# Three-Dimensional Simulation Analysis of the Safety Impact of High-Rise Building Adjacent to Rail Tunnel Construction

Xiangyu Cui

Chongqing Xingjin Architectural Planning and Design Co., Ltd. , Chongqing China

717692502@qq.com

**Abstract.** With the rapid development of tunnel cities, building density continues to increase, and land resources are becoming increasingly scarce. Pursuing coordinated above-ground and underground construction has gradually become a major trend in urban development. As a result, the issue of proximity between buildings and underground transportation has become prominent. Conducting research on the safety impact of high-rise buildings adjacent to rail tunnel construction is of significant engineering value for ensuring the safe coordinated construction of urban infrastructure. This paper takes a high-rise building adjacent to a rail tunnel in Chongqing as a case study. Using MIDAS/GTS finite element software, it calculates and analyzes the impact of building foundation pit excavation, structural construction, and adjacent usage on the construction safety of the planned Line 7 interval tunnel, as well as the subsequent impact of tunnel construction on the safety of the existing building. Targeted safety control standards are proposed.

**Keywords:** high-rise building; rail tunnel; side adjacency; three-dimensional simulation; safety impact

## 1 Introduction

With the rapid advancement of urbanization in China, the demand for intensive urban space utilization has become increasingly urgent. The coordinated construction of high-rise buildings and rail transit has become a typical feature of development in megacities. According to statistics from the Ministry of Housing and Urban-Rural Development, in 2023, the number of newly constructed high-rise buildings in China exceeded 12,000, and the operational mileage of rail transit surpassed 10,000 kilometers, with 30% of new rail lines needing to pass through densely populated high-rise building areas or form side adjacency relationships. While this spatial coupling improves land use efficiency, it also introduces significant safety risks. On one hand, ground disturbances caused by tunnel construction may lead to excessive settlement of adjacent high-rise building foundations[1]. On the other hand, deep foundation pit excavation and pile loads from high-rise buildings may exacerbate deformation accumulation in existing tunnel structures. This interaction effect is particularly complex[2,3] under complex


G. Zhao et al. (eds.), *Proceedings of the 2025 8th International Conference on Traffic Transportation and Civil Architecture (ICTTCA 2025)*, Atlantis Highlights in Engineering 39,
https://doi.org/10.2991/978-94-6463-793-9_61

geological conditions such as soft soil and water-rich strata. Traditional two-dimensional analysis methods can no longer meet the needs of refined safety assessments. Therefore, conducting three-dimensional simulation research on the safety impact of high-rise buildings adjacent to rail tunnel construction is of great engineering value for ensuring the safe coordinated construction of urban infrastructure.

Domestic and international research has also been conducted on related issues. In terms of theoretical research on tunnel-building interactions, scholars have achieved a series of results. Internationally, Peck's empirical formula for ground settlement laid the theoretical foundation for predicting surface deformation caused by tunnel excavation[4~6]. Loganathan and Polous further established an analytical solution for three-dimensional soil displacement induced by shield construction, providing an early theoretical framework for analyzing the impact on adjacent buildings[7] In recent years, numerical simulation technology has advanced rapidly. Mroueh and Shahrour used the finite element method to systematically study the influence of tunnel-building spacing[8] and foundation types on interactions[9], revealing the nonlinear relationship between pile load transfer and tunnel convergence deformation[10]. Domestic research started later but has progressed rapidly. Academician Wang Mengshu's team validated the superposition effect of additional loads from building groups above subway tunnels through model experiments[11,12]. Zhang Dingli and others, based on engineering cases in Shanghai's soft soil, proposed a dynamic prediction method for tunnel deformation considering spatiotemporal effects[13]. In terms of construction safety simulation analysis, current research follows two technical approaches: one is based on continuum mechanics (e.g., finite element/finite difference methods such as ANSYS and FLAC3D), which excels in simulating complex geological conditions and structure-soil coupling interactions. Xiong Guikai and others successfully predicted the impact of foundation pit excavation for a super high-rise building in Shenzhen on adjacent subway tunnels using a three-dimensional elastoplastic model[14]. The other approach involves discrete element and discontinuous deformation analysis (e.g., PFC and 3DEC), which is more advantageous in simulating large deformations in rock and soil masses and structural interface behavior. Su Zhiyin and others used a coupled discrete element-finite element method to reveal the stress redistribution mechanism in pile-tunnel interactions[15,16].

