Numerical simulation study on the influence of double-line foundation pit and shallow tunnel on high-pressure tower in loess area

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Abstract. Xi 'an Tourism Avenue is the main planning road of the north span. Based on the research background of Tourism Avenue, this paper discusses the influence of double-line foundation pit and shallow buried tunnel on high-pressure tower in loess area. The three-dimensional model of foundation pit and tunnel is established by using finite difference software FLAC^{3D}, and the simulation analysis of surface settlement and supporting structure stress induced by different excavation methods of double-line is completed. The numerical simulation shows that the unloading period of staggered excavation is short, the displacement of deep soil is small, the change of soil structure and the change of interaction force are small, which effectively weakens the influence of soil uplift on construction, facilitates the control of stratum uplift and is conducive to construction safety. The larger the excavation surface of the foundation pit, the higher the soil uplift, and the uplift height is inversely proportional to the distance from the monitoring point to the excavation surface; the vertical stress of the unloading support structure of the foundation pit excavation decreases, and the vertical stress of the support structure increases after the soil backfill.

Keywords: loess area; foundation pit; shallow tunnel; numerical simulation

1 Introduction

With the rapid development of urban underground track in China, more stringent requirements are put forward for construction. It is necessary to ensure the safety and quality of construction, and strictly control the surface subsidence induced by the construction process to avoid damage to adjacent buildings. The traditional open-cut method can no longer meet the current construction requirements. The pipe jacking method is a kind of subsurface excavation construction method for tunnels and underground pipe networks crossing buildings[1-3]. It only needs to excavate the starting well and the receiving well, and does not need to excavate the ground. The layout of the pipeline reduces the impact of construction on surrounding buildings and surrounding traffic. At present, the pipe jacking method is mainly used to build shallow

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tunnels under the high-pressure iron tower in China, which effectively reduces the surface settlement induced by construction[4-5].MENG GW[6] based on the mined tunnel of Nanchang Metro Line3, studied the construction deformation characteristics of shallow buried tunnel under ultra-close dense pipeline by means of numerical simulation and field test. JI HX[7] Optimized the rectangular pipe jacking construction scheme and pipe jacking machine, solved the ground subsidence outside the reinforcement area in front of the launching shaft and the damage of the water stop during the pipe joint docking, and ensured the smooth completion of the shallow buried large section rectangular pipe jacking project under the Beijing-Hangzhou Grand Canal. WANG ZJ[8] based on the Suzhou rectangular pipe jacking project, the 'displacement control method' is used to realize the numerical simulation of the whole process of rectangular pipe jacking excavation and analyze the law of surface deformation. REN JX[9] based on the interval tunnel of Xi 'an Metro Line5, the optimal construction method of shallow buried tunnel excavation in large section loess area is obtained by numerical simulation and field measurement.

At present, there are many studies on the construction of shallow buried tunnels in loess areas, but there are few studies on double-line foundation pits and shallow buried tunnels under existing buildings (structures). Therefore, based on the background of Xi 'an Tourism Avenue, this paper uses $FLAC^{3D}$ to simulate the construction of double-line foundation pit and shallow buried tunnel with different excavation steps, which induces the surrounding surface settlement and the change law of pipe jacking stress. Further, a better scheme for the construction of double-line foundation pits and shallow tunnels in loess areas is proposed, in order to find the best solution to effectively control surface subsidence, improve construction speed and save money in the feasible scheme.

2 Project overview

The east section of Xi 'an Tourism Avenue (Fig.1) is an east-west secondary trunk road in the international port area. The length of the road is 3.95 km, and the width of the red line of the road is 40m~50m. The supporting projects of the road project mainly include rainwater, sewage, water supply, transportation, power trench engineering, etc. The high-voltage tower is located in the center of the planned road. In order to reduce the impact of construction on the tower, the rainwater pipe is constructed by pipe jacking method, with a buried depth of 6.8m. The buried depth of power trench and sewage pipe is 4m and 5.8m, and the open trench excavation method is adopted, and the slope ratio is 1:1.5. Groundwater is located at 2.6m underground, and dewatering project must be carried out before construction.

