Key Control Factors and Countermeasures in Quality Management of Municipal Road and Bridge Construction

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Keywords: Municipality; Quality management; Control factors

Abstract: Urban roads and bridges shoulder the dual missions of traffic operation and urban renewal. Their construction quality directly relates to structural durability, safe passage, and life-cycle costs. Currently, against the backdrop of rapid construction and complex environments, issues such as deviations in the implementation of design outcomes, imbalanced process coordination, fluctuations in material quality, and weaknesses in on-site management are prone to triggering quality risks. There is an urgent need to enhance the intrinsic safety and benefits of projects through whole-process control. Focusing on the above situation, this article sorts out key control factors from three aspects: pre-construction design control, dynamic construction process control, and supervision and inspection closure. It diagnoses problems such as the disconnection between design and construction, uneven capabilities of construction teams, lax material quality control, and disordered on-site organization. Subsequently, it proposes countermeasures including strengthening pre-construction quality planning and optimization, systematically improving personnel skills and work standards, establishing a sound material procurement and inspection chain, and perfecting on-site quality supervision and information traceability, aiming to construct an executable and quantifiable quality management system.

1. Introduction

With the accelerated reshaping of urban spaces, municipal investment has shifted from quantity expansion to quality and efficiency enhancement. The combination of peak traffic flows, dense underground pipelines, and significant differences in strata and hydrology poses objective constraints. How to ensure quality stability at each process and node has become a common proposition and management pain point in the industry. Based on this, this article selects key processes and easily out-of-control links in municipal road and bridge construction. It focuses on pre-construction design planning, dynamic construction control, and supervision and inspection coordination, striving to provide clear paths and operational points for quality improvement through executable systems and methods, thereby bridging the "last mile" of standard implementation.

2. Key Control Factors in Quality Management of Municipal Road and Bridge Construction

2.1 Pre-construction Design Control Elements

The design stage is the starting point of quality management and should be comprehensively controlled based on the principles of "constructibility at the source, controllability during the process, and usability during operation." Firstly, based on traffic volume forecasts, geological and hydrological surveys, and the conditions of surrounding existing facilities and pipelines, multiple design options should be compared and selected, and clearance checks should be conducted to ensure that the structural system, bridge deck system, and foundation type match site constraints and life-cycle requirements. Secondly, key node practices and detailed construction drawings should be refined, and allowable tolerances, process interfaces, and inspection batch requirements should be clearly defined to avoid on-site secondary interpretations and arbitrary changes. Thirdly, a design planning checklist should be established, incorporating material indicators, durability targets, drainage and protection measures, seismic and temperature effects, and boundary conditions for

  DOI: 10.25236/icacel.2025.018

construction temporary bridges and traffic diversion. Simultaneously, construction risk assessments and special demonstrations should be carried out [1]. Finally, a design change control mechanism and technical verification process should be set up to ensure that design intentions remain unchanged during the procurement and implementation stages, providing clear and traceable quality references for subsequent dynamic control and supervision and inspection.

2.2 Dynamic Quality Control during Construction

Quality control during the construction stage focuses on "real-time mastery, proactive prevention, and closed-loop handling." The key is to grasp process interfaces. Clear requirements for first-piece approval and on-site supervision should be established for key processes such as surveying and staking out, foundation treatment, formwork systems, steel bar welding, and connector installation, forming a model of sample-first and process signing-off. Full-process monitoring should be implemented for concrete mixing, transportation, pouring, vibration, and curing. Temperature and strength double curves should be established, and temperature and strain monitoring points should be arranged according to the age and component parts to prevent cracks and voids. For subgrade and bridge abutment backfilling, the principles of "thin layer paving, sufficient compaction, and layer-by-layer acceptance" should be adhered to, with deflection and nuclear density gauge measurements serving as release criteria. For parts prone to changes, such as bearing settings, expansion joints, and drainage details, technical disclosures should be reviewed and re-measured and re-inspected. A two-dimensional code traceability system for material entry, witness sampling, and re-inspection linkage should be established, and abnormal batches should be immediately isolated. On-site management should adopt early warning threshold management and problem list management, with designated personnel, time limits, and measures for rectifying problems. After completion, rectification should be verified through actual measurements and third-party sampling inspections to ensure that quality deviations are identified early and controlled within allowable limits.

2.3 Full-process Quality Assurance through Supervision and Inspection

Supervision and inspection should run through every link from project commencement to completion, with the core being to set quality thresholds in advance and address problems on-site. Before construction, drawings, plans, personnel, and equipment qualifications should be verified, and work stoppage points, key process on-site supervision points, and witness sampling lists should be clarified. During construction, progress should be advanced according to the sequence of "first-piece process patrol inspection - concealed work acceptance - stage review": mass production can only commence after the first piece passes inspection; key inspections should be carried out on foundation excavation, steel bar nodes, concrete pouring, bridge deck paving, expansion joints, and bearing installation, and actual measurement indicators such as flatness, compactness, strength, and water permeability coefficient should be used to determine whether to release the work. Materials and components should undergo double-certificate verification, batch sampling, and isolation of non-conforming items, and projects related to load-bearing safety must be re-inspected. Deviations found should be documented in rectification orders, with clear responsibilities and time limits, and closure should be confirmed after re-inspection is qualified [2]. For key nodes, joint reviews involving design, construction, and supervision should be organized to avoid information gaps. During the completion stage, comprehensive inspections of structural appearance, alignment, durability, and load-bearing performance should be conducted, and a quality assessment should be given based on data verification and sampling inspection results to ensure that the project is deliverable, maintainable, and traceable.