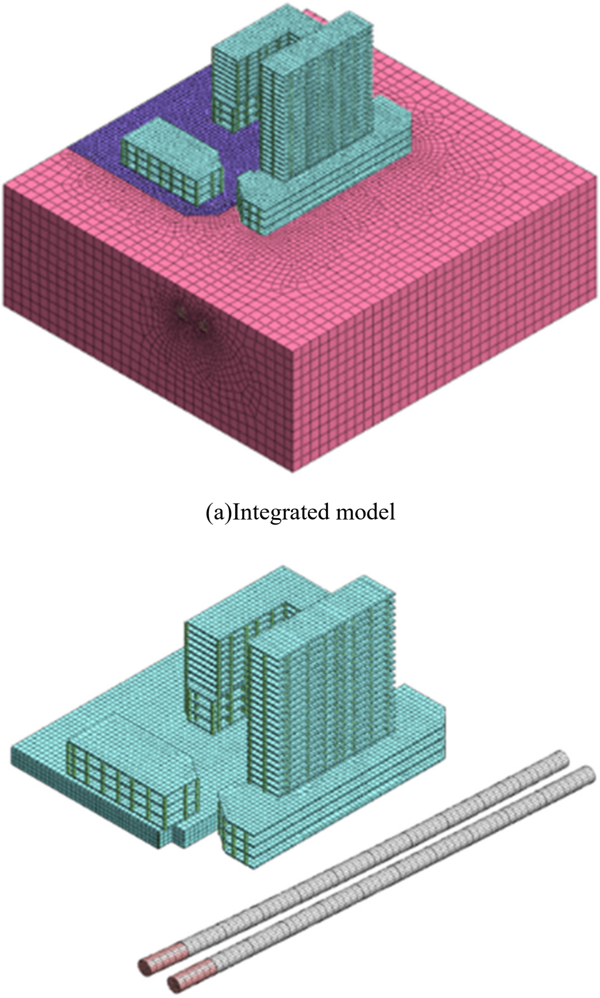
Current research indicates that due to increasingly complex engineering geology and building structures, traditional theoretical formulas often deviate significantly from actual projects. The refinement level of numerical analysis models is relatively low, with building models often simplified through load modeling. Most studies focus on interactions under static loads, with insufficient consideration of the temporal effects of dynamic construction processes such as tunnel excavation and layered foundation pit excavation, making it difficult to accurately capture deformation accumulation processes. To address these shortcomings, this paper, based on a planned project in Chongqing, conducts a refined three-dimensional analysis using MIDAS to evaluate surrounding rock stability and structural safety under different construction methods and stages, and proposes safety control standards.

## 2 Project Overview

A building project in Chongqing (primarily commercial and office buildings, totaling five structures) includes one commercial hotel (building height of 79.5 meters, with a 3-story commercial podium and 21-story hotel above ground, and 2 underground levels) located close to the planned rail transit line within the rail protection zone. The minimum horizontal distance between the building's edge and the interval tunnel is 2.31 meters, while the minimum horizontal distance between the pile foundation and the interval tunnel structure is 9.06 meters. The minimum vertical distance between the bottom of the building's pile foundation and the interval tunnel rail surface is 8.296 meters. After the project's completion, it may affect the subsequent implementation and operational difficulty of the planned Line 7 interval tunnel structure. Within the rail protection zone, the project employs pile foundations, independent foundations, and strip foundations. The rail protection zone features a double-track single-line tunnel constructed using the tunneling machine method, with a tunnel excavation diameter of 6.6 meters and a segment thickness of 0.35 meters. The overlying soil and rock thickness ranges from 9 to 12 meters, classifying it as a shallow tunnel. The surrounding geology of the tunnel consists of fill soil (0–2.6 meters thick), highly weathered rock (1–3.6 meters thick), and moderately weathered mudstone (4.5–9.0 meters thick), with a surrounding rock grade of V.