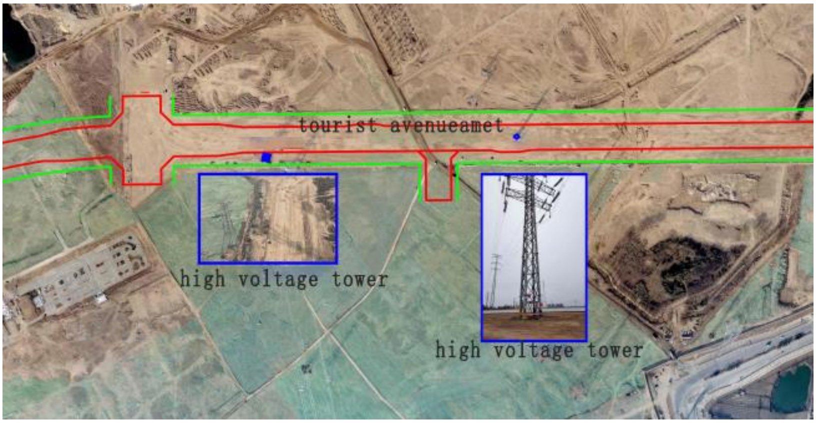


Fig. 1. Road planning map

3 Model establishment and parameter establishment

3.1 Model establishment

The surrounding settlement induced by the construction of double-line foundation pit and shallow tunnel is studied, and the whole road model is established around the excavation stage of foundation pit and shallow tunnel (Fig.2). FLAC^{3D} software is used to establish a three-dimensional numerical model. The horizontal displacement is limited on both sides of the model, the vertical displacement is limited at the bottom, and the upper surface is a free boundary. The model calculates that the overall span is 101m, the height is 30m, the longitudinal length of the foundation pit and the tunnel is 25m, and the maximum excavation span of the power pipe and the sewage pipe is 5m and 8.8m respectively, which are 20m and 30m away from the model boundary respectively, which meets the requirements of ignoring the boundary effect. The groundwater level is 2.6m. The initial pore pressure distribution is shown in Fig.3.

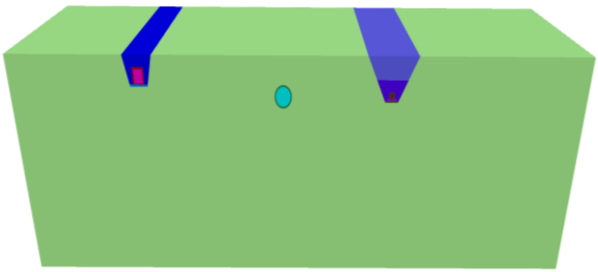


Fig. 2. Road overall model

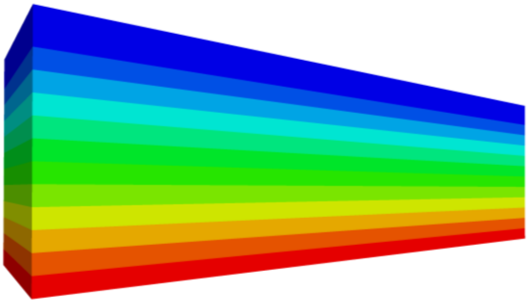


Fig. 3. Initial pore pressure distribution

3.2 Determination of simulation parameters

In this numerical simulation, it is assumed that each soil layer is uniform, using solid element, Mohr-coulomb simulation; the high-voltage tower is realized by applying a 25KPa load; considering the road surface pressure and surface live load, a vertical downward pressure of 30KPa is applied to the model surface. The supporting parameters and soil physical and mechanical parameters are shown in Table.1 and Table.2.

Table 1. Physical and mechanical parameters of soil

Name of soil layer	Lamination thickness/m	Natural density/(kg·m^{-3})	Cohesion/kPa	Angle/(°)	Poisson ratio
plain fill	4.8	1590	15	15.0	0.35
miscellaneous fill	5.1	1750	24	21.0	0.28
silty clay	4.5	1740	26	23.0	0.28
neo-loess	3.5	1590	20	22.5	0.29

Table 2. Mechanical parameters of supporting materials

material type	Poisson ratio	Gravity/(kg·m^{-3})	Elastic modulus/MPa
pipe-jacking	0.28	22.0	32500
Foundation pit support	0.2	23.0	36000
Power tube	0.2	23.0	31500

3.3 Selection of scheme

The excavation of shallow buried foundation pit is easy to induce the surrounding surface uplift. In order to reduce the damage to the high-pressure tower caused by the construction, the pipe jacking construction is carried out after the excavation of the double-line foundation pit. The excavation method of the foundation pit is as shown in table.3. After the back filling of the foundation pit, the pipe jacking method is carried out, and each excavation is 2.5m.

