotcrete: arch wall sprayed C25 concrete, inverted arch sprayed C25 concrete; reinforced mesh: HPB300 steel bar, diameter 6mm; rockbolt: side-wall C22 mortar rockbolt; arch wall: C35 reinforced concrete: inverted arch: C35 reinforced concrete. The detailed excavation procedures and lining section structure are shown in Figure 2 below.

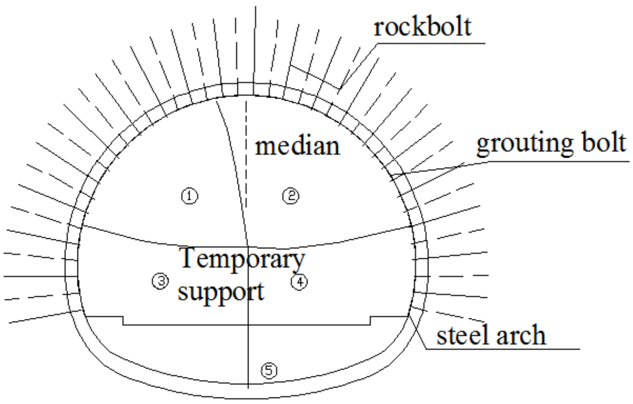


**Figure 2.** Excavation steps and lining cross-section structure drawing.

## 3. Engineering Risk Analysis

### *3.1. Local Instability Damage Risk*

The iron tower may have hidden dangers in its structural design, steel fatigue resistance, service life, external load (wind load, heavy rain, dynamic earthquake load ), etc., and will face the risk of local instability damage, and now large-section tunnel construction is carried out underneath it, which will further increase the risk of local instability of the iron tower.

### *3.2. Integral Tilt and Settlement Deformation Risk*

Because of the thin layer and long span above the tunnel, the effect of excavation behaviour on the stability of the tower will be very obvious. The external load is asymmetric and the foundation of the tower is an independent pile foundation, which makes the tower foundation extremely prone to uneven settlement, leading to tilting deformation of the iron tower, causing deformation of the rod or excessive inclination of the local damage may lead to the overturning of the iron tower as a whole. In addition, the disturbance caused by the tunnel excavation to the stratum will inevitably lead to the subsidence of the tower. If the tower settlement is too large, the condition of the transmission line elements such as the span, running tension and distance to the ground will change, resulting in the transmission line being unable to transmit electricity safely [2].

Excessive tilt or even collapse of iron towers will disrupt transmission lines, cause extremely bad social impacts, cause incalculable economic losses, and trigger accountability risks. At present, the anti-deformation ability and force mechanism of high-rise transmission towers such as high-voltage transmission towers are still unclear [3]. In addition, the Wangqiao tunnel is buried in shallow depth and has a large span, so the construction and excavation will inevitably disturb the stability of the surrounding rock many times. Thus, the stability of the tower is greatly affected.

## 4. Monitoring Measurement Schemes and Results

### *4.1. Monitoring Schemes*

The specifications and procedures adopt the following requirements: “National first and second Level Measurement Specifications” (GB 12897-2006); “Building Deformation Measurement Regulations” (JGJ 8-2007); “110 ~ 750 kV overhead transmission line design Specification” (GB50545-2010) [4].

### *4.2. Analysis of Monitoring Results*

The displacement temporal curves of the settlement of the four measuring points TT1, TT2, TT3, and TT4 on the tower foundation are plotted out in two months, as shown in Figure 3 below.

