Key Technical Points for Subgrade Surface Construction in Settlement Sections of Municipal Road and Bridge Engineering

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Abstract: Municipal road and bridge projects constitute the core components of urban infrastructure, with their construction quality directly influencing the safety of urban transportation and the service life of facilities. During the construction of municipal roads and bridges, the settlement section of the subgrade emerges as a critical area prone to issues. Affected by factors such as geological conditions, construction techniques, and seasonal climate, the settlement section of the subgrade often experiences problems such as excessive settlement, cracks at joints, and insufficient bearing capacity. These issues not only lead to a decline in pavement smoothness and increased vehicle bumpiness but, in severe cases, can also result in structural deformation of bridges and roads, heightening safety risks. Based on this, the article systematically summarizes applicable technical methods from aspects including pre-construction preparation, core technical points, technology selection and adaptation strategies, as well as dynamic monitoring and parameter adjustments during the construction process. Its objective is to provide guidance for engineering practice and assist in resolving issues related to the settlement section of subgrade construction, ensuring the long-term stable operation of municipal road and bridge projects.

1. Introduction

Municipal road and bridge projects constitute the core infrastructure of urban transportation networks, playing a pivotal role in ensuring residents' mobility, connecting functional urban areas, and supporting economic development. With the acceleration of China's urbanization process, municipal authorities have continuously raised standards for the scale and quality of road and bridge construction. These structures must not only possess sufficient traffic-carrying capacity but also ensure long-term stability and safety. The subgrade surface, serving as the load-bearing foundation for the superstructures of roads and bridges, directly determines their overall service life as well as operational and maintenance costs.

2. Pre-construction Preparations for Subgrade Surface in Settlement Sections of Municipal Road and Bridge Projects

2.1 Technical Preparations

Technical personnel must first conduct a thorough review of the construction drawings, comparing them with the overall design plans for the municipal road and bridge project. They should focus on verifying dimensions, elevations, and connection details between the subgrade surface in settlement sections and adjacent structures such as bridge abutments or underground passages. Any discrepancies or ambiguities identified must be promptly communicated with the design unit for clarification to ensure drawing accuracy.

Subsequently, a technical disclosure meeting shall be organized, during which technical personnel must comprehensively explain the construction process requirements for the subgrade surface in settlement sections to on-site construction teams, quality inspectors, and monitoring personnel. This includes clarifying settlement control criteria, critical operational procedures, and quality acceptance standards to ensure all participants fully understand technical specifications [1].

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Technical personnel should then conduct an in-depth analysis of geological survey reports, paying particular attention to soil types in the area (e.g., soft soil, silty clay, or sand), soil bearing capacity, and groundwater depth. These geological conditions must be evaluated to identify potential settlement risks, providing a basis for formulating specialized construction plans. Finally, a comprehensive construction plan must be developed, incorporating settlement monitoring protocols, specific process parameters for subgrade filling and reinforcement, and contingency measures. This plan requires formal review and approval prior to implementation to ensure operational feasibility.

2.2 Material Preparations

The first step for material management personnel is to select appropriate fill materials for the subgrade. Based on design requirements and geological survey reports, high-strength, water-permeable, and low-compressibility fill materials should be chosen. Commonly used options include graded crushed stone and improved soil, while materials with poor stability must be avoided. For reinforcement materials such as geogrids, crushed stone for pile foundations, and cement slurry for cement-mixed piles, suppliers must be rigorously vetted to ensure compliance with design specifications. For example, the tensile strength and elongation of geogrids must meet standards, while crushed stone particle sizes should be controlled within the 20–50 mm range. Upon material arrival, management personnel must organize sampling inspections. For each batch of fill and reinforcement materials, samples must be taken and submitted to accredited testing institutions in accordance with standard requirements [2]. Testing parameters include moisture content and compaction degree of fill materials, as well as the physical and mechanical properties of reinforcement materials. Only materials passing these tests may be approved for use. Simultaneously, dedicated storage areas must be planned, with different types of fill materials segregated and isolated to prevent mixing. For moisture-sensitive materials such as cement and geogrids, weatherproof shelters or tarpaulins should be provided. Storage zones for moisture-sensitive fill materials should incorporate drainage slopes to prevent abnormal moisture content due to rainwater infiltration, ensuring materials remain in qualified condition prior to use.

