Application of Comprehensive Construction Technology for Steel Sheet Piles in High Water Level Highway Foundation Pit Engineering with Saline Soil in Confined Space

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Keywords: Restricted Space, High Water Level Foundation Pit, Highway Engineering with Saline Soil, Steel Sheet Pile, Comprehensive Construction Technology.

Abstract: This paper takes the foundation pit project of a highway reconstruction and expansion project in saline soil areas in western China as an example. In the process of dealing with foundation pits in highway engineering projects with high water levels and high salt content, the comprehensive construction technology of steel sheet piles has been successfully applied to address the impact of uneven distribution of soil pressure and salt expansion force on foundation pit excavation and support. Compared with the diaphragm wall and row - pile support schemes, the steel sheet pile support scheme applied in this project has obvious advantages. Steel sheet pile construction features high efficiency, good safety performance, and relatively low costs. Steel sheet piles can better meet the requirements of noise reduction, green energy conservation in highway engineering projects around urban areas. They are characterized by high utilization rate of urban space, good economy, safety, and stability, as well as convenient operation. They are suitable for comprehensive operations in space - restricted foundation pit construction around urban areas. At the same time, they can isolate salt migration and counteract salt expansion force in highway engineering projects. They are particularly suitable for foundation pit projects of highway projects around urban areas with high groundwater levels, high salt content, high construction risks, and limited space, providing valuable experience for similar engineering construction in the future.

1 INTRODUCTION

The term "large deformation" first originated from the concept of mechanics and emerged in contrast to the small deformation in the field of elasticity mechanics. In the study of elasticity mechanics, (Xu, 2016) assumed that after an object is subjected to force, the displacements of all points in the entire object are far smaller than the original dimensions of the object, resulting in both the strain and the rotation angle being much smaller than 1. This is the small-deformation assumption, while large deformation does not meet the above conditions. With the development of geotechnical engineering, large deformation has been introduced from the field of mechanics into the engineering field to describe the deformation with a large amount of deformation, a long convergence time, and the potential to cause damage to conventional support structures. In tunnel engineering, there is still no unified description of large deformation. Many scholars often have different emphases on the definition of large deformation according to the problems they study; (Jiang, 2004) defined the large deformation of tunnel surrounding rock as a progressive and time-effect-obvious plastic deformation failure of the surrounding rock of tunnels and underground engineering. It is different from the brittle failure of rock burst movement and also different from the collapse, sliding and other failures restricted by certain structural planes in the loose circle of the surrounding rock; (Yu, 1998) made the following regulations on the large deformation of the surrounding rock of squeezing tunnels based on the

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deformation of the early support of squeezing surrounding rock: during tunnel construction, if the displacement of the initial support exceeds 25 cm (for single-track tunnels) and 50 cm (for double-track tunnels), it is considered that large deformation has occurred; (Zhang 2003) suggested taking the displacement value of the initial support and the damage phenomenon of the support as indicators and defined large deformation as follows: when the initial support of a tunnel with conventional support suffers different degrees of damage due to high ground stress and the ratio of the displacement value Ua to the radius a of the tunnel wall is greater than 3%, it is considered that large deformation has occurred. China's current relevant highway code, the code (Ding et al., 2023) set this limit ratio as 0.013 and divides large deformation into four grades according to the magnitude: slight, moderate, severe, and extremely severe. (Liu et al., 2008; Fei et al., 2012; He et al., 1994; Kang et al., 2022; He, 2014), etc. believed that the large deformation of the surrounding rock is closely related to the actual engineering phenomena, and thus proposed a definition of large deformation based on the influence effect of rock mass deformation and its engineering significance, that is, the surrounding rock deformation that is significantly greater than the normal level and may cause adverse consequences. (He, 2014; The Second Survey and Design Institute of the Ministry of Railways, 1997; Wang, 2003; Wei et al., 2017; Wang, 2022; Liu et al., 2005; Chen et al., 2017; Li, 2014; Wang et al., 2017; Fu and Ming, 2007; Yuan, 2016; Yang and Kang, 2002), etc. the domestic and foreign scholars have conducted a lot of research on the excavation and support of foundation pits in restricted spaces, but there is less research on foundation pit excavations with a small space and high groundwater levels in soft strata.