3. Main Problems in Quality Management of Municipal Road and Bridge Construction

3.1 Disconnection between Design and Construction

In many projects, the disconnection between design and construction is prominent: Survey data is not updated in a timely manner, and changes in geology, hydrology, and surrounding pipelines are not fed back to design outcomes; the design depth is insufficient, with missing detailed construction drawings, node practices, and dimensional tolerances, leading to frequent on-site oral explanations; inconsistencies exist between bidding drawings and construction drawings, with deviations in technical conditions, material indicators, and measurement rules; design disclosures are formalistic, with unclear construction sequences for key parts, temporary structures, and traffic diversion boundaries; BIM models do not match two-dimensional drawings, and clearance, limit, and collision problems are only exposed on-site; the design change and technical verification chain is lengthened, with delays in approval and information transmission, causing work stoppages and rework; insufficient consideration is given to constructibility and equipment and tooling requirements, leading to repeated on-site adjustments to formwork systems, lifting paths, and scaffold arrangements; interfaces between different disciplines are not smooth, with misalignments in drainage, lighting, pipeline integration, and bridge deck systems, accumulating quality risk points.

3.2 Uneven Technical Levels of Construction Teams

In actual construction, some teams have weak technical foundations. They have a poor understanding of surveying and staking out, elevation control, and alignment smoothness, often resulting in significant deviations in the first piece; they have inadequate mastery of steel bar cutting and binding processes, with protection layer thickness, anchorage length, and node lap joints easily going out of control; they lack experience in formwork system selection and reinforcement calculations, leading to formwork bulging, running, and misalignment; they are arbitrary in implementing concrete mix proportions, with inaccurate control of pouring temperature, slump, and vibration timing, resulting in honeycomb surfaces, interlayers, and early cracks; for high-precision processes such as bridge bearing installation, expansion joint slot treatment, and drainage details, repeated rework occurs due to unskilled operators; improper compaction methods are used for subgrade and bridge abutment backfilling, with missing records of water content control and compaction passes, leading to uneven settlement; they have weak awareness of measurement review, concealed work acceptance, and data synchronization, with delayed records or inconsistencies with the actual structure; frequent personnel turnover and complex subcontracting levels result in many process disconnections, with technical disclosures not reaching the bottom level, and on-site execution showing a "do-it-yourself" approach, with poor quality stability.

3.3 Non-standard Material Quality Control and Procurement Management

Firstly, there is arbitrariness in the material procurement process. The technical terms in bidding documents are vague, with unclear boundaries on brands and performance, leading to fluctuations in cement strength, insufficient compatibility of admixtures, and imbalances in steel bar grades and welding material matching. This, in turn, causes batch differences and hidden risks, and the supply cycle is out of sync with the project progress, resulting in frequent on-site replacements. Secondly, on-site acceptance and inspection are lax. Quality assurance certificates and compliance certificates are copied and filled in, with insufficient witness sampling proportions and missing re-inspection items. Key indicators such as sand and gravel silt content and water content lack continuous data over the long term. The physical property control of asphalt, emulsifiers, expansion joint adhesives, and bearing rubber is rough. Warehouse stacking and moisture-proof and sun-proof conditions do not meet standards, causing material performance degradation during storage. Finally, procurement and usage records are incomplete, with interrupted batch traceability chains. Meter calibration and measuring instrument verification are overdue, and on-site batching deviates from the design mix proportions. The technical conditions and applicable boundaries of alternative materials are not clearly defined. The lowest-bid-wins principle leads to low-quality supplies and the substitution of inferior materials for good ones, resulting in discrete entity quality and an increase in rework and claim disputes.

3.4 Disordered On-site Organization and Management

On the one hand, disordered on-site organization is reflected in plan disarray and poor coordination. Weekly and daily plans are disconnected, and cross-operations lack temporal and spatial separation. The site layout is arbitrary, with material stacking encroaching on passageways and unordered mechanical access, leading to queuing for key processes and mutual interference in lifting, pouring, and transportation. Temporary power and temporary roads are repeatedly modified, affecting alignment control and proces . Concealed work acceptance is often squeezed by construction progress [3]. On the other hand, job responsibility boundaries are blurred, with construction, testing, measurement, and data personnel working independently. Sign-off and circulation are slow, and on-site supervision and patrol inspection records are delayed. There is no one to follow up on problem closure, with weak night and holiday duty arrangements. Communication between subcontractors and labor teams is fragmented, and safety warnings and finished product protection are inadequate. Construction arrangements during the rainy and high-temperature seasons are adjusted arbitrarily, resulting in rework overlap and quality fluctuations, which are ultimately concentratedly exposed before key milestones.

