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Analysis of the Influence of New Tunnel Passing through Old Buildings on the Safety of Building Structure

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Abstract: With the advancement of urbanization, available land is becoming more and more scarce and difficult to develop. The underground engineering through the mountains has become an important choice in the process of urbanization construction. In the process of new tunnel construction in the city, there are more and more proximity projects. Especially in the core urban areas, there are more and more existing houses that will be involved, so how to protect the safety of existing housing structures has been paid more and more attention. Through the study of the influence of the old buildings near the new urban tunnel on the safety of the housing structure, the technical reference is provided for the design, construction, and operation of the new tunnel near the old buildings, to further ensure the safe construction and operation of the tunnel.

Keywords: New tunnel; Under pass; Old houses; Safety

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1. Introduction

Since the reform and opening up in 1978, China's rapid economic development has led to a rapid increase in the urbanization rate. In the stage of rapid urbanization development, the urbanization rate increased from 17.9% in 1978 to 26% in 1995. In the stage of rapid urbanization, the urbanization rate increased from 26% in 1995 to 63.9% in 2020. Currently, the urbanization rate is still in the stage of rapid development, and it is expected that the peak urbanization rate will reach about 80%.

Under the background of the red line protection of 1.8 billion mu of arable land, the available land in the process of urbanization is increasingly scarce and difficult to develop. The underground engineering through the mountains has become an important choice in the process of urbanization construction. By 2021, the number of highway tunnels in China has reached 23, 268 (with a total length of 246, 9892 m).

In the process of new tunnel construction in the city, there are more and more proximity projects. Especially in the core urban areas, there are more and more old houses in the area, so how to protect the safety of existing housing structures has been paid more and more attention.

This paper will study the impact of new urban tunnels near old houses on the safety of housing structures, and provide technical references for the design, construction, and operation of tunnels near old houses in new tunnels, to further ensure the safe construction and operation of tunnels [1].

2. Project overview

The proposed project is located in the downtown area and is an urban sub-thoroughfare connecting the two major communities. Its road grade is I class of urban secondary road; It was built according to a two-way four-lane design, and the standard width of the road is 16 m; The design load is highway II class; The design speed is 40 km/h.

According to the proposed scheme, it is proposed to adopt the double-arch tunnel type, as the tunnel section type is shown in **Figure 1**. The tunnel entrance is located on the R = 87.473 m arc, the tunnel body is located on the R = 77.5 m arc, and the exit entrance is located on the R = 300.0 m arc. The design longitudinal slope is 3.53%, the clearance width of the limit is 10.5 m, the clearance height of the motor road is 5.00 m, and the access road is 2.50 m. This section of the tunnel passes through the middle of the school. To ensure the safety of the related buildings, the impact of the new project on the structural safety of the housing section is evaluated.

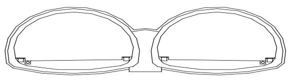

Figure 1. Schematic diagram of section form of double-arch tunnel

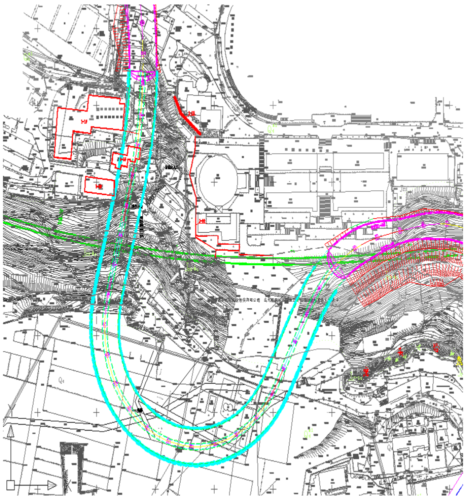

Figure 2. Schematic diagram of the relationship between the new tunnel and the plane position of the building

In this safety assessment, data are collected first, and on-site investigations are conducted on buildings affected by the construction of new tunnels. The deformation control indicators of buildings are determined according to relevant norms, and then according to the investigation results and relevant technical data, the new tunnel structure, underground depth, geological condition, relative position with adjacent buildings, structure and foundation form of adjacent buildings are analyzed, and the ground settlement and building deformation caused by the new tunnel construction are numerically simulated and predicted. Based on the analysis results, and by analogy with the practical experience of similar projects already built at home and abroad, the safety of the surrounding buildings is comprehensively evaluated, and the measures to be taken in the subsequent design and construction are proposed [2].