It is not difficult to see from the above numerous elaborations that the definition of large deformation is mainly expressed from two aspects. One is the external manifestation of large deformation. Most definitions of this type take the absolute or relative value of the displacement of the surrounding rock and the degree of damage to the support structure caused by it as the criteria for judgment. They are intuitive, quantitative, and easy to understand, but they fail to reveal the essence of the large deformation of the surrounding rock and have no guiding significance for the further prevention and control of large - deformation surrounding rock. The other is the inducing mechanism of large deformation. Most definitions of this type start from the mechanical properties that cause large deformation and take the internal causes and laws as the criteria for judgment. They have reference value for the same type of surrounding rock, but due to the complexity of the geological environment, most of them are too one - sided and cannot cover the many characteristics of large - deformation surrounding.

2 PROJECT OVERVIEW

2.1 Engineering Background

This reconstruction and expansion project is located in a western city with saline soil, and it has a length of 14.543 km. The highway is expanded to a two - lane dual - carriageway, classified as an urban arterial road. The project includes the Nanqiao Bridge, which is 51.5 m long and 18.6 m wide and requires widening and renovation. This bridge poses the greatest construction difficulty and is a key control project. Therefore, the construction of the Nanqiao section needs to be strengthened. The auxiliary pipe gallery beside the Nanqiao Bridge renovation on the main road needs to have its pipelines widened to a position close to the river on the original basis. During the construction, the relocation of pipelines across the river is involved. The green belts on both sides of the river, the artificial slopes, and the original pipe gallery foundation are built in the silt area of the riverbed. The silt has a high water content and is in a fluid - plastic state. The slope during construction is an earth slope. Moreover, the excavation and backfilling of saline soil need to be given due attention during the construction process. To ensure the smooth progress of the relocation project and the safe and effective earthwork excavation, steel sheet piles are used for temporary protection, with a design life within the construction period. The construction area is located in the northwest region, and attention should be paid to winter construction., as shown in Figure 1.

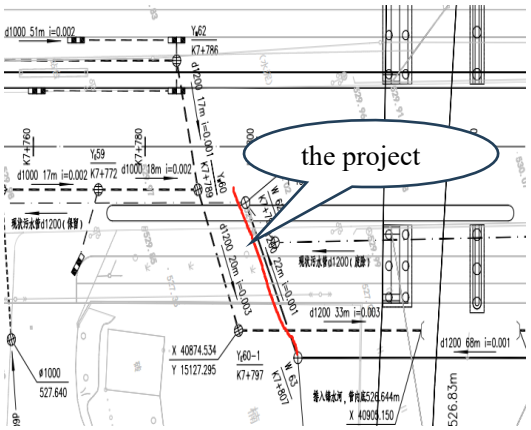

Figure 1: Location of the project.

2.2 Scheme Comparison and Selection

We have compared three construction methods, namely the diaphragm wall excavation scheme, the row - pile support method, and the steel sheet pile construction method. On the basis of considering various factors such as the specific characteristics of the project, construction period, and cost, the steel sheet pile construction method has been selected. A comparative analysis of the three construction schemes has been carried out in terms of construction difficulty, project cost, applicability, etc., as shown in Table 1.

2.3 Overall Project Layout Deployment

T Nanqiao Bridge spans a local natural river. The river flows from the northwest to the southeast. The width of the river section at Nanqiao ranges from 10.0 to 30.0 meters, and the depth is approximately 4.5 to 5.0 meters. Both banks are protected by mortar - laid strip - stone slopes. During the survey, there was a small amount of flowing water in the river, with a water depth of 0.5 to 1.5 meters. The excavation of the pipe gallery is close to the river. Soft muddy soil, as well as layers of eggs and gravel, are distributed on the surface. Surface water is well - developed. According to the comparison of the schemes in Table 1, it can be concluded that from the perspectives of construction safety, investment, and dewatering, the steel sheet pile method is preferentially selected for foundation pit support.

Table 1: Comparison Table of Excavation Support Plans.