2.3 Equipment Preparations

Equipment management personnel must first compile a detailed equipment inventory based on the construction plan. Compaction equipment should include rollers of varying tonnages and small impact hammers; measurement and monitoring equipment requires total stations, leveling instruments, and settlement observation devices; while reinforcement equipment must be selected according to specific processes, such as vibroflotation machines for gravel piles and cement mixing pile drivers[3]. Subsequently, equipment operators must conduct thorough inspections and adjustments on all machinery. This includes verifying braking systems and roller conditions, checking for oil leaks or abnormal noises, and calibrating tonnage displays and rolling speedometers on compactors. Measurement and monitoring instruments must undergo precision calibration by accredited institutions to ensure data accuracy—for example, leveling instrument collimation axis errors must comply with specifications. For reinforcement equipment, operators should inspect pile frame verticality, drill bit wear, and adjust cement slurry pump pressure and flow rates to guarantee stable operation during construction. Additionally, equipment managers must establish maintenance schedules and stockpile common wear parts to prevent construction delays caused by equipment failures.

3. Application Strategies for Subgrade Surface Construction Technologies in Settlement Sections of Municipal Road and Bridge Projects

3.1 Selection of Appropriate Construction Technologies

For settlement sections with varying geological conditions, technical personnel must select tailored construction techniques, which construction teams shall implement according to corresponding requirements to ensure subgrade stability. Specific approaches include:

3.1.1 Settlement Sections with Soft Soil Subgrade

Technical personnel should prioritize the combined application of "gravel pile + cement-mixed pile reinforcement" technology, supplemented by dynamic compaction, to effectively compact soft soil and enhance foundation bearing capacity. Construction teams must follow a sequential process:

Gravel Pile Installation: Pile length shall be controlled to at least 1.5 times the thickness of the soft soil layer, ensuring penetration into the underlying hard stratum.

Cement-Mixed Pile Construction: Pile diameter should be maintained at 50 cm with a spacing of 1.8 m between piles to prevent uneven reinforcement. During installation, thorough mixing of cement slurry and soil must be ensured [4]. Dynamic Compaction: A compaction energy level of 2,000–2,500 kJ shall be applied, with drop points arranged in a quincunx pattern. Each point should receive 6–8 blows to achieve further soft soil compression.For soft soil layers exceeding 5 m in thickness, technical personnel shall mandate the installation of two additional geogrid layers. Construction teams must ensure longitudinal overlaps of 18 cm and transverse overlaps of 22 cm, securing the grids with specialized fasteners to prevent displacement and enhance overall subgrade deformation resistance.

3.1.2 Settlement Sections in Fill Subgrade

When addressing settlement sections in fill subgrade, technical personnel typically adopt lime-stabilized soil filling technology. By incorporating lime into the fill material, this method improves its engineering properties and reduces the required compaction effort. The construction team shall follow these procedures:

Material Preparation: The original soil must first be dried and crushed, followed by uniform mixing with lime at a dosage of 8%–10% by weight. The moisture content of the mixture shall be tested and adjusted to remain within ±2% of the optimum compaction moisture content to prevent post-compaction deformation [5]. Layered Filling: The stabilized material shall be placed in layers with a thickness of 25–30 cm per layer. Each layer must be compacted 5–6 times using a 20-ton heavy-duty roller. After each compaction pass, surface evenness shall be inspected to avoid under-compaction. Geogrid Reinforcement: After every three filled layers, a geogrid layer shall be installed and properly anchored before continuing with subsequent filling operations. This reinforcement enhances the structural integrity of the fill section and minimizes interlayer settlement.