## 3 Model Establishment and Parameter Selection

The calculation was performed using MIDAS GTS NX finite element analysis software. In the model, rock and soil masses were modeled using solid elements, building structures were modeled with beam and plate elements, tunnel initial support was modeled with shell elements, and secondary lining was modeled with solid elements. The Mohr-Coulomb elastoplastic material model was used for rock and soil masses and rock layers, while elastic models were used for building and tunnel structures. To ensure sufficient computational accuracy while minimizing workload, the calculation scope was limited: 200 meters along the tunnel axis, 200 meters perpendicular to the tunnel axis, and 70 meters downward from the surface. The minimum clearance between the final calculation boundary and the structure was 40 meters, meeting the requirements for simulation boundary conditions. Horizontal displacements were constrained at the left, right, front, and rear boundaries, while the top boundary was left free. The planar position relationship and the established finite element model are shown below. Mechanical parameters for rock and soil masses and concrete structures were determined based on geological survey data, the "Code for Design of Concrete Structures," and the "Code for Design of Highway Tunnels." The specific three-dimensional simulation analysis model is shown in Figure 1.



(a)Integrated model

(b)Building-tunnel positional configuration

**Fig. 1.** Three-dimensional simulation analysis model

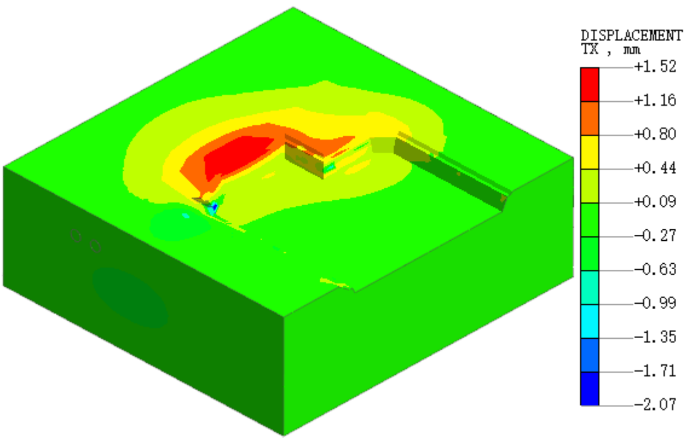
## 4 Analysis of Surrounding Rock and Structural Stability

**(1) Analysis of Building Construction Stage**

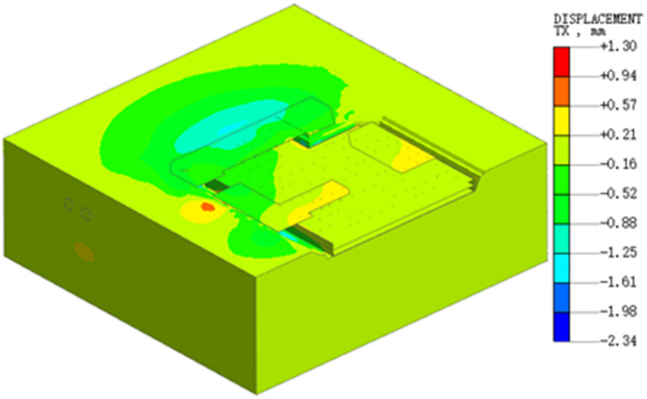
The building construction process was divided into four steps: foundation pit excavation, lower structure construction and backfilling, podium construction, and upper structure construction. The foundation pit was excavated in three layers. Displacement cloud diagrams of the surrounding rock perpendicular to the tunnel axis and vertical displacement during different construction stages were extracted for analysis (Figures 2–5). Figure 2 shows that as the depth of foundation pit excavation increased, the displacement of the surrounding rock perpendicular to the tunnel axis increased, with a maximum of +1.51 mm/-2.07 mm. During the backfilling process of the building structure, the displacement perpendicular to the tunnel axis decreased and then increased as the upper structure was constructed. After project completion, the displacement was +1.30 mm/-2.34 mm. Figure 3 shows that the displacement at the tunnel location was minimal, with a maximum of +0.03 mm/-0.50 mm, meeting the control standard of <10 mm. Figure 4 indicates that during construction, the vertical displacement of the surrounding rock increased with excavation depth, primarily showing uplift deformation, with a maximum of +8.57 mm/-0.14 mm. After backfilling and upper structure construction, the vertical displacement was +3.83 mm/-5.22 mm. Figure 5 shows that the vertical displacement at the tunnel location was minimal, with a maximum of +1.80 mm/-0.10 mm, meeting the control standard. Figure 4 shows the distribution of plastic zones around the tunnel during different construction stages. No plastic failure zones appeared within 5 meters of the tunnel during building construction, indicating no significant increase in construction difficulty or safety risks.