3. Engineering geological conditions

The site belongs to a structural denudation hilly landform. The K0+000~K0+600 section of the line maintains the original terrain. The left slope top of K0+000~K0+320 is a dangerous rock zone, and the dangerous rock zone is a steep cliff formed by sandstone. The length is about 170 m, the slope is generally 70°–85°, and the local area is nearly upright or introverted, the elevation is 302.80–323.33 m, and the height difference is about 20 m. K0+000~K0+600 section of the line travels on the original slope terrain, the slope angle of the slope is 20°–35°, and the slope foot has a school. The K0+600~ terminal section of the line is affected by human engineering activities, and the terrain is relatively flat with a ground elevation of 230–250 m.

The exposed strata in the survey area can be divided into a quaternary Holocene fill layer (Q4ml), residual slope deposit (Q4el+dl) silty clay layer, and Jurassic middle Shaximiao formation (J2s) sedimentary rock layer from top to bottom.

The site is located in the paraxial part of the west wing of the syncline, the rock strata are monoclinal output, the rock strata occurrence is 150°∠10°, no-fault passes through, and the geological structure is simple.

The field is a hilly landform of tectonic denudation with large relief. No surface water was seen in or near the site. The groundwater in the site is mainly fracture water and pore water in the bedrock, which is mainly replenished by atmospheric precipitation and domestic water. The plain-filled soil and sandstone are permeable layers. The mudstone is a relatively waterproof layer.

The slope top on the left side of section K0+000~K0+320 of the line is a dangerous rock belt, and the dangerous rock belt is a steep cliff formed by sandstone. According to the investigation and data collection, the dangerous rock belt has been treated, the dangerous rock unloading belt has been anchored by a point anchor bolt, and the rock cavity developed in the dangerous rock belt has been fully filled with rubble concrete wall support. It is sealed with cement mortar grouting.

According to Figure A1 of China ground motion peak acceleration zoning map (1/400) million GB18306-2001 and Figure B1 of China ground motion response spectrum characteristic period zoning map (1/4 million) GB18306-2001, the seismic fortification intensity of the proposed site is 6 degrees, and the designed basic peak acceleration of ground motion is 0.05 g.

4. Structural safety analysis

In the numerical model, analysis is carried out according to the following assumptions and principles.

The Drucker-Prager (D-P) criterion is adopted in the tunnel surrounding rock constitutive model; The tunnel lining structure is simulated with elastic isotropic materials [3].

The bolt element is used for simulation, and the advance support (pipe shed, small conduit, grouting, and so on) is simulated by improving the stiffness of isogenerational layers around the tunnel [4].

The house is simulated with linear elastic materials and solid units.

The parameter values of the double-arch tunnel are as follows: the supporting length of the pipe shed in the entrance section is 30 m, the initial supporting of the tunnel is combined support with anchoring and spraying (thickness is 15 cm), and the secondary lining is reinforced concrete structure (C30 reinforced concrete, thickness is 35 cm). The supporting calculation parameters are selected according to the specifications [5].

Summary of mechanical parameter values: The mechanical calculation parameters of the typical section can be obtained from the geological data and building materials of the tunnel site, and the specific parameters adopted are shown in **Table 1** [5].