Serial Number	plans	applicability	Feasibility analysis based on on-site conditions
1	Underground continuous wall	(1) For deep foundation pit engineering projects, the excavation depth generally exceeds 10m. (2) There are safety - protected buildings or structures in the vicinity. (3) The space within the deep foundation pit is relatively limited. (4) The top - down construction method is adopted.	The disposal of waste slurry is highly inconvenient. As a temporary retaining structure, the diaphragm wall incurs higher costs compared to other methods. In case of an inappropriate construction method or special construction geological conditions, misalignment and seepage may occur at the ends of adjacent wall segments. In this project, there are soft muddy soils and alluvial layers containing boulders. The soft muddy soils are fluid, which increases the construction difficulty and poses significant construction risks.
2	Row pile	(1) Foundation pits are classified into three safety levels: level - one, level - two, and level - three foundation pits. (2) It is mostly applied to the support of basements with poor - quality soil for excavation, complex surroundings around the foundation pit, and relatively deep excavation.	In this project, the row - pile support generally comes with a relatively high cost. Additionally, the excavation site has limited space, the groundwater level is high, and there are stringent requirements for construction personnel and equipment.
3	Steel sheet pile	(1) It is applicable to construction sites where the amount of earthwork for foundation pit excavation is small, mechanized construction operations can be carried out smoothly, and drainage is unobstructed.	From the perspectives of cost - saving, construction convenience and the characteristics of the construction site itself in this project, steel sheet piles can be reused. They can be easily driven into soft muddy soil and clay. Steel sheet piles have excellent water - retaining performance, high adaptability, reliable quality, and can bring high economic benefits.

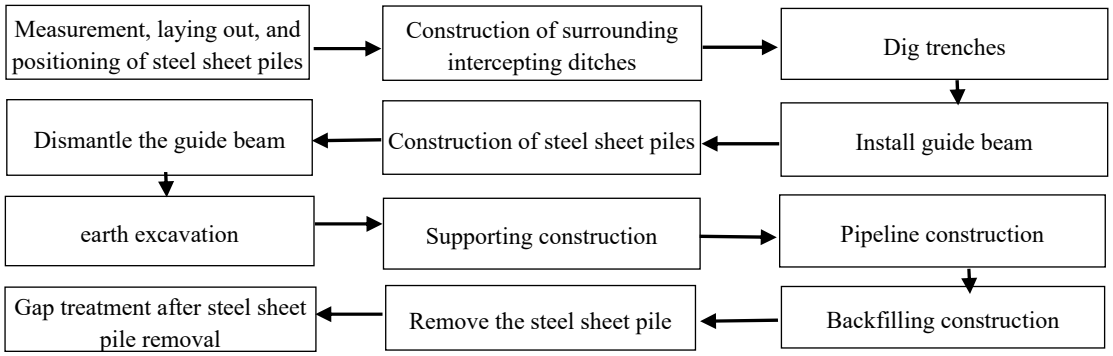

Figure 2: Schematic diagram of steel sheet pile process flow.

Table 2: Standardize slope ratio.

name	slope height	Saline filled soil	silt	Medium sand	Loose pebbles	Slightly dense pebbles	Medium density pebbles	Dense pebbles
Slope rate	H＜5m	1:2	1:2.5	1:1.5	1:1.25	1:1	1:0.75	1:0.5
	H=5~10m	1:2	1:3.0	1:1.5	1:1.5	1:1.25	1:1	1:0.75

H represents the height of slope or foundation pit excavation, measured in meters.

2.4 Construction Scheme

The depth of the foundation pit in this project is approximately 4.7 - 7.7m. The backfill, silt, and sand layers on the foundation trench walls have a loose structure, classifying this as a "high - risk project". Appropriate measures should be taken to ensure the safe construction of the foundation trench. It is recommended to adopt an excavation plan combining slope-setting with temporary support. There are a large number of underground pipelines distributed on both sides of the original municipal roads near the project site. These mainly include water supply, sewage, rainwater, gas, power, and communication pipelines, with a burial depth of around 0.7m-7.7m. Therefore, it is proposed to conduct surveys and marking of underground pipelines before construction, formulate key protection plans, and move or remove pipelines that may affect construction when necessary to ensure construction safety. In practice, protection measures should be implemented according to the actual situation at the construction site, such as using reinforcement treatment. Based on the characteristics of this project and the survey data, the technological process is shown in Figure 2. The slope ratios of various soils for the building slope are specified as shown in Table 2.