The three-dimensional simulation analysis results of the building construction stage show that under the most unfavorable conditions, surrounding rock deformation increases with excavation depth. The maximum displacement perpendicular to the tunnel axis was -2.07 mm, and the maximum vertical displacement was +8.57 mm. At the tunnel location, the maximum displacement perpendicular to the tunnel axis was -0.85 mm, and the maximum vertical displacement was +2.26 mm, both below the 10 mm control standard. After backfilling and upper structure construction, the maximum displacement perpendicular to the tunnel axis was +2.34 mm, and the maximum vertical displacement was -10.33 mm. At the tunnel location, the values were +1.14 mm and -4.68 mm, respectively, still meeting the control standard.

At the same time, as shown in Figure 6, during the building construction stage, the displacement of the surrounding rock near the tunnel was minimal, with no plastic failure zones, indicating no significant increase in tunnel construction difficulty or safety hazards.

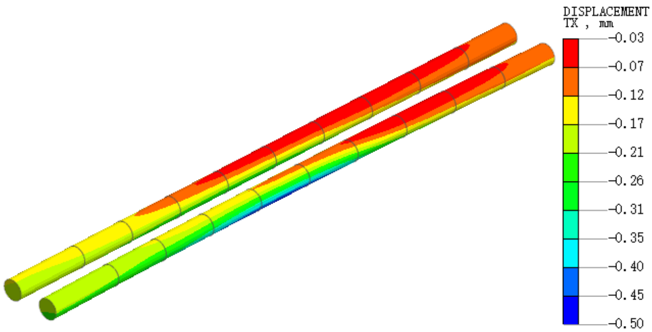



(a)Completion of foundation pit excavation

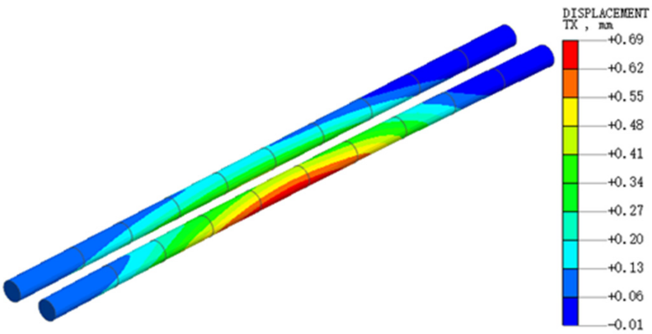



(b)Completion of superstructure construction

**Fig. 2.** Contour map of displacement in surrounding rock perpendicular to the tunnel alignment adjacent to the building