Table 1. Summary of calculation parameters

Project	Severe (KN/M3)	Elasticity modulus (MP)	Poisson's ratio	Cohesive force (KPa)	Frictional angle φ
Powdery clay	20	50	0.45	10	10
Backfill	20	50	0.45	—	25
Sandy mudstone	25.9	1935.14	0.29	598.5	31.2
Sandstone	24.3	8136.92	0.18	2014.95	35.35
C25 shotcrete	22	23000	0.2	—	—
C30 concrete	25	31000	0.2	—	—
House	310	1000	0.2	—	—
Overhead support	20.5	$2.03x10^3$	0.2	15	20

The large finite element analysis software of tunnel and rock was used for simulation and analysis.

Geometric model: The geometric model of numerical analysis is established according to the spatial position relationship between the above buildings and the tunnel. The simulation range is that the top of the tunnel is taken to the surface, the left side of the tunnel is 65 m outward from the excavation line, the right side is 45 m outward from the excavation line, and the lower side is 3 times the excavation height, about 50 m. The length of the tunnel ranges from K0+680 to K0+780. The model view is shown in **Figure 3** [6].

Boundary conditions: horizontal displacement constraints are applied to the left and right edges of the model, vertical displacement constraints are applied to the bottom, and the top surface is free.

Construction phase division: excavation is carried out according to tunnel design scheme and simulated tunnel construction sequence. The excavation sequence is 14 steps (including initial ground stress), and the safety evaluation and analysis model of the surrounding rock of the S5c lining section can be established.

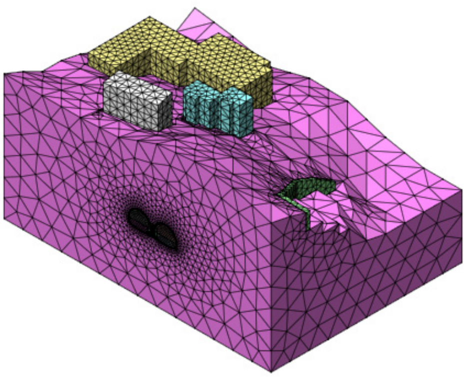

Figure 3. Numerical calculation model diagram

According to the construction of the middle guide tunnel and the left and right holes, the vertical deformation of the tunnel, buildings, and retaining walls in each construction step according to the above model analysis is shown in **Figure 4**. It can be seen from the figure that the settlement of rock and soil mass caused by tunnel excavation is mainly concentrated in the small horizontal range from the tunnel body and above the surface. The maximum settlement of rock and soil mass caused by tunnel excavation is 8.2 mm and 8.7 mm, respectively, at the vault position. The ground settlement gradually decreases along the vertical direction, and the maximum surface settlement value is 6.6 mm, which occurs directly above the tunnel palm face of section K0+690.