2.5 Construction Plan

Before connecting the new pipeline to the old sewage pipeline, a confined - space operation plan should be formulated. After it is approved, the operation must be carried out strictly in accordance with the requirements of the plan. Provide safety and technical training to the operating personnel, distribute labor protection supplies, and ensure an adequate supply of emergency response items. Before the operation, conduct gas detection and ventilation of the old pipeline. The operation can only commence once the conditions meet the requirements. During the operation, assign dedicated personnel to monitor and conduct continuous gas detection in the working area. For the personnel involved in pipeline connection work, arrange for two or more workers to carry out the construction simultaneously.

3 SAFETY CALCULATION OF STEEL SHEET PILE ENCLOSURE STRUCTURE

According to the excavation specifications for steel sheet piles, it is necessary to convert the uniformly distributed load within a certain range on the outer

side of the steel sheet pile into a certain height of the soil column,

$h_0 = q/\gamma = 20kPa/20\text{kN/m}^3 = 1.0m$, h_0— *convert the height of the soil column*, q — the load around the foundation pit, γ— *convert the weight of the soil,* the design adopts 12 m Larson steel sheet piles, Minimum depth of steel sheet pile into soil: H_{min}=1.2 × (0.53+1.53)=2.5 m, Length of steel column: L=2.5+5.0=7.5 m, Compliant with regulatory requirements.

3.1 Construction Process of Steel Sheet Piles

(1) Prepare the pile driving machine.

(2) During concrete pouring, first use machinery to lift the sheet piles to the pile - insertion point for pile insertion. Align them manually and precisely aim at the pile - insertion port. Then, construct the steel sheet piles one by one using the driving method. To ensure the vertical angle, two levels are used for control. Set up a fastening plate at the lock - mouth of the steel sheet piles in the correct direction of the piles. Once the piles are inserted in place, immediately weld and fix them to the steel purlins with steel bars or steel plates.

(3) When driving the steel sheet piles, if there are gaps at the joints due to tilting, special - shaped sheets with a wider upper part and a narrower lower part, or with a width exceeding or less than the standard distance are generally used for adjustment. If processing is difficult, the center - line modification method can also be adopted for correction.

(4) When vibrating and driving into the soil layer, if there are crushed stones thrown into the foundation, the vibrating pile - driving construction can be used to pull out the piles first, and then drive them again. Vibrate up and down and drive several times until the piles are successfully driven in.

(5) Drive each pile into the soil layer in turn. At the same time, pay attention to the accurate positioning and alignment of the lock - mouths to ensure the construction quality. Measure and determine the position of the sheet piles according to the construction drawings and install the guide frame (the guide frame consists of guide beams and purlin piles).

3.2 Common Issues in Steel Sheet Pile Construction

Accurately measure and determine the position of the sheet piles according to the construction drawings and install the guide frame. The guide frame is composed of guide beams and steel purlins.

(1) Use a level and a leveling instrument to control and adjust the position of the guide light.

(2) The height of the beam should be appropriate, reserving a certain height space for steel sheet pile construction and improving work efficiency.

(3) As the steel sheet piles are poured, the guide beam should not sink or deform.

(4) The position of the slide rail should be as vertical as possible and should not collide with the steel sheet piles.

4 CONCLUSION

This paper takes the high-water-level foundation pit project of the pipe gallery in the Chengdu-Pengzhou Road Reconstruction and Expansion Project as an example to study the practical application effect of the comprehensive construction technology of steel sheet piles in dealing with high - water - level foundation pits.

(1) Steel sheet piles can better meet the requirements of urban noise reduction, green energy conservation. They have advantages such as high utilization rate of urban space, good economy, safety, and stability, as well as convenient operation. They are suitable for comprehensive operations in urban foundation pit construction spaces with limitations (in terms of height). They are particularly applicable to urban foundation pit projects with high groundwater levels, high construction risks, and limited space.

AUTHOR CONTRIBUTION

Xiyuan Liu: conceptualization, methodology, data curation, writing-original draft preparation. Shanzhi Fan: review & editing.

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DATA AVAILABILITY

The data used to support the findings of this study are

available from the corresponding author upon request.

CONFLICTS OF INTEREST

We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

REFERENCES

Xu, Z. L. 2016. *Elasticity*. Higher Education Press, Beijing. Vol. 58, Issue 11, pages 76-80.

