Journal of World Architecture, 2025, Volume 9, Issue 6
https://ojs.bbwpublisher.com/index.php/JWA
Online ISSN: 2208-3499
Print ISSN: 2208-3480

Exploration and Research on In-Situ Protection Technology of Existing Pipelines in Municipal Project Construction

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Abstract: This paper systematically studies the in-situ protection technology system under complex conditions where municipal road and bridge open-cut tunnels are adjacent to or pass through existing pipelines, under the condition that the pipelines do not need to be relocated. The key mechanism of the MJS technology in the reinforcement of the pit side wall and water sealing is analyzed, and the technical principles and implementation methods for controlling ground deformation and ensuring pipeline safety are clarified. The paper elaborates on the formulation of protection standards based on pipeline types and environmental conditions, the collaborative design of support systems, the collaborative construction mechanism among multiple units, and the construction and data application of high-precision real-time monitoring platforms. Through typical engineering cases, the effectiveness and limitations of key technologies such as MJS in practical applications are verified, providing practical basis and optimization suggestions for the safe and controllable protection of pipelines in similar open-cut tunnel projects.

Keywords: Municipal road and bridge; Open-cut tunnel; Pipeline protection

Online publication: December 31, 2025

1. Introduction

With the acceleration of urbanization, municipal road and bridge construction is becoming increasingly frequent. Policies related to urban infrastructure construction released in 2022 emphasize the importance of protecting existing facilities during construction. Open-cut tunnel construction, as a crucial part of municipal road and bridge projects, presents significant challenges regarding its construction technology and the protection of existing pipelines. Different geological conditions pose various difficulties, while pipeline protection requires the establishment of a standardized system considering factors such as material, diameter, and medium properties. Particularly, how to achieve in-situ protection of pipelines through advanced construction techniques without relocating them is a core challenge in current engineering practice, necessitating in-depth research and discussion.

2. Characteristics of open-cut tunnel construction technology

2.1. Features of the open-cut tunnel method

Open-cut tunnel construction is characterized primarily by surface excavation and is suitable for areas with ample construction space and where environmental impact is controllable. Its excavation methods mainly include slope excavation, supported excavation (e.g., pile-bracing, pile-anchor systems), and the cover-excavation method. The selection must comprehensively consider geological conditions, excavation depth, surrounding environment, and pipeline protection requirements [1]. The support system is key to ensuring excavation stability and construction safety. It typically involves retaining structures (such as diaphragm walls, bored piles, SMW method, etc.) combined with internal bracing or anchor systems, along with necessary pre-construction measures like dewatering and soil improvement, to effectively control excavation deformation and groundwater influence. In weak, fractured, or water-rich strata, controlling excavation disturbance is particularly important. Techniques such as dewatering, grouting reinforcement, and layered, segmented excavation are often required to reduce ground settlement and water ingress risks. During open-cut construction, excavation sequence, timely installation of supports, and deformation monitoring are core to controlling the impact on the surrounding environment, especially for protecting adjacent pipelines and other facilities. This requires refined construction and dynamic adjustment to ensure pipeline safety and normal operation.

2.2. Construction challenges in complex strata

Open-cut tunnel construction in complex strata faces multiple technical challenges. Soft soil layers have low strength and high compressibility, prone to significant settlement and lateral displacement, threatening excavation stability and nearby pipelines. In one project, the soft soil layer had an average water content of 45%, with a maximum daily settlement exceeding 15 mm during excavation, necessitating dynamic control measures [2]. Sandy layers have poor self-stability and are prone to sand flow and piping, especially under water-rich conditions, where the risk of water ingress is significant. While rock strata generally have high bearing capacity, they may feature fissure development or karst phenomena, requiring high control over slope stability during excavation. If blasting is involved, vibration must be strictly controlled to ensure its impact on adjacent pipelines remains within permissible limits.

Figure 1. Soft soil stratum construction excavation site.

3. In-situ protection technology system for existing pipelines

3.1. Classification and grading standards for pipeline protection

A three-tier protection standard is established based on pipeline material, diameter, and medium properties. Taking a main road reconstruction project in a city as an example, within the construction influence zone, there existed a 1.2m diameter steel water main, a DN600 cast iron gas pipe, and multiple communication cables. Among these, the water pipe has poor deformation resistance, with allowable settlement controlled within 10 mm; the gas pipe carries hazardous medium, strictly prohibiting differential settlement; communication lines are sensitive to vibration, requiring vibration velocity to be controlled below 1.5 cm/s [3]. Based on the actual distribution and operational status of pipelines in engineering practice, differentiated monitoring indicators and emergency response plans are formulated.