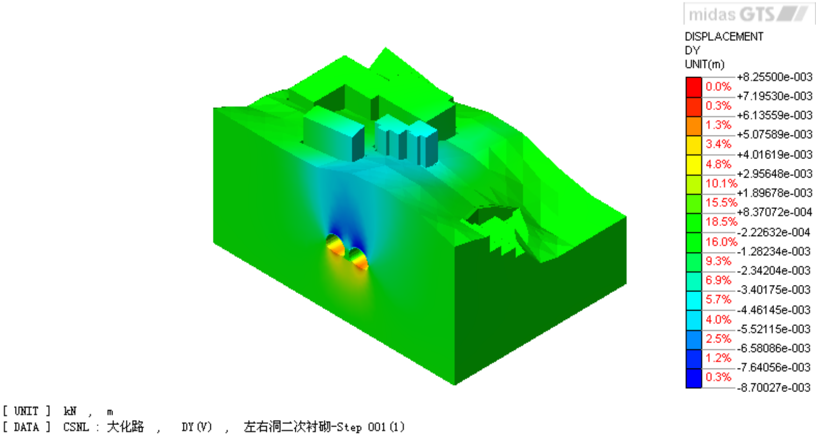

Figure 4. Vertical displacement diagram of rock and soil mass and structure

According to the calculation results, the cumulative settlement curves of each construction step of the three houses in the tunnel construction process can be drawn, as shown in **Figure 5**. As can be seen from the figure, the maximum settlement of 1-1#, 1-2#, and 1-3# houses is 2.0 mm, 3.9 mm, and 3.9 mm respectively. The construction steps that caused the largest settlement of the house were concentrated in steps 5–7 and 9–11, corresponding to the excavation and initial support of the upper step of the left hole and the excavation and initial support of the upper step of the right hole respectively. From the above calculation, it can be seen that when the tunnel core soil is excavated, the arch roof settlement is the largest, which is the most dangerous construction step. According to the above calculation results, the characteristic displacement size and safety evaluation of the tunnel are shown in **Table 2** [7].

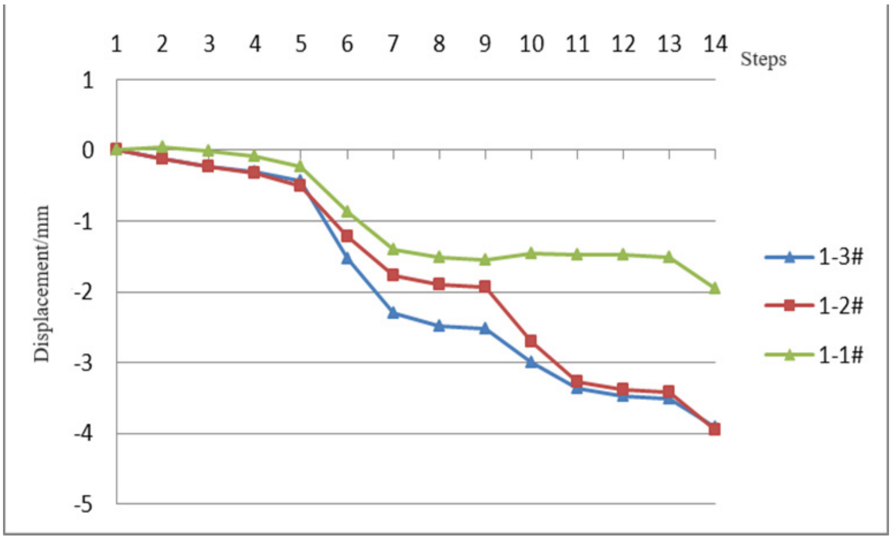

Figure 5. Cumulative vertical displacement diagram of building base during tunnel construction

The final force diagram of rock mass caused by tunnel construction obtained by model analysis is shown in **Figure 6**. It can be seen that the maximum compressive stress of rock mass caused by tunnel construction is 2774 KPa, which is less than the recommended value of the corresponding design parameters in the geological survey report. The maximum compressive stress at the bottom of the slope retaining wall caused by tunnel construction is only 42.6 KPa.

The final diagram of the lining structure caused by tunnel construction is shown in **Figure 7** and **Figure 8**. The maximum tensile stress and compressive stress of the left tunnel lining are 83.6 KPa and 217 KPa respectively. The maximum tensile stress of the right tunnel lining is 90 KPa and the maximum compressive stress is 289 KPa.

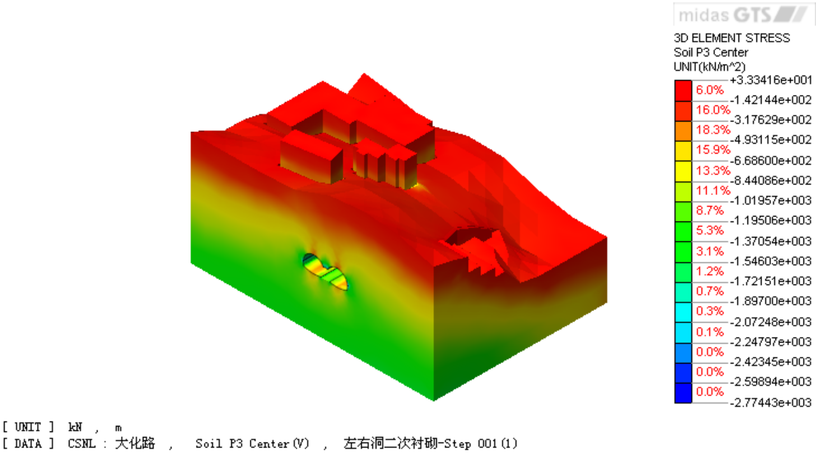

Figure 6. Final stress diagram of rock and soil mass caused by tunnel construction

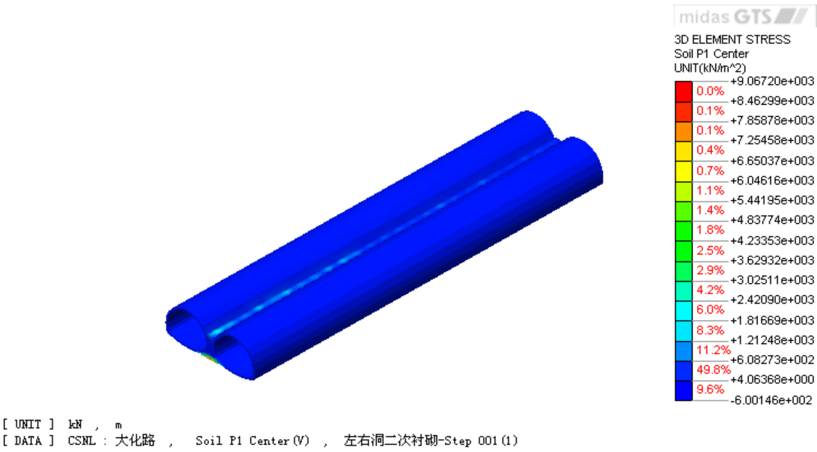

Figure 7. Maximum principal stress diagram of tunnel secondary lining

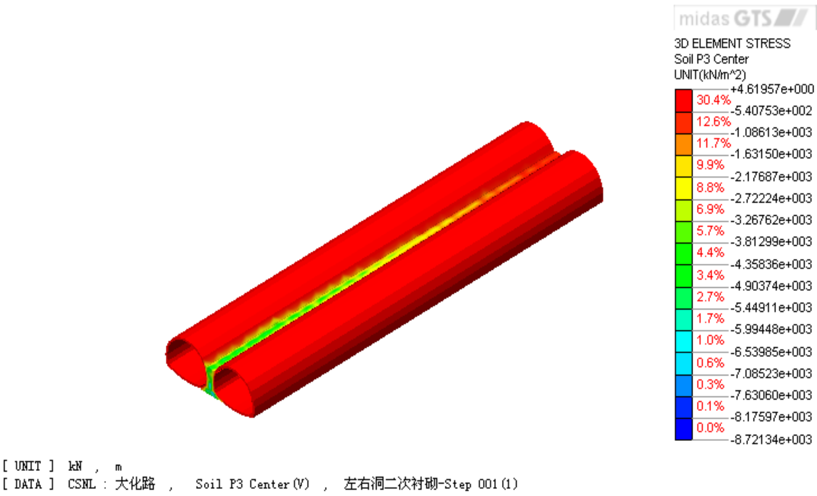

Figure 8. Minimum principal stress diagram of tunnel secondary lining

For existing buildings, the settlement has already occurred under the action of structural dead weight and live load. After many searches, the entrusting party and the building users failed to provide the observation data of the foundation settlement of the building. Considering the control experience of similar projects in the region and the importance of buildings traversed by the project, the deformation safety control standards for existing buildings of the project are finally determined, as shown in **Table 2** [8].

Table 2. Actual deformation limits of building foundation

No.	Type of structure	Building foundation deformation limit value
1	Masonry load-bearing structures	Local inclination of foundation ≤ 0.001
2	Multi-story and high-rise buildings	When H ≤ 24 m, overall tilt ≤ 0.002;
3		When 24 < H ≤ 60 m, overall tilt ≤ 0.0015
4		60 < H ≤ 100 m, overall tilt ≤ 0.00125
5		When100 < H, the overall tilt is 0.001
6	Foundation settlement for all types of buildings	≤ 8 mm

Based on the above calculation results, the maximum settlement value and overall inclination value of each house are obtained, as shown in **Table 3**. It can be seen that the maximum settlement and overall inclination value of each house are less than the safety limit value of foundation deformation, indicating that the impact of tunnel construction on each house structure is within the allowable range, and the structure is safe under normal conditions of use. However, it is suggested to strengthen the relevant monitoring of the structure during construction, especially in the steps causing large settlement, including the excavation of the upper steps of the left and right caves, the initial support stage, and the secondary lining application stage, and adjust the construction progress and support measures in time according to the needs.

Table 3. House deformation evaluation table

Building number	Maximum tilt	Accumulated settlement	Maximum settlement excavation step	Evaluation conclusion
1-1#	0.04	-2.0 mm	Excavation of the upper step of the left hole	Satisfy the requirements
1-2#	0.20	-3.9 mm	Excavation of the upper step of the left and right holes	Satisfy the requirements
1-3#	0.16	-3.9 mm	Excavation of the upper step of the left and right holes	Satisfy the requirements

According to the relevant data, the proposed tunnel is close to the ground building (about 7.2–8.6 m) in the interval of K0+706.3~K0+770.9. At the same time, considering the construction period of the surrounding buildings, the current structural condition, and the importance of the buildings, combined with the control experience of similar projects in the Chongqing area, it is suggested that the safe allowable particle vibration speed should not exceed 1.0 cm/s. It is suggested that a special blasting scheme should be designed before construction, and the monitoring and measurement of tunnels and buildings should be strengthened during construction. Based on the monitoring and analysis results, the blasting vibration control benchmark, excavation method, initiation mode, and blasting parameters should be reasonably adjusted and optimized to ensure the safety of existing buildings.

5. Conclusion

According to the numerical analysis results, the following conclusions can be drawn according to the actual situation of the project.

To minimize the influence of the construction process on the surrounding buildings, the excavation advance should be controlled, the blasting vibration control standards should be strictly implemented during the blasting construction process, the initial support or advance support should be strengthened, and the secondary lining should be applied.

The construction plan and construction process should be optimized before construction; During the construction process, the deformation observation of the structure and the surface building should be strengthened in the construction steps that cause large surface settlement (such as the excavation of the upper steps of the left and right caves, the initial support stage and the secondary lining application stage, and so on). The tunnel construction process shall be monitored and measured, and the abnormal situation shall be found and timely fed back information to the investigation and design units, and the supporting measures and construction parameters shall be adjusted according to the monitoring situation to ensure the safety and reliability of construction.

A special blasting scheme should be designed before construction, and the monitoring and measurement of tunnels and buildings should be strengthened during construction. Based on the monitoring and analysis results, the blasting vibration control benchmark, excavation method, initiation mode, and blasting parameters should be reasonably adjusted and optimized to ensure the safety of existing buildings.

In the design and construction process, the stability of the rock mass and slope at the entrance and exit of the tunnel should be fully considered, and relevant preventive and reinforcement measures should be taken to strengthen the monitoring during the construction process to ensure safe and reliable construction.

If the groundwater is large, the construction difficulty and risk will be further increased, and the stability and water stop of the rock and soil should be taken as the focus, monitoring efforts should be increased, and the quality of grouting should be ensured, and measures such as geological prediction should be taken to implement dynamic design and information construction.

Disclosure statement

The authors declare no conflict of interest.

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