Jiang, Y. 2004. *Research on Prediction, Forecasting and Countermeasures of Large Deformation of Surrounding Rock in Highway Tunnels*. Chengdu University of Technology, Chengdu.

Yu, Y. 1998. The mechanism and determination method of large deformation in compressive rock support. *World Tunnel*, (01): 46-51.

Zhang, Z. D. 2003. Exploration and Research on Large Deformation of Squeezing Surrounding Rock Tunnels. *Modern Tunnel Technology*, (02): 5-12+40.

Ding, X. L., Zhang, Y. T., Huang, S. L., et al. 2023, Mechanism of Large Deformation of Tunnel Surrounding Rock, Prediction and Application of Squeezing Large Deformation. *Journal of Rock Mechanics and Engineering*, 1-24.

Liu, Z. C., Zhu, Y. Q., Li, W. J., Liu, P. X., et al. 2008. Research on the Mechanism and Grading Standards of Large Deformation in Squeezing Surrounding Rock Tunnels. *Journal of Geotechnical Engineering*, (05): 690-697.

Fei, W. P., Zhang, J. M., Cui, H. L., et al. 2012. Analysis of Large Deformation Mechanism of Surrounding Rock during Construction of Deep Underground Caverns. *Journal of Rock Mechanics and Engineering*, 31 (S1): 2783-2787.

He, M. C., Peng, T., Chen, Y. J. 1994. Large deformation problems and research methods in soft rock engineering. *Hydrogeology and Engineering Geology*, (05): 5-8.

Kang, Y. S., Geng, Z., Liu, Q. S., et al. 2022. Research progress on control technology and methods for large deformation disasters in soft rock in China. *Rock and Soil Mechanics*, 43 (08): 2035-2059.

He, M. C. 2014. Research progress and challenges in deep soft rock engineering. *Coal Journal*, 39 (08): 1409-1417.

The Second Survey and Design Institute of the Ministry of Railways. 1997. *Stability and Support Technology of High Stress Ratio Coal bearing Strata Roadways (Research Report)*. The Second Survey and Design Institute of the Ministry of Railways, Chengdu.

Wang, R. 2003. *Research on the Mechanism and Prevention Measures of Large Deformation of Surrounding Rock in Zhegushan Tunnel of National Highway 317*. Chengdu University of Technology, Chengdu.

Wei, L., Liu, Q., Huang, P. 2017. A review of research on the mechanism and control measures of large deformation in high stress soft rock tunnels. *Highway*, 62 (07): 297-306.

Wang, Y. 2022. Research on Large Deformation Control Technology of Soft Surrounding Rock in Qingyunshan Tunnel. *Value Engineering*, 41 (29): 106-108.

Liu, G., Zhang, F. Y., Li, X. Z., et al. 2005. Characteristics and Mechanism Analysis of Large Deformation in Muzhailing Tunnel. *Journal of Rock Mechanics and Engineering*, (S2): 5521-5526.

Chen, S. H., Li, Z. P., Ma D. 2017. Xinguanjiao Tunnel on Qinghai Tibet Railway. *Tunnel Construction*, 37 (07): 907-911.

Li, J. L. 2014. *Rock Mechanics*. Chongqing University Press: A Series of Textbooks for Undergraduate Guidance Professional Standards in Civil Engineering for Higher Education Institutions, 318.

Wang, W. J., Dong, E. Y., Yuan, C., et al. 2017. Research Progress on Anchor Rod Support Theory and Technology for Deep and Large Deformation Tunnels. *Mining Engineering Research*, 32 (02): 1-10.

Fu, Q., Ming, A. X. 2007. Mechanism of anchor rod (cable) span reduction and its application in deep buried large-span tunnels. *China Mining*, (05): 64-65+68.

Yuan, Y. 2016. *Research on High Ground Stress Soft Rock Large Deformation Control Technology for Lanxin Second Line Daliang Tunnel*. Southwest Jiaotong University, Chengdu.

Yang, S. S., Kang, L. X. 2002. Summary and Prospect of Research on Anchor Rod Support in Coal Mine Roadways. *Journal of Taiyuan University of Technology*, (04): 376-381.