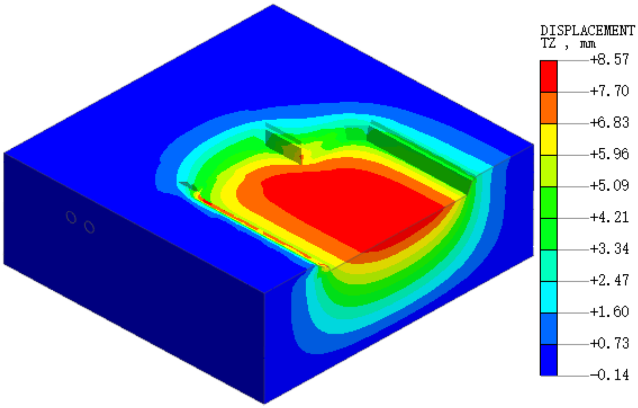



(a)Completion of foundation pit excavation

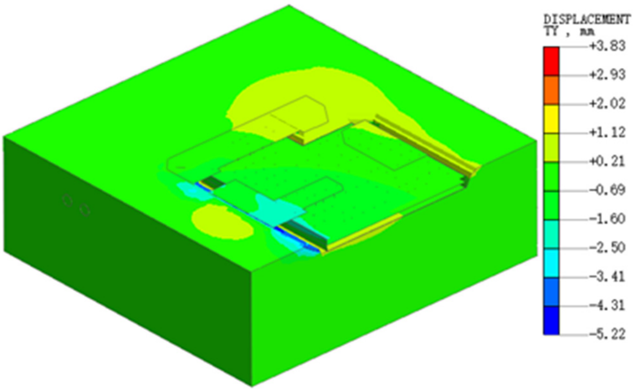



(b)Completion of superstructure construction

**Fig. 3.** Contour map of displacement in surrounding rock perpendicular to the tunnel alignment at the rail tunnel

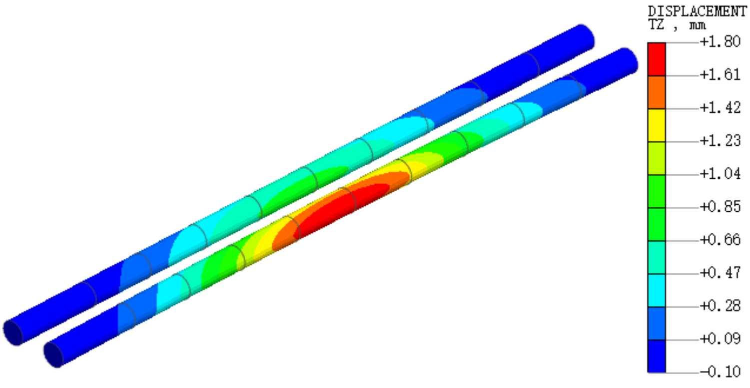



(a)Completion of foundation pit excavation

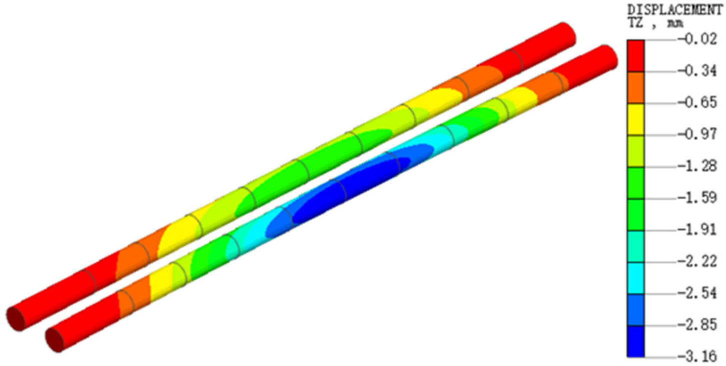



(b)Completion of superstructure construction

**Fig. 4.** Contour map of vertical displacement in surrounding rock adjacent to the building




(a)Completion of foundation pit excavation




(b)Completion of superstructure construction

**Fig. 5.** Vertical displacement contour map of surrounding rock at the track tunnel

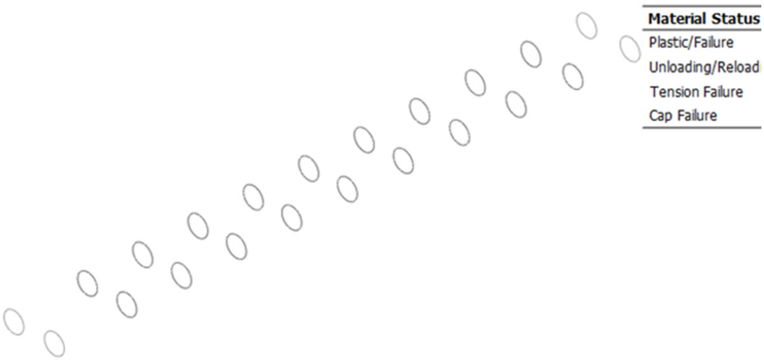
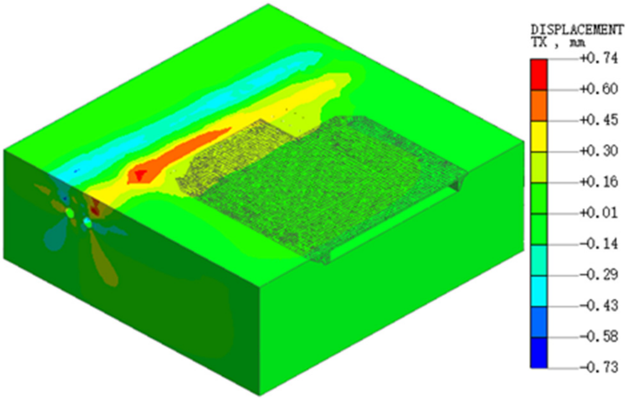