Table 3. Working conditions

	Excavation methods	Distance from the face of the palm/(m)	foundation pit backfill
Condition one	Staggered excavation	10	Backfill at the same time
Condition two	full-face excavation	25	

3.4 Monitoring point layout

In the simulation calculation, considering the three-dimensional boundary effect, the surface monitoring section selects the model station Y=15m as the research surface. The surface monitoring points are set along the X direction. One monitoring point is arranged at 1m, 3m and 6m outside the two boundaries of power pipe ditch, sewage pipe and rainwater pipe. From left to right, the monitoring points are 1~6, among which WS6 and YS1 are the same monitoring points. The monitoring section is shown in Fig.4.

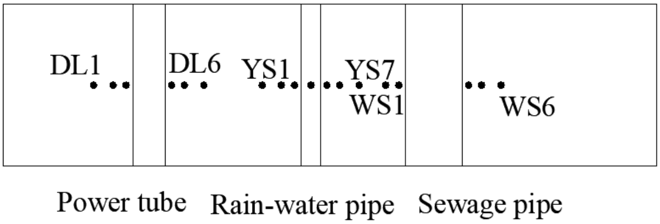


Fig. 4. Monitoring section

4 Numerical simulation

4.1 Precipitation analysis

The dewatering project must be carried out before the excavation of the foundation pit to ensure that the groundwater is located below the foundation pit project. The pore pressure distribution of the model after dewatering is shown in Fig.5. After dewatering, the groundwater is located under 2m of each construction, and the displacement cloud map (Fig.6) shows the overall uplift. The excavation of the foundation pit is unloaded, and the uplift of the bottom of the pit drives the uplift of the surrounding soil layer through the bearing structure.