Figure 2. Underground power cable protection zone construction Site.

3.2. Collaborative design of support structures

For open-cut excavations adjacent to multiple important pipelines, a composite support system combining row piles, internal bracing, and anchor cables is adopted. Taking an underpass tunnel project as an example, the excavation depth was 15 m, adjacent to a 1.5m diameter stormwater pipe and a high-voltage cable trench. Design utilized PLAXIS numerical simulation analysis to determine pile diameter of 1.2 m with 1.5 m spacing, and 3 levels of internal bracing with a horizontal spacing of 10 m. Simulation results indicated this scheme could control the maximum pipeline displacement within 8 mm, meeting safety requirements [4]. During actual construction, dynamic adjustment of bracing axial force based on monitoring feedback effectively balanced excavation deformation and pipeline protection.

4. Core technologies for in-situ pipeline protection

4.1. Pipeline protection monitoring and control

4.1.1. Real-time monitoring system construction

A multi-variable monitoring system composed of automated total stations, hydrostatic leveling instruments, and strain gauges is established. In one open-cut tunnel project, 62 monitoring points were arranged along 385 m of pipeline, collecting settlement, horizontal displacement, and pipe strain data at a frequency of 1 Hz. Monitoring data was uploaded in real-time to a BIM management platform, where algorithms identified deformation trends and automatically pushed warning information. Monitoring frequency was adjusted based on construction phases, increasing to once every 30 minutes during the excavation stage, effectively guiding the fine-tuning of MJS grouting and excavation sequences. This monitoring strategy is particularly crucial in coastal water-rich strata, significantly enhancing the response capability to deformation caused by groundwater [5].

4.1.2. MJS construction disturbance control on pipelines

The impact of MJS (Metro Jet System) construction on pipelines is controlled through parameter optimization and process improvement. In an actual project, for a DN800 gas pipe located only 3 m from the excavation, the injection pressure was reduced from the conventional 40 MPa to 28 MPa, the lifting speed controlled at 2.5 cm/min, and a skip-two-holes construction sequence was adopted. During construction, the maximum pipeline vibration recorded was 1.8 cm/s, with settlement only 3.2 mm, meeting control requirements. Additionally, a row of mini-piles was constructed between the pipeline and the MJS zone to form an isolation barrier, further reducing disturbance. Such control measures have proven effective in protecting sensitive pipelines during large-section tunnel proximate construction [6].

4.2. Pipeline deformation control technology after excavation

4.2.1. Excavation face support and underpinning technology

After excavation, to ensure in-situ protection of existing pipelines, adjacent concrete struts on both sides of the pipeline are used as support beams for suspended protection. Based on pipeline weight and stress analysis, reinforcement calculation for the support beams is conducted to ensure sufficient bearing capacity. The selection of suspension facility type and specification must comprehensively consider pipeline material, diameter, and self-weight. High-strength steel cables or special hangers are commonly used, with suspension point spacing and fixation methods determined through precise calculation to prevent pipeline deformation during excavation. The suspension system is fixed to the concrete support beams via embedded parts or special connectors, ensuring overall stability. This type of underpinning technology has been widely applied in municipal engineering for protecting important pipelines such as water supply and gas pipes [7].

4.2.2. Construction sequence transition technology between excavation and suspension protection

During the transition between excavation and suspension protection, the following technical measures are necessary to ensure the pipeline remains unaffected. For instance, install and commission the suspension system before excavation, using temporary supports to fix the pipeline's initial position for stability, followed by the adoption of a segmented, progressive excavation method, strictly controlling the depth and scope of each excavation phase to minimize instantaneous soil disturbance on the pipeline. Simultaneously, during the sequence transition, monitor pipeline deformation and stress changes in real-time, dynamically adjusting the tension and position of the suspension facilities based on the data. Finally, implement transitional protective measures, such as temporarily filling lightweight material (e.g., foam concrete) beneath the pipeline to mitigate the impact of soil stress release caused by excavation. Through these measures, pipeline stability is maintained during sequence transitions, preventing deformation or displacement, and ensuring functional safety. Related practices indicate that systematic process control is key to avoiding pipeline incidents during construction [8].

5. Engineering application case analysis

5.1. Practice in soft soil stratum

5.1.1. Engineering geological conditions

An open-cut tunnel project in a city center area featured a crisscrossing network of pipelines, including a high-pressure gas pipe (DN500), two municipal water pipes (DN1200, DN800), and multiple communication lines, with minimum spacing less than 2 m. The excavation depth was 14 m, located in alternating layers of silty clay and sand, with groundwater level only 2 m deep, presenting extremely high construction risks. Under such proximate construction conditions, excavation can easily induce soil stress release and groundwater seepage, significantly impacting existing pipelines. Particularly, gas and water pipes are highly sensitive to differential settlement, requiring strict control measures [9].

5.1.2. Application of protection technology

A hydraulic cutting excavation method combined with a servo support system was employed. Excavation block size was controlled at 4×6 m, and support installation time did not exceed 4 hours. Through block-by-block, layer-by-layer excavation and timely support, soil deformation was effectively suppressed. Monitoring data during construction showed: cumulative settlement of the gas pipe was 9.5 mm, water pipes settled 8.2 mm, with differential settlement less than 1/1000, meeting pipeline safety operation requirements. Furthermore, combined with special waterproofing technical measures, the adverse effects of groundwater seepage on pipeline and excavation stability were effectively controlled [10]. All pipelines remained in normal operation throughout the construction period.

Figure 3. Application of support during construction.

5.2. Application in dense pipeline zones

5.2.1. Pipeline distribution characteristics

This open-cut tunnel project was located in an urban core area with a complex underground pipeline network, including a DN500 high-pressure gas pipeline, two large-diameter water supply pipes (DN1200 and DN800), and multiple telecommunication and power cables. The minimum clear distance between various pipelines was less than 2 meters, imposing significant spatial constraints. The excavation depth was 14 meters, with the stratum primarily consisting of alternating silty clay and loose sand layers. The groundwater level was only 2 meters deep, and the water-rich sand layer was prone to water and sand inrush, further increasing excavation risks. How to achieve micro-disturbance protection for multiple types of pipelines under conditions of high water level and narrow spacing became the main technical challenge of this project.

5.2.2. Micro-disturbance construction technology

The project adopted a combined construction method of "hydraulic cutting precise excavation + servo steel support system". The excavation phase was conducted in 4m×6m blocks, strictly controlling the unsupported exposure time. The support system utilized servo hydraulic struts with automatic pressure compensation, with installation time controlled within 4 hours. During construction, the gas and water pipes were monitored throughout. Data showed cumulative settlement of the gas pipe was 9.5 mm, and the water pipes settled 8.2 mm. Differential settlement between pipelines was less than 1/1000, far below code limits. All pipelines remained in normal operation throughout the construction period, demonstrating that micro-disturbance control technology effectively suppressed adverse effects from soil stress release.

5.3. Implementation at a traffic hub node

5.3.1. Project overview

This project involved an open-cut tunnel in an urban interchange area, with a total tunnel length of 520 meters and varying excavation depths from 10 to 14 meters. The surrounding environment was extremely complex. Surface traffic was busy with frequent heavy vehicle vibrations; underground pipelines were distributed in multiple layers and directions, including a large reinforced concrete rectangular drainage culvert (2.2×1.8 m) built in the 1980s, which was structurally aged and sensitive to deformation. Additionally, there were multiple water supply, gas, and communication main lines, with the closest pipeline only 3 meters from the excavation. Under such conditions, construction needed to control both excavation stability and minimize impact on existing pipelines.

5.3.2. Technology application and safety control

A protection system combining MJS horizontal reinforcement and steel internal bracing was adopted. MJS piles had a diameter of 2.4 m with an overlap thickness of 0.8 m, forming a continuous underground waterstop and reinforcement body. Internal bracing used H-beams combined with a bidirectional prestressing system to enhance overall stiffness. During construction, process parameters, including grouting pressure, excavation sequence, and strut axial force, were dynamically adjusted based on real-time monitoring data. Ultimately, the maximum excavation deformation was controlled at 21 mm, settlement of the old concrete culvert was only 12 mm, and displacements of other pipelines were within safe thresholds. This scheme fully leveraged the precise control advantages of MJS technology in complex environments, achieving high-safety construction beneath an operational traffic hub.

6. Conclusion

Key technological innovations in in-situ pipeline protection during open-cut tunnel construction, particularly MJS construction technology for excavation sidewall reinforcement and water sealing without pipeline relocation, and technical guarantees for preventing pipeline deformation after excavation, are the core of achieving in-situ pipeline protection. The application and refinement of these technical methods have significantly enhanced the ability to protect existing pipelines during construction. The applicability of these technologies varies under different engineering conditions and requires rational selection based on actual situations. Based on the development direction of smart construction sites, new opportunities and challenges will emerge for pipeline protection technology.

Disclosure statement

The author declares no conflict of interest.

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