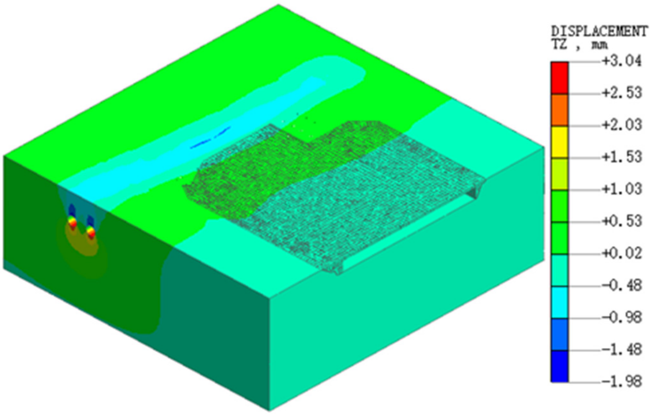

**Fig. 6.** Distribution of Plastic Zones in Surrounding Rock at Tunnel Location

**(2) Analysis of Tunnel Construction Stage**

The tunnel was constructed using the drill-and-blast method, with a cyclic excavation advance of 3 meters, an invert step distance of 45 meters, and a secondary lining step distance of 70 meters. For simplification, both tunnels were excavated simultaneously. Displacement cloud diagrams of the surrounding rock near the building during tunnel construction were extracted (Figures 7–8). Figure 7(a) shows that during tunnel excavation and support, the displacement of the surrounding rock perpendicular to the tunnel axis increased, reaching a maximum of +0.74 mm/-0.73 mm after completion. Figure 7(b) shows that the vertical displacement reached a maximum of +3.04 mm/-1.98 mm after secondary lining construction. Figure 8(a) indicates that the horizontal displacement increment of the building structure during tunnel construction was minimal, with a maximum of +1.01 mm/-0.02 mm, meeting the control standards for overall tilt (<0.0025) and foundation tilt (<0.005). Figure 8(b) shows that the vertical displacement increment was also minimal, with a maximum of +0.27 mm/-0.38 mm, meeting the settlement control standard of <20 mm.

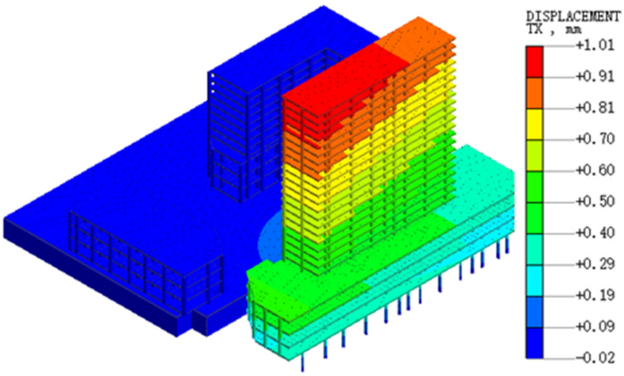



(a)Perpendicular to the tunnel alignment

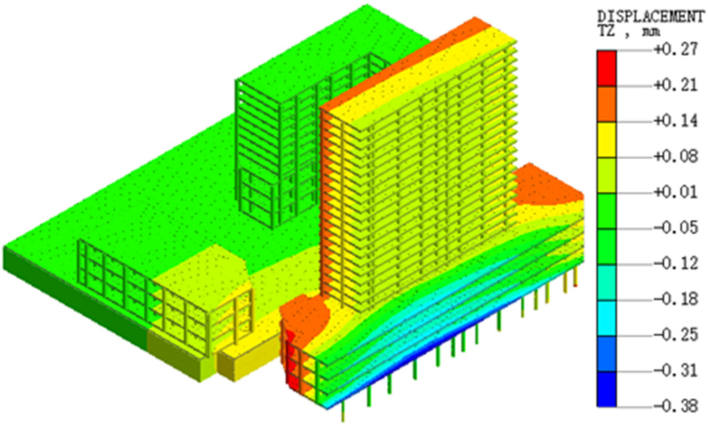



(b)Vertical

**Fig. 7.** Contour map of surrounding rock displacement




(a)Perpendicular to the tunnel alignment




(b)Vertical

**Fig. 8.** Contour map of building structural displacement

The three-dimensional simulation analysis results of the tunnel construction stage show that under the most unfavorable conditions, structural displacement is primarily influenced by geological conditions and tunnel excavation. Since the building's foundation is embedded in rock outside the 45° influence line of tunnel excavation and the tunnel is located in moderately weathered rock, the settlement and tilt of the building's upper structure and foundation were minimal after tunnel completion. The maximum displacement perpendicular to the tunnel axis was -1.47 mm, the maximum uplift was +3.04 mm, and the maximum settlement was -1.98 mm. The building's maximum horizontal displacement increment was +1.01 mm/-0.02 mm, and the maximum vertical displacement increment was +0.27 mm/-0.38 mm, both meeting control standards.

# 5 Discussion

**(1) Construction Sequence Impact Characteristics**

The construction sequence between the building structure and the proposed Metro Line 7 is as follows: excavation of the proposed project's foundation pit → construction of the proposed project's foundation → construction of the proposed project's garage → erection of the proposed project's tower → metro construction. There is a possibility of concurrent implementation between the tower construction and metro works. Both the building foundation and garage will precede the construction of the section tunnels for Metro Line 7. Barring unforeseen circumstances, the tower construction will precede the Metro Line 7 construction. In exceptional cases, the tower construction and the section tunnels of Metro Line 7 may proceed simultaneously. During concurrent construction, synchronized deformation adjustments can be implemented, and since the structures are not yet operational, personnel safety risks are minimal.

The computational analysis prioritizes the most adverse scenario. If safety risks remain controllable under such conditions, the overall project risks will also fall within acceptable limits. However, if the adverse scenario presents significant safety risks, targeted reassessment must be conducted during relevant construction phases based on actual conditions to ensure mitigation measures are technically and operationally viable.

**(2) Safety Impacts from Building Structure Construction**

The building structure is situated laterally above the proposed Metro Line 7. During the excavation of the building's foundation pit, unloading of surrounding rock induces ground heave deformation in the underlying strata. However, since the excavation depth is relatively shallow (maximum ≈9m) and the minimum horizontal distance between the foundation pit and the metro structure is substantial (≈14m), with the metro tunnel located outside the 45° strong influence zone of structural displacement, the impact of pit excavation on metro tunnel construction can be qualitatively assessed as negligible to moderate.

During the construction of the building's superstructure, increasing structural height amplifies the total vertical load and foundation pressure, exerting additional stress on the underlying soil. This stress may cause damage or failure of the underlying structures, thereby compromising the construction conditions of the metro infrastructure. Based on the relative positional relationship, the metro tunnel lies outside the 45° load diffusion angle of the building's pile foundation. Qualitative analysis indicates that the metro structure is minimally affected by the pile foundation's load transmission.

**(3) Safety Impacts from Tunnel Construction**

The construction of Metro Line 7 section tunnels employs the shield tunneling method, where excavation, support, and grouting are completed synchronously. Compared to traditional mining methods, shield tunneling eliminates blasting-induced vibrations, thereby better preserving the integrity of the surrounding rock and avoiding dynamic failure. Generally, tunnel excavation impacts are governed by rock mass conditions and excavation diameter.

In this project, the tunnel structure is situated within moderately weathered bedrock devoid of unfavorable structural planes. The tunnel's circular cross-section (excavation diameter: 6.6m) ensures balanced stress distribution, minimizing the loosened zone and facilitating natural arch formation in the surrounding rock. Additionally, the building foundation lies outside the 2× tunnel diameter influence range of the tunnel, resulting in limited interaction.

In summary, during the construction of the building structure, the likelihood of rock mass damage near the proposed metro alignment is extremely low. This will neither significantly increase construction complexity nor elevate safety risks for metro construction. During tunnel construction, the building structure remains outside the arch formation zone, ensuring minimal impact on building safety. However, since load redistribution, transfer mechanisms, and stress distribution are influenced by project-specific engineering characteristics, quantitative computational validation remains necessary in subsequent phases to confirm these qualitative findings.

## 6 Conclusions

This paper takes a high-rise building adjacent to a rail tunnel in Chongqing as a case study. Using MIDAS/GTS finite element software, it calculates and analyzes the impact of building foundation pit excavation, structural construction, and adjacent usage on the construction safety of the planned Line 7 interval tunnel, as well as the subsequent impact of tunnel construction on the safety of the existing building. Safety control standards are proposed.

(1) If the building project is constructed before Line 7, the building construction will alter the stress state of the surrounding rock, affecting the difficulty of tunnel construction. When the displacement of the surrounding rock near the tunnel is <10 mm, no plastic failure occurs.