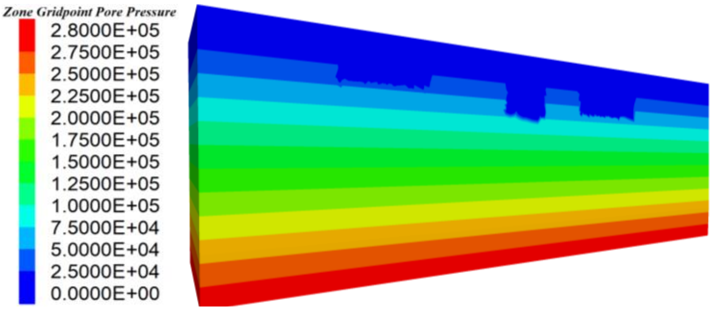


Fig. 5. Distribution of pore pressure after precipitation

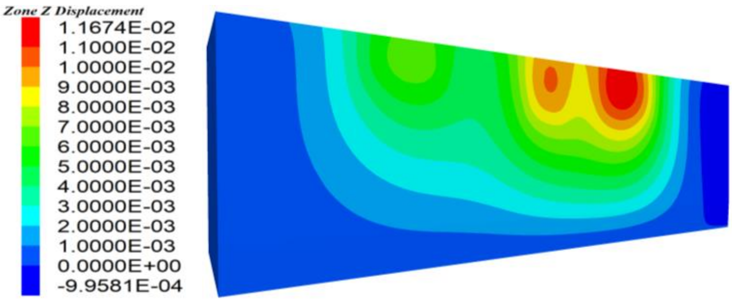


Fig. 6. Soil displacement cloud after precipitation

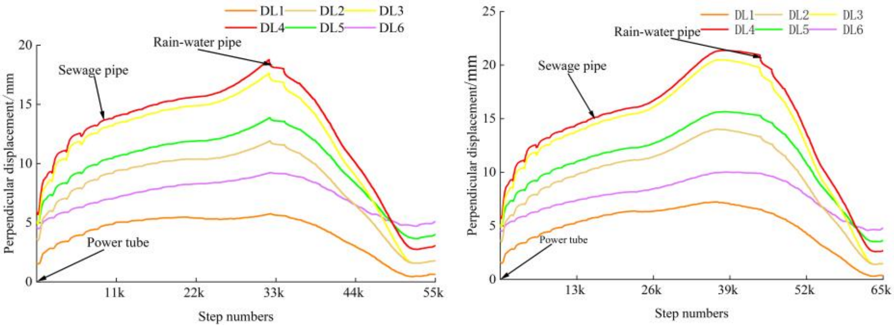
4.2 Displacement analysis

Figure 7 is the time-history curve of soil uplift induced by power pipe trench. The maximum uplift of each monitoring point of staggered excavation is 5.72mm, 11.89mm, 17.54mm, 18.76mm, 13.80mm, 9.24mm. The maximum uplift of each monitoring point of staggered excavation is 7.2mm, 10.01mm, 20.49mm, 21.33mm, 15.62mm, 9.96mm.

Figure 8 is the time-history curve of soil uplift induced by pipe jacking construction. The maximum uplift of staggered excavation monitoring points is 9.11mm, 10.31mm, 12.53mm, 14.64mm, 16.54mm, 18.68mm, 22.58mm, and the maximum uplift of staggered excavation monitoring points is 9.57mm, 10.59mm, 12.68mm, 14.67mm, 16.80mm, 19.58mm, 23.44mm.

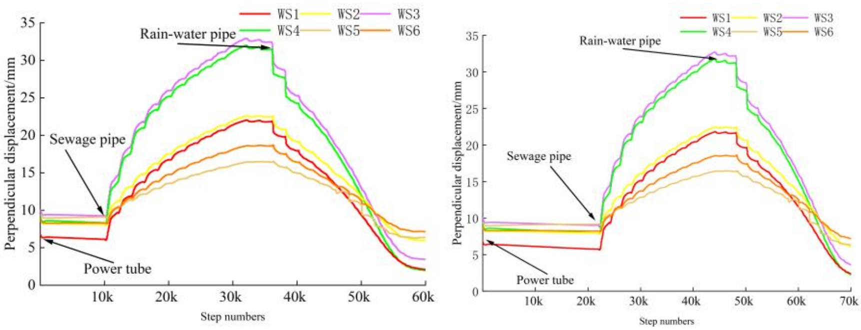
Fig.9 shows the time-history curve of soil uplift induced by sewage ditch. The maximum uplift of each monitoring point in staggered excavation is 21.58mm, 22.31mm, 32.73mm, 31.96mm, 18.60mm and 16.47mm. The maximum uplift of each monitoring point in staggered excavation is 21.88mm, 22.44mm, 33.50mm, 32.66mm, 18.22mm and 16.16mm. The soil displacement induced by staggered excavation is greater than the staggered distance. Because the construction unloading period of staggered excavation is shorter, the displacement of deep soil is smaller, the change of soil structure and interaction force is smaller, and the influence of soil uplift on construction is effectively weakened. It is convenient to control surface settlement and is conducive to construction safety. After the construction of the supporting structure of the power pipe trench and the sewage pipe trench, the soil is backfilled, which can reduce the unloading cycle of the foundation pit soil.

Fig.10 shows the displacement cloud diagram of deep soil after construction. The unloading at the bottom of the foundation pit induces soil uplift, and the excavation amount of the power pipe trench is small. The soil uplift induced by construction has little effect on the surface around the rainwater pipe and sewage. The amount of sewage pipe excavation is large, the amount of soil unloading is large, the soil layer uplift induced by excavation is large, the soil uplift around the rainwater pipe and sewage continues to increase, and the soil uplift on the left side of the power pipe trench and rainwater pipe is greater than that on the right side. The rainwater pipe is constructed by pipe jacking method, and the original stress balance of the soil is destroyed. After the stress redistribution, the soil settles.



