

Challenges and Technical Measures in Road, Bridge, and Tunnel Construction

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Abstract: Roads, bridges, and tunnels are key transportation facilities with great importance in construction. However, they face difficulties such as complex geological conditions, limited construction environments, and complicated structural stresses. Different geological layers bring high risks; the environment is restricted by space, facilities, and natural conditions; and structural loads are challenging due to dynamic forces and system changes. To solve these problems, measures such as geological survey and treatment, construction environment improvement, and structural design with construction control are applied. Through integrated technologies, systematic optimization, and precise management, construction safety and quality can be ensured, promoting the development of transportation infrastructure.

Keywords: Road bridge tunnel; construction difficulties; technical measures; structural design

Introduction

In modern transportation systems, roads, bridges, and tunnels play a central role as important links for regional economic exchange and human mobility. With rapid urbanization and increasing demand for transport, their construction scale has expanded and the level of difficulty has also grown. The construction of roads, bridges, and tunnels not only improves transport efficiency but also has long-term effects on regional economic development, city image, and people's quality of life. In practice, many challenges arise from geological, environmental, and structural conditions. Analyzing these difficulties and exploring technical measures is essential to ensure project progress, improve quality, and guarantee safety.

1. Importance of Road, Bridge, and Tunnel Construction

As key components of transportation infrastructure, roads, bridges, and tunnels play an irreplaceable role in regional connectivity and economic growth. From the perspective of transport operation, they are important nodes in the traffic network. They can cross natural barriers such as rivers and valleys, enabling smooth connections in areas that were difficult to access, and greatly shortening time and distance between regions. Bridges allow vehicles and pedestrians to cross wide waterways, while tunnels can pass through mountains to provide continuous and convenient routes. Together, they improve transport efficiency, ensure smooth logistics and passenger flow, help ease congestion, and enhance the overall quality of the transportation system.



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From the perspective of economic development, the construction of roads, bridges, and tunnels acts as a strong driver of regional growth. Convenient transport attracts investment, promotes industrial clustering and upgrading, reduces transport costs for enterprises, and increases product competitiveness. It also supports the growth of local industries and the expansion of foreign trade. At the same time, construction itself drives related industries such as building materials and engineering machinery, creating many jobs and promoting local prosperity. Road, bridge, and tunnel projects also contribute to the city's image and the improvement of residents' living standards. Modern bridges and tunnels are not only transportation facilities but also landmark structures that show a city's technical strength and cultural features. They improve travel conditions, make life more convenient and comfortable, and enhance people's sense of belonging and happiness, helping to build a harmonious and livable urban environment.

2. Construction Challenges in Road, Bridge, and Tunnel Projects

2.1 Complex Geological Conditions

In the construction of roads, bridges, and tunnels, the complexity of geological conditions constitutes a fundamental constraint on project advancement. Such complexity is primarily manifested in the heterogeneity and unpredictability of strata, with geological structures often exhibiting significant regional variation. In mountainous areas, tunnel excavation frequently encounters fault fracture zones that substantially compromise rock mass integrity. These formations are characterized by low shear strength and are highly susceptible to collapse and instability under excavation-induced disturbance, while concurrent fracture water seepage further exacerbates the weakening of the rock mass. In karst-developed regions, construction risks are particularly pronounced due to the irregular distribution of subsurface cavities and concealed river systems. Failure to detect these features in advance may result in sudden water intrusions or mud surges, potentially inundating the tunnel face, damaging equipment, and causing severe construction hazards. Excavation through weak surrounding rock presents equally severe challenges. Such rock masses typically display high plasticity and low strength, undergoing continuous

deformation upon stress release. Without the prompt implementation of appropriate support measures, phenomena such as crown settlement, sidewall convergence, and even cracking of the initial support lining are likely to occur, thereby threatening structural stability. Similarly, in bridge foundation construction, the presence of thick soft soil layers significantly reduces pile-bearing capacity, predisposing structures to uneven settlement and pier inclination under service loads. In regions characterized by stratigraphic heterogeneity, pile drilling may encounter alternating soft and hard layers, resulting in borehole deviation, accelerated tool wear, and increased difficulties in construction control.

2.2 Restricted Construction Environment

(1) Road, bridge, and tunnel construction is often limited by space, surrounding facilities, and natural conditions, all of which affect organization and technical implementation. In urban reconstruction or expansion projects, construction areas are surrounded by buildings, leaving little space. Large equipment cannot easily enter, operations are constrained, and efficiency is low. Dense underground pipelines increase excavation risks, and detection and protection are both difficult and costly.

(2) Projects crossing ecologically sensitive areas must meet stricter environmental requirements, such as strict control of dust, noise, and vibration. Near residential areas, night work must meