Application of Settlement Control Technology in Municipal Water Supply and Drainage Pipeline Construction

Zihao Su

Ma'anshan Capital Water Co., Ltd., Ma'anshan, Anhui, 243000, China

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Abstract: Municipal water supply and drainage pipelines are core components of urban infrastructure, and their construction quality directly affects urban operational efficiency and residents' quality of life. However, settlement issues frequently occur during construction, often leading to pipeline ruptures and damage to the surrounding environment. To reduce the incidence of this problem, construction enterprises need to effectively apply settlement control technology in municipal water supply and drainage pipeline construction. This article analyzes the influencing factors of settlement in municipal water supply and drainage pipeline construction, clarifies the preliminary preparation work for applying settlement control technology, and discusses the specific application of settlement control technology in such projects. It aims to provide theoretical reference and practical guidance for improving the construction quality of municipal water supply and drainage pipeline engineering.

1. Introduction

The rapid development of cities places higher demands on the stability and durability of infrastructure. Municipal water supply and drainage pipelines, as critical hubs for urban operation, undertake the important functions of transporting potable water and discharging wastewater. Their safe operation is a fundamental guarantee for the normal functioning of a city. In recent years, with the acceleration of urbanization, the number of municipal water supply and drainage pipeline projects has surged. However, complex geological conditions in construction areas, coupled with dense surrounding buildings and underground utilities, frequently lead to settlement issues during construction. The essence of settlement is vertical displacement caused by imbalanced stratum forces and soil deformation during construction. The industry has currently formed an integrated settlement control system covering geological investigation, design planning, construction management, and monitoring feedback. Nevertheless, optimization is still needed regarding the targeting of technology selection and the coordination among various stages. Therefore, based on the actual needs of municipal water supply and drainage pipeline construction and incorporating typical engineering experience, it is necessary to deeply analyze the application scenarios and implementation key points of settlement control technology to provide practical solutions for improving pipeline engineering quality and reducing settlement risks.

2. Influencing Factors of Settlement in Municipal Water Supply and Drainage Pipeline Construction

Settlement in municipal water supply and drainage pipeline construction is caused by the synergistic effect of multiple factors. Clarifying the mechanism of each factor is the core prerequisite for formulating targeted control technologies. Based on engineering practice, these can be categorized into three key types: geological conditions, construction technology, and surrounding environment.

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2.1 Geological Conditions

Geological conditions are the fundamental cause of settlement, with soil properties playing a decisive role. Soft soil strata, characterized by high water content and strong compressibility, are prone to consolidation settlement under construction loads. Sandy soil strata have weak particle cohesion; if dewatering operation parameters are improperly controlled, it can easily induce piping or quicksand, leading to stratum instability and settlement. Special structures like geological faults and karst caves can cause local imbalances in stratum bearing capacity, directly leading to uneven pipeline settlement [1]. Simultaneously, changes in groundwater level can exacerbate settlement risks. Excessively rapid dewatering rates or excessive depth can increase the effective stress in the stratum, promoting soil compression deformation and further expanding the settlement scope.

2.2 Construction Technology

Construction technology factors directly determine the effectiveness of settlement control. During the trench excavation phase, failure to use layered excavation, uncontrolled excavation speed, or improper selection of support structures can disrupt the original stress balance of the stratum, causing trench slope collapse and surrounding stratum settlement. During pipeline foundation construction, incomplete ground improvement, insufficient concrete foundation strength, or inadequate curing can lead to reduced foundation bearing capacity, creating hidden settlement risks for later pipeline operation. During pipeline laying and joint handling, uneven stress on pipelines due to lifting collisions or poor joint sealing can exacerbate leakage risks induced by settlement. During the trench backfilling stage, using miscellaneous fill or high-water-content soil, or failing to achieve the designed compaction density, can lead to later consolidation of the backfill, squeezing the pipeline and causing settlement.

2.3 Surrounding Environment

The influence of surrounding environmental factors on settlement is conductive and regional. Loads from old buildings and dense roads around the construction area can superimpose onto the construction stratum, increasing the probability of settlement. In areas with dense underground utilities, improper protection of existing pipelines can not only cause pipeline damage but also trigger settlement through stratum disturbance conduction. Construction dewatering without supporting recharge measures can lead to a drop in the groundwater level of the surrounding stratum, inducing regional settlement and threatening the safety of surrounding buildings and pipelines [2].

3. Preliminary Preparations for Settlement Control in Municipal Water Supply and Drainage Pipeline Construction

Settlement control in municipal water supply and drainage pipeline construction follows the principle of prevention first, combining prevention and mitigation. Preparations before construction are key to reducing settlement risks, mainly covering three core aspects: detailed geological investigation, reasonable engineering design, and formulation of a scientific monitoring plan.

In the geological investigation phase, the goal is to obtain accurate and comprehensive data. The investigation scope needs to cover the pipeline route and an area 5-10m on both sides. The depth should exceed the pipeline foundation bottom by 3-5m, mainly to explore deep soil properties and groundwater level distribution. Specific methods combine drilling, geophysical prospecting (e.g., ground-penetrating radar), and in-situ testing (e.g., Standard Penetration Test, Cone Penetration Test) to comprehensively judge key parameters such as soil bearing capacity and compressibility.

After investigation, data needs to be compiled and analyzed, and geological profile maps drawn to identify high settlement risk areas such as soft soil concentration zones and high groundwater level areas, while proposing targeted risk response suggestions [3].

In the engineering design phase, the scheme should be optimized around the core of "anti-settlement." In specific practice, route planning should prioritize avoiding high-risk areas; when unavoidable, special treatment measures should be taken. Pipeline materials should select those with good toughness and strong crack resistance, such as PE pipes and ductile iron pipes, replacing traditional brittle concrete pipes. Foundation design should be selected based on geological conditions: concrete strip foundations can be used in soft soil strata to enhance bearing capacity, while gravel foundations can be used in sandy strata to enhance stability. Trench excavation and backfill parameters should be clearly defined, e.g., excavation slope in soft soil should be controlled at 1:1.5 ~ 1:2.0; backfill material should preferably choose well-graded gravel with a compaction degree reaching over 95%.

In the monitoring plan design phase, to ensure data reflects settlement dynamics in real-time, monitoring points should cover the pipeline route, trench slopes, surrounding buildings, and existing utilities. One monitoring point should be set every 20-30m along the pipeline route, with separate points at the corners of important surrounding buildings. Monitoring indicators include settlement amount, settlement rate, and horizontal displacement. Instruments should balance precision and practicality: levels with an accuracy of ±1mm can be used for settlement, total stations with an accuracy of ±2mm for horizontal displacement, while automated settlement gauges can be installed for real-time transmission. Monitoring frequency should be adjusted according to the construction phase: 1-2 times daily during excavation and backfilling stages, and once every 3 days after pipeline laying is completed, until settlement stabilizes [4].

4. Specific Application of Settlement Control Technology in Municipal Water Supply and Drainage Pipeline Construction

4.1 Settlement Control Technology in the Trench Excavation Stage

Trench excavation, being the construction phase most directly disturbing the stratum, requires a combined technical system of "layered excavation + support protection + dewatering stabilization" to control stratum deformation and reduce the incidence of settlement risk. Specifically, during the layered excavation stage, the application of settlement control technology requires strict adherence to design standards: the excavation depth per layer must not exceed 1.5m, and the excavation speed should be controlled at 2-3 layers per day, avoiding sudden changes in stratum stress due to excessive excavation speed. During the excavation process, a 0.3-0.5m thick protective layer of undisturbed soil should be retained and manually removed just before the pipeline foundation is laid, minimizing disturbance to the base soil layer. In terms of support structure selection, precise matching based on geological conditions and trench depth is necessary. For soft soil strata or trench depths exceeding 3m, sheet pile support should be prioritized. The length of the sheet piles should exceed the trench depth by 2-3m, with an embedment depth of not less than 1.5m to ensure support stability. In sandy soil strata, row pile support is suitable, with pile spacing controlled at 1.2-1.5m, and a capping beam needs to be set at the pile top to enhance overall rigidity [5]. When applying dewatering stabilization technology, selection should be based on the depth of the groundwater table. In areas where the groundwater table depth is less than 6m, wellpoints are suitable, with a spacing of 1.0-1.5m. In areas where the depth is greater than 6m, deep wells should be used, with the well depth needing to exceed the groundwater level by 3-5m. During the dewatering process, the groundwater level must be monitored in real-time, ensuring it is controlled to 0.5-1.0m below the trench bottom to avoid water level fluctuations inducing stratum settlement.

4.2 Settlement Control Technology in the Pipeline Foundation Construction Stage

The pipeline foundation, being the core structure bearing the pipeline load, requires two-dimensional measures of ground improvement and foundation quality control to enhance the overall bearing capacity and reduce later settlement problems from the root cause. During specific construction, when applying ground improvement technology, construction enterprises should make targeted selections based on specific geological conditions. For soft soil strata, the replacement method can be used: excavate the weak soil layer and replace it with well-graded gravel or lime soil, compacted in layers to ensure density. For sandy soil strata, the compaction pile method should be selected, where piles compact the soil structure to enhance the foundation's bearing performance. In complex geological areas such as those with dense existing utilities, grouting reinforcement can be used. By injecting cement slurry or cement-sodium silicate double-fluid slurry, the foundation stability is improved after the slurry diffuses and solidifies, ensuring significantly enhanced bearing capacity after reinforcement [6].

The foundation pouring process requires strict quality control throughout. Commercial concrete is preferred for the concrete foundation, its strength grade and mix ratio determined through testing to ensure slump meets construction requirements. Pouring should adopt a layered operation method, ensuring each layer is thoroughly vibrated and compacted to avoid affecting foundation strength due to construction defects. After pouring, timely moisture-retaining curing is necessary, and loading is strictly prohibited during the curing period to prevent foundation deformation due to early stress. Furthermore, flexible foundation technology can be introduced in soft soil construction. Geogrids are laid at the bottom of the foundation, utilizing the tensile properties of the grid to disperse loads, better adapt to slight settlements, and reduce the risk of foundation cracking.

4.3 Settlement Control Technology in the Pipeline Laying and Joint Handling Stage

The quality of pipeline laying and joint handling directly determines the pipeline's resistance to settlement. Therefore, smooth laying operations and flexible joint technology should be employed to reduce pipeline damage and leakage risks caused by settlement. In specific construction, corresponding work must be done well. On one hand, during pipeline laying, emphasis should be placed on stability and precision control: specialized lifting tools should be used during hoisting to avoid direct contact between rigid tools and the pipeline; hoisting speed should be controlled to keep the pipeline stable; collisions with trench slopes or the base during lowering should be prevented to avoid pipeline deformation due to uneven stress [7]. Strict adherence to design elevation and gradient during laying is necessary, with regular checks of elevation and centerline position to avoid localized stress concentration in the pipeline due to laying deviations. On the other hand, flexible joint technology should be prioritized for joint handling to adapt to slight settlements. Corresponding flexible joint types should be selected for different pipe materials: rubber ring joints should be used for ductile iron pipes, selecting specific material rubber rings and using lubricant to ensure sealing effect; butt fusion joints should be used for PE pipes, controlling butt fusion parameters according to pipe characteristics to ensure joint stability; after joint completion, leakage tests must be conducted to check sealing performance, ensuring no hidden leakage risks. Additionally, concrete thrust blocks should be set at special locations such as pipe bends and size changes; rubber gaskets should be added at the contact surface between the thrust block and the pipeline to reduce rigid collisions between the pipeline and the block during settlement, further enhancing anti-settlement capability.

4.4 Settlement Control Technology in the Trench Backfilling Stage

As the final construction phase, the quality of trench backfilling can directly affect later settlement conditions. Construction personnel need to scientifically select materials, standardize compaction techniques, and conduct dynamic monitoring during the process to effectively control backfill consolidation settlement and ensure pipeline safety. When selecting backfill materials, construction personnel should consider both anti-settlement performance and environmental requirements, making differentiated selections according to different parts of the pipeline. For critical areas such as the sides and directly above the pipe, well-graded gravel or lime soil should be prioritized. Soil containing stones, impurities, or abnormal water content should be avoided to prevent settlement caused by material properties later. For the area from above the pipe to the ground surface, plain soil can be used for backfilling, but large particles and impurities must be removed beforehand to ensure uniformity of the backfill soil [8]. During the backfilling and compaction process, the thickness of each backfill layer should be controlled according to the backfill position and material characteristics, matched with suitable compaction machinery. Simultaneously, the water content of the backfill soil must be monitored in real-time during compaction, adjusted by air drying or sprinkling to keep the water content within a suitable range, enhancing the compaction effect. Furthermore, settlement monitoring needs to continue throughout the backfilling process to dynamically grasp stratum changes. If abnormal settlement rates are detected, backfilling operations should be immediately suspended, the root cause investigated, and reinforcement measures taken. Construction can resume only after settlement stabilizes, avoiding the escalation of settlement problems.

5. Conclusion

Settlement control in municipal water supply and drainage pipeline construction is a systematic project that must run through the entire construction process. In the process of applying settlement control technology, effectively reducing settlement risks and ensuring pipeline safe operation requires accurately identifying influencing factors, scientifically selecting control technologies, and strictly implementing quality management measures. After analyzing the influencing factors of settlement control in municipal water supply and drainage pipeline construction, construction enterprises should clarify the specific application points of settlement control technology from the trench excavation stage, pipeline foundation construction stage, pipeline laying and joint handling stage, to the trench backfilling stage. This will help reduce settlement problems in these critical construction phases, minimize impact on the surrounding environment, and provide strong technical support for the high-quality development of municipal water supply and drainage pipeline engineering.

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