4. Countermeasures to Improve Quality Management of Municipal Road and Bridge Construction

4.1 Strengthen Pre-construction Design Quality Control

To strengthen pre-construction design quality control, "constructibility, manageability, and maintainability" should be embedded throughout the entire process. Firstly, improve surveying and current situation investigations, supplement key data on soft soil, groundwater, existing pipelines, and traffic organization, and simultaneously carry out multi-option technical and cost comparisons to clarify the applicable boundaries of foundation types, structural systems, and durability indicators. Secondly, enhance design depth and expression accuracy, refine construction node details, dimensional tolerances, and inspection batch divisions, and provide constraints on formwork, scaffolding, temporary structures, and traffic diversion. Use models for collision checks and clearance verifications to expose interface conflicts in advance and resolve them in the drawings. Finally, establish cross-disciplinary joint reviews and change control paths, clarify work stoppage points and sign-off requirements, ensure stable transmission of design intentions to procurement and construction sites, and provide clear and traceable references for subsequent quality monitoring and risk prediction.

4.2 Improve Construction Personnel Technical Skills and Qualities

Firstly, compile job-specific courseware and operation points around surveying and staking out, steel bar connections, formwork systems, concrete temperature control, and bridge deck details. Implement entry examinations and certification for key processes to ensure that standards are implemented by individuals. Secondly, establish a mentor-apprentice system and team competitions, set quantitative indicators such as sample quality, actual measurements, rework rates, and data consistency, and link results to pricing, awards, and subcontractor access, motivating personnel to improve through comparison. Thirdly, for processes prone to errors such as bearing installation, expansion joint treatment, drainage details, and backfill compaction, implement a "problem photo library + error collection" rolling review, forming visual warnings and retraining lists. Simultaneously, improve on-site processes for measurement review and concealed work acceptance to ensure real-time synchronization of technical disclosures, on-site supervision records, and test data, reducing information gaps. Finally, establish a rapid integration mechanism for mobile personnel and seasonal construction special training, combining safety, quality, and process interfaces in explanations to enable the team to maintain stable operational standards and quality output under different working conditions.

4.3 Standardize Material Procurement and Quality Supervision Systems

To standardize material procurement and quality supervision systems, technical standards, supply chain management, and on-site verification should be closely linked to form a closed loop from the source to the entity. Around key materials such as cement, steel bars, admixtures, asphalt, expansion devices, and bearings, clearly define performance indicators, test methods, and acceptance frequencies, and incorporate compatibility, durability, and environmental adaptability into procurement technical conditions and contract terms to avoid vague descriptions. Improve supplier access and dynamic evaluation, set weights based on historical performance, batch pass rates, delivery stability, and price reasonableness, and establish black and white lists and early warning thresholds. Implement a three-in-one system of witness sampling, re-inspection, and sample retention for incoming batches, achieve account-based and trend-based management of indicators such as sand and gravel silt content, water content, grade curves, and steel bar mechanical properties, and immediately trigger isolation and re-inspection for abnormalities. Arrange storage areas according to classification, ventilation, moisture-proof, sun-proof, and pollution prevention requirements, set first-in-first-out and expiration date management, calibrate measuring instruments on schedule, and cooperate with automatic weighing and two-dimensional code traceability to ensure accurate batching and traceability [4].

4.4 Improve On-site Construction Quality Supervision Mechanisms

Around key processes such as surveying and staking out, foundation treatment, steel bar nodes, concrete pouring, bridge deck paving, and backfill compaction, set on-site supervision points and work stoppage points, and implement first-piece approval and sample-led approaches. Supervisors should conduct daily patrols and special spot checks simultaneously, with actual measurements covering flatness, compactness, strength, alignment, and water permeability indicators, and results should be immediately recorded in ledgers and presented as trend charts. Strictly implement witness sampling, re-inspection, and sample retention, and use two-dimensional code traceability for material batches, equipment metering, and construction logs to ensure consistency between data and the actual structure. Issue rectification orders for deviations and defects, with clear responsibilities, time limits, and re-inspection methods, and only release the work after re-inspection is qualified. Organize multi-party reviews and technical verifications for key nodes to control the length of the change chain and information lag, ensuring that design intentions remain unchanged and process is uninterrupted. Implement comprehensive inspections of appearance, actual measurements, and load or functional tests before project completion and form traceable quality assessments.

5. Conclusion

In conclusion, quality management of municipal road and bridge projects must run through the "source, process, and result" levels, forming a manageable chain that is traceable, measurable, and closed-loop. Take design as the leader to consolidate constructibility and durability targets; take construction as the core to grasp key processes and interface details; take supervision and inspection as the guarantee to uphold quality thresholds with data and systems. Simultaneously, consolidate personnel capabilities, material control, and on-site organization, and clear information transmission and change control bottlenecks to ensure consistency between standards, data, and the actual structure. Through sample-led approaches, risk pre-emption, and continuous improvement, stabilize the project quality baseline and enhance the safety, durability, and operational performance of urban transportation infrastructure.

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