3.1.3 Settlement Sections at Bridge Abutment/Culvert Transitions

For settlement sections at bridge abutment/culvert transitions, technical personnel shall adopt a "small-scale rammer + thin-layer filling" construction method to address compaction deficiencies caused by limited access for large equipment. The construction team must adhere to the following principles: Thin-Layer Filling: Each fill layer thickness shall be controlled at 15–20 cm (thinner than standard fill layers).Dynamic Compaction: A small rammer with 30 kN impact force shall be used to deliver 8–10 repeated blows per layer, ensuring full compaction of materials at transition zones [6].Bonding Agent Application: Prior to filling, a bonding agent (similar to adhesive) shall be applied to the abutment side surfaces. Filling operations may commence only after the bonding agent has fully cured. This treatment enhances the structural integrity between the subgrade and abutment, reducing the likelihood of post-construction cracking or differential settlement at the connection points.

4. Strengthening Dynamic Monitoring During Construction

During the construction of subgrade settlement sections, monitoring personnel, technical staff, and the construction team must collaborate to conduct real-time monitoring, promptly analyze data, and dynamically adjust parameters to ensure subgrade settlement remains within design-permitted limits. Specific measures include:

4.1 Implementation of Dynamic Monitoring

Monitoring personnel shall establish an automated monitoring system supplemented by manual verification. Automated settlement observation instruments should be pre-installed at critical locations on both sides of the subgrade settlement section and at bridge abutment connection points. These devices must be securely fixed to stable observation posts to prevent vibration-induced data errors. The instruments automatically collect data every 2 hours, including millimeter-level vertical settlement of the subgrade surface, daily settlement rates, and lateral displacement distances. Simultaneously, monitoring personnel must conduct daily manual data verification using leveling instruments and total stations to re-measure observation points. The automated data shall be cross-checked against manual measurements to ensure accuracy and eliminate potential equipment malfunctions [7]. All monitoring data must be promptly recorded and transmitted: after each collection or verification, personnel shall immediately organize the data into standardized tables indicating collection time, observation point ID, settlement magnitude, and settlement rate, then upload the information in real-time via the construction control platform. Delays must be avoided to prevent missed early warning opportunities for potential risks. Additionally, monitoring personnel shall perform regular equipment maintenance, including weekly cleaning of dust and rainwater from instrument surfaces and monthly precision calibration to ensure long-term stable operation.

4.2 Analysis and Interpretation of Monitoring Data

Upon receiving monitoring data, technical personnel must complete analysis within one hour: Threshold Comparison: The design alert values are first compared against current data to determine whether any readings exceed permissible limits. Settlement Curve Analysis: A settlement curve is plotted with time (x-axis) and settlement magnitude (y-axis) to evaluate trend patterns. A steady downward curve indicates stable subgrade settlement, while sudden steepening or a sustained settlement rate exceeding 1 mm/day for two consecutive days is classified as "abnormal settlement," triggering immediate corrective actions. Technical personnel must also contextualize data analysis with construction progress. For example, during the fifth-layer filling of the subgrade, if the settlement rate exceeds alert thresholds, they must determine whether the cause is "excessive layer thickness" or "insufficient compaction passes." If the first four layers (30 cm thick, compacted 5 times with satisfactory results) exhibited normal behavior but the fifth layer shows abnormalities under identical parameters, possible causes may include elevated moisture content in the fill material [8]. When using newly sourced fill materials, their performance must be verified to avoid misdirected adjustments stemming from superficial data interpretation without identifying root causes.

5. Conclusion

In summary, the application of subgrade construction technologies in municipal road and bridge engineering should encompass a comprehensive process of "pre-construction preparation—adaptive technology selection—in-process control—dynamic optimization." Pre-construction preparation establishes a solid foundation for technical implementation, while adaptive technology selection based on geological conditions, combined with real-time monitoring data-driven parameter adjustments during construction, forms a closed-loop technical control system. This methodology effectively addresses common challenges such as excessive subgrade surface settlement and poor connection quality, enhancing both surface stability and load-bearing capacity. It also extends the service life of municipal infrastructure projects while reducing long-term maintenance costs. As construction precision requirements continue to rise, subgrade settlement control technologies can be further integrated with intelligent monitoring systems and advanced reinforcement materials to achieve technological innovation and upgrading. It is recommended that engineering practitioners flexibly apply the technical approaches outlined in this paper based on project-specific conditions, continuously accumulate practical experience, and drive the evolution of subgrade settlement control technologies toward greater efficiency and precision. Such efforts will contribute to elevating the overall quality of urban infrastructure development.

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