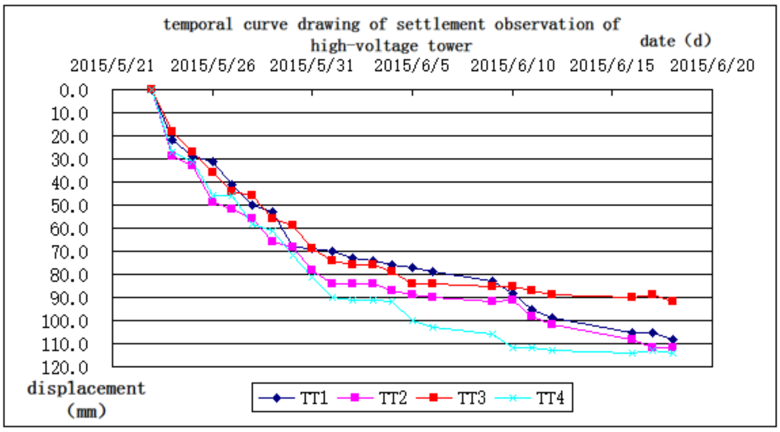


**Figure 3.** Temporal curve drawing of settlement observation of high-voltage tower.

The curve shows that the settlement of the four monitoring points at the initial stage of excavation is large, and the individual reverse bending points may be due to the fact that the strength of the support after excavation in the four-step CD method has not been reached. Then it enters the slow deformation stage, and after about 20 days, it enters the basic stable state, and the settlement development is extremely small. At this time, the tunnel excavation face has passed through the high-voltage tower on the surface of the mountain, and the influence of spatial effect is decreasing day by day. The average settlement value of the four tower foundation is 10.65mm, which is far less than the specification.

## 5. Finite Element Simulation Analysis (MIDAS/GTS)

### *5.1. Calculation Model*

The finite element model is established by MIDAS/GTS software, which is located in the area of 40 m in the lateral direction of the tunnel, 30 m in the lower part of the tunnel and 25.16 m from the surface of the tunnel arch, as shown in Figure 4. The top surface of the model is a free surface, the bottom surface is a vertical constraint, and the left and right boundaries are horizontal constraints. In the calculation of tunnel surrounding rock and supporting structure, two-dimensional solid elements are used, and the surrounding rock is considered as two layers, the upper layer is silty clay and the lower layer is weathered sandy slate.

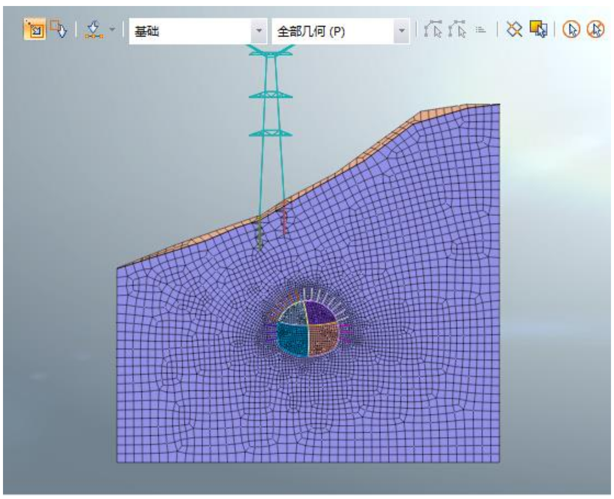


**Figure 4.** Overall grid partition diagram of model.

### *5.2. Calculation Assumptions*

The force and deformation of the model are extremely complicated. For the convenience of calculation, the simplified treatment is carried out here: the high-voltage tower is simplified into a beam and truss mixed model, that is, the lower four main materials are simplified into beam elements, and the cross-sectional dimensions are exactly the same as the actual ones. It is simplified as a truss unit; the tower foundation is a pile foundation unit, and the rockbolt rod is an implanted truss unit. The external load of the tower is simplified to the longitudinal, transverse and vertical concentrated force components of the wire hanging point; in the aspect of grouting and reinforcement of pipe shed, the simulation is carried out by increasing the surrounding rock parameters in the calculation; The contact between tower body, tower foundation and the stratum is realized by binding and coupling [2]; the constitutive model of the calculation model adopts the Mohr-Coulomb yield criterion. According to the past experience, the load release ratio of the secondary lining stage is less than 10%, so the second lining is not considered in the calculation model of this paper. The load release coefficient of the calculation model is set to 0.4 during excavation, and 0.4 in the initial support stage. The hardening stage of first concrete is set to 0.2 [5].

### *5.3. Calculation Parameters*

The calculation parameters are based on the empirical data of previous similar projects and are combined with the geotechnical tests at the Wangqiao Tunnel site, as shown in Table 1 below.

**Table 1.** Model calculation parameter table.

| Material | $\gamma$ (kN/m$^3$) | E (GPa) | $\mu$ | C (kPa) | $\varphi$ (°) |
|---|---|---|---|---|---|
| Silty clay | 20 | 0.6 | 0.35 | 80 | 29 |
| Sandy slate | 23 | 1.05 | 0.3 | 190 | 33 |
| rockbolt | 78 | 210 | 0.2 | — | — |
| shotcrete | 23 | 7.67 | 0.25 | — | — |
| Shotcrete hardening | 23 | 23 | 0.25 | — | — |
| Tower steel structure | 78 | 210 | 0.2 | — | — |
| Tower Foundation | 23 | 30 | 0.25 | — | — |

### *5.4. Calculation Results*

*5.4.1. Force Analysis of Tower Structure* from Figure 5 above, it can be found that the main material on the left side of lower part of the tower body is under pressure, the pressure value is 485kN, the effective cross-sectional area of the angle iron is 0.0025m$^2$, that is the stress intensity is 194MPa; the right main material is subjected to tensile force, and the tensile force value is 320kN. That is, the stress intensity is 128 MPa. The design strength of the tower angle steel is 265 MPa [4]. It is found that the force of the rod is within the bearing capacity range, which will not lead to steel stress fatigue and fracture.

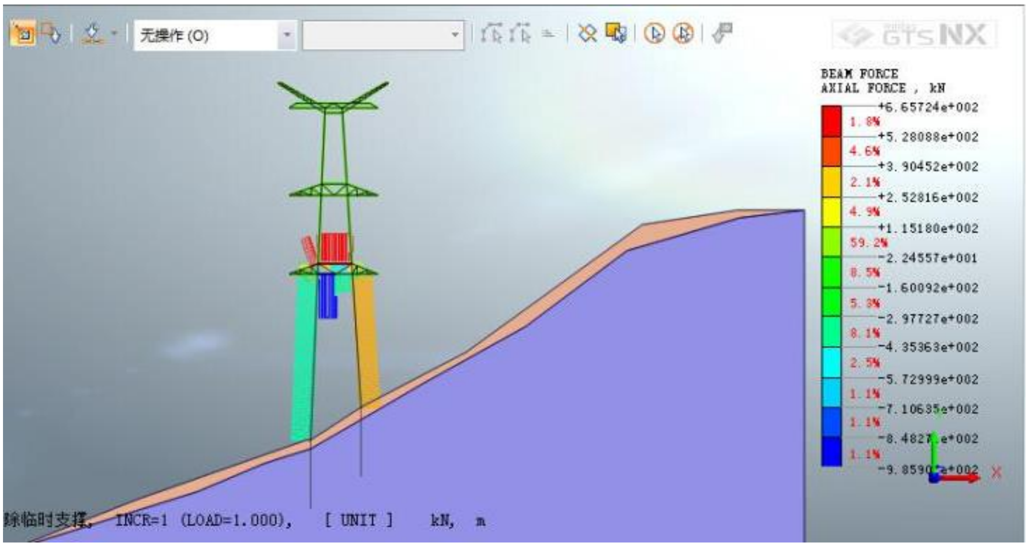


**Figure 5.** Axial force diagram of the lower structure of the tower body.

*5.4.2. Analysis of Tower Foundation Deformation and Force* The following are the forces and deformations of the tower pile foundation, as shown in Figures 6-7 below.

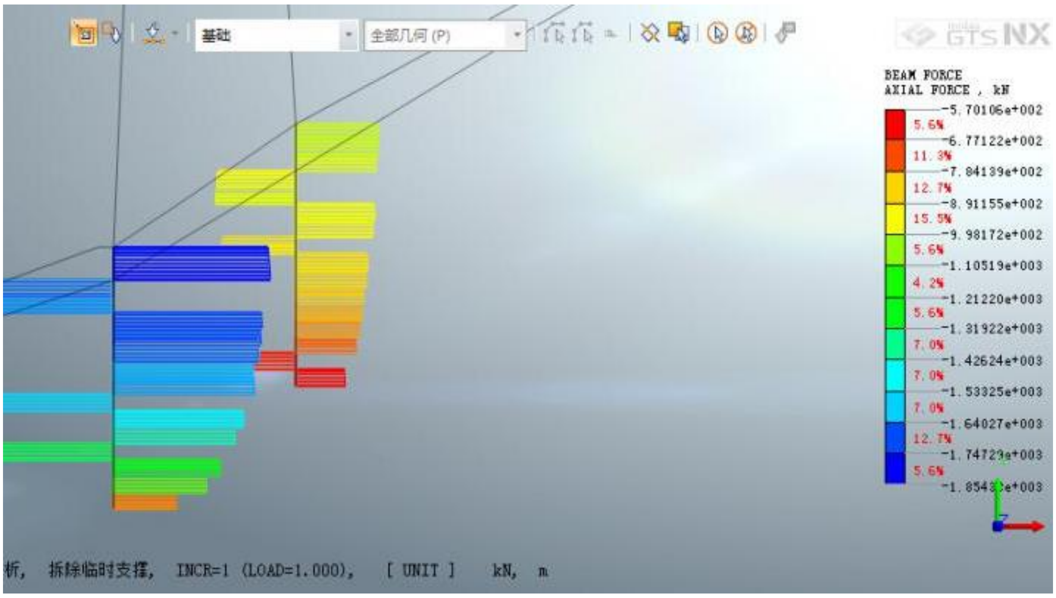


**Figure 6.** Distribution diagram of axial force of pile foundation.

As can be seen from the above figure, the force of the tower foundation is not large, and it is all pressure stress. Taking the cross-sectional area of $1m^2$, the average axial force of the left pile foundation is 1.486MPa, and the average axial force of the right pile foundation is 0.891MPa. The pile foundation is reinforced concrete, and the force is within the bearing range.