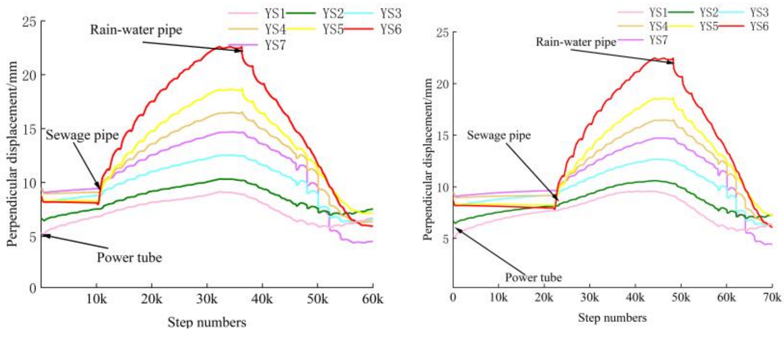
(a)25m (b)15m

Fig. 7. Time history curve of surface displacement of power trench



(a)25m (b)15m

Fig. 8. Time-history curve of surface displacement of sewage pipe



(a)25m (b)15m

Fig. 9. Time history curve of surface displacement of pipe jacking

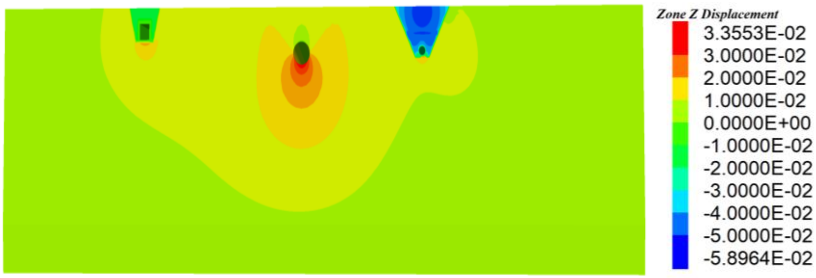
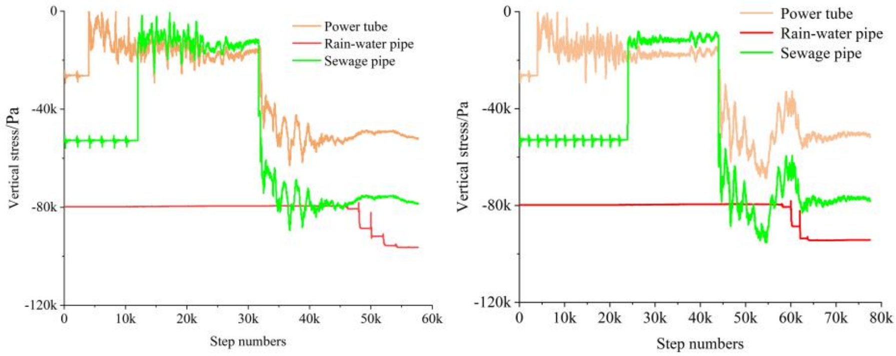


Fig. 10. Displacement cloud diagram

4.3 Stress analysis

Fig.11 is the time history curve of vertical stress of staggered and staggered construction pipeline. The vertical stress of power pipe and sewage pipe support structure decreases first and then increases, and tends to be stable after backfilling. The excavation and support of the rainwater pipe are carried out at the same time. The excavation destroys the original balance of the soil. Under the combined action of the supporting structure and the surrounding rock, the stress tends to be stable after redistribution. The buried depth of the sewage pipe is different, which leads to the vertical stress slightly larger than that of the power pipe, and the vertical stress of the rain water pipe is larger than that of the sewage pipe because the rain water pipe is located below the high voltage tower. The variation trend and amplitude of the vertical stress of the staggered and staggered excavation pipelines are basically the same. After the excavation of the foundation pit, the stress of the soil unloading monitoring point decreases. As the excavation continues, the soil stress is redistributed many times, resulting in the vertical stress of the pipeline floating up and down. The closer to the monitoring section, the greater the floating. After the foundation pit is backfilled, the stress of the monitoring point continues to increase and tends to be stable during the pipe jacking construction.



(a)25m (b)15m

Fig. 11. Stress time history curve

5 Conclusion

In this paper, the double-line foundation pit and the high-pressure tower under the shallow tunnel in the loess area are taken as an example. Based on FLAC^{3D}, the model is established to predict the surface settlement induced by the excavation of the double-line foundation pit and the shallow tunnel, guide the on-site construction of the station, and analyze the surface settlement law. The following conclusions are drawn:

(1) Double-line foundation pit excavation, soil unloading induced soil uplift, the wider the excavation surface, the greater the amount of uplift. Pipe jacking construction destroys the original stress balance of soil and induces surface settlement.

(2) The staggered excavation unloading period is short, the displacement of deep soil is small, the change of soil structure and interaction force is small, and the influence of soil uplift on construction is effectively weakened, which is convenient to control the surface settlement and is beneficial to the construction safety.

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