(2) During subsequent tunnel construction, if the existing building structure is damaged, it may trigger a chain reaction, affecting tunnel construction safety or increasing protection costs. Therefore, the displacement control standards for the building during tunnel construction are: foundation settlement <20 mm, overall building tilt <0.0025, and foundation tilt <0.005.

(3) The analysis shows that the impact of the planned high-rise building on the safety of the planned Line 7 interval tunnel is controllable. Relevant measures should be taken during construction to ensure the safety of the tunnel structure and operation.

## References

1. PAULSON B C MSCEM.Under ground transit station construction in japan[J].American Society of civil Engineering, Journal of the Construction Division, 1982, 108(1): 23-37
2. Ran Dong'ao. Research on the Construction Mechanical Effects of Tunnel Anchors and Adjacent Shallow-Buried Branch Tunnels in Densely Built Areas [D]. Chongqing University, 2023.
3. Geng Cheng. Safety Control Technology of Subway Tunnels Crossing under the Adjacent Buildings [J]. Urban Mass Transit,2016,19(09):115-119.
4. Geng Yi, Fang Pengshuai, Jing Zhe, et al. Study on Surface Settlement Characteristics of Super-Large Diameter Pipe Jacking in Soft Soil Based on Modified Peck Formula [J]. Journal of Hunan City University (Natural Science Edition), 2023, 32(05): 7–14.
5. Lan Biguan, Huang Mingfeng, Yang Hao, Liu Bin, Zhou Shijun. Prediction of Surface Settlement of Underground Tunnel Based on Modified Peck Formula [J]. Guangzhou Architecture,2025,53(02):1-6.
6. Zhang Jinshan, Xu Shiguang, Liu Jinyu, Qin Yujie. Numerical simulation and prediction of land subsidence based on Peck modified formula [J]. Industrial Safety and Environmental Protection,2024,50(01):18-23.
7. Jin Zhiwei. Analysis of the Impact of Small-Angle Close-Range Crossing of Existing Tunnels by Double-Line Shield Tunnels [J]. Low Temperature Architecture Technology, 2025, 47(01): 110–113.
8. Zhou Yingbo, Li Jing, Li Lvman, et al. Study on the Deformation Impact of Shield Tunnel Underpass Construction on Adjacent Transmission Towers [J]. Highway Engineering, 2024, 49(06): 29–34+71.

9. Shen Liang, Fang Fei. Study on the Influence of Spacing Between New Tunnel and High-Rise Building on Its Foundation [J]. Highway, 2015, 60(09): 286–288.
10. Zhang Qianqing, Liu Jinghang, Wang Maolin, et al. Study on the Cross-Section Convergence Mode of Shield Tunnels During Adjacent Pile Foundation Excavation [J/OL]. Chinese Journal of Rock Mechanics and Engineering, 1–11 [2025-03-22].
11. He Lichao, Wang Mengshu, Li Yujie. Study on the Impact of Subway Tunnel Mining Construction on Surface Dense Buildings [J]. China Civil Engineering Journal, 2015, 48(S1): 311–315.
12. Qin Dongping, He Ping, Li Yujie. Impact analysis of post-construction settlement of ppen-cut metro station on adjacent buildings[J]. China Railway Science, 2011, 32(5): 83-89
13. Fang Qian, Du Jianming, Li Jianye, et al. Analysis of Ground Settlement Characteristics Induced by Large-Diameter Shield Tunneling Adjacent to and Underpassing Existing Subway (English) [J]. Journal of Central South University, 2021, 28(03): 882–897.
14. Xiong Guikai, Tan Shuangquan, Zhu Bo. Study on the Safety Impact Mechanism of High-Rise Building Construction on Adjacent Rail Tunnels [J]. Urban Roads Bridges & Flood Control, 2019, (02): 207–211+24.
15. Su Zhiyin, Xie Jiachong, Wang Ziyi. Impact of Shallow-Buried Super-Large Diameter Shield Tunneling on Existing Viaduct Pile Foundations [J]. Science Technology and Engineering, 2024, 24(24): 10439–10448.
16. Xu Q W, Zhu H H, Ma X F, et al.A case history of shield tunnel crossing through group pile foundation of a road bridge with pile underpinning technologies in Shanghai [J].Tunnelling and Underground Space Technology, 2015, 45: 20-33.