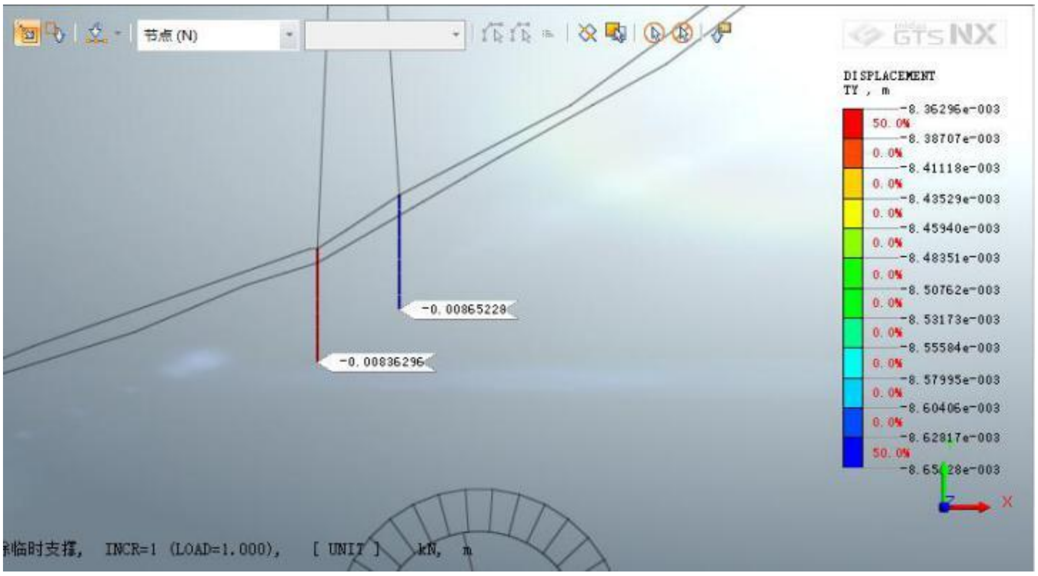


**Figure 7.** Mark map of vertical displacement result of pile foundation.

It can be seen from the above Figure 7 that the displacement value of the pile foundation is small, in which the horizontal displacement of the pile bottom is 2.4 mm on the left side and 1.6 mm on the right side; the vertical displacement is 8.4 mm on the left side and 8.7 mm on the right side. The maximum allowable settlement value is 400 mm, and the allowable tilt value is 5‰ for the deformation control of buildings with heights between 50 and 100 m in reference to the “High-rise Structural Design Specification” (GB50135-2006) [6]. It can be seen that the excavation of the tunnel has little impact on the high-voltage electric tower on the surface, and the iron tower is in a safe state. The average value of measured settlement of the four tower foundation is 10.65mm, which is basically an order of magnitude compared with the analog values.

*5.4.3. Analysis of Tunnel Deformation* from the above Figure 8, it can be seen that the comprehensive construction scheme of “surface grouting reinforcement & mechanical excavation & strengthening design support parameter & settlement monitoring” adopted in the CD four-step excavation method is effective and the settlement deformation of tunnel arch is strictly controlled. The mean value of the three calculated points in the arch is 12.33mm, and the headroom convergence deformation value at the side-wall is 0.7mm to the left and 1.0mm to the right. These all meet the requirements for the deformation of surrounding rock excavation in the “Code for Design of Highway Tunnels” (JTJ D70-2004) [7].

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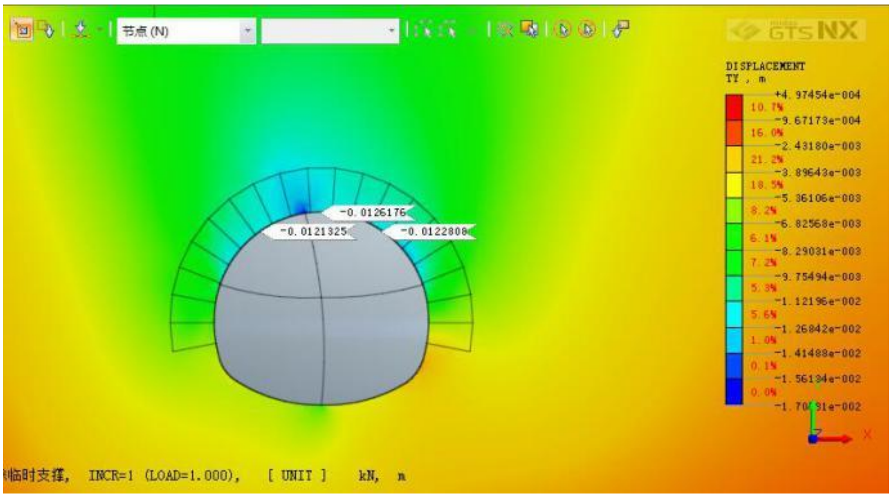


**Figure 8.** Result mark map of tunnel arch settlement.

## 6. Conclusion

(1) Through the construction scheme of the 220kV high-voltage transmission tower under the Wangqiao tunnel, the results show that the comprehensive construction scheme of "surface grouting reinforcement & mechanical excavation & strengthening design support parameters & settlement monitoring" adopted in the CD four-step excavation method is very effective, which reduces the uneven settlement of the tower. The stress and deformation of the tower are within the allowable range. The whole structure of the tower is safe, which avoids the settlement and deformation of the tower caused by tunnel excavation.

(2) Comparing the monitoring data of the tunnel with the numerical simulation results, it is found that most of the data are well-fitted and are located in the same order of magnitude, but there are also large differences in individual data. The main fitting point is that the deformation trend of the tunnel and the iron tower is similar when considering only the flat strain problem, and the result of the impact is roughly the same; and the difference may be that there are many interference and influence factors on the site construction, which leads to the error of monitoring data, and it may also be due to a slight errors between the physical parameters of the rock and soil used in the numerical simulation and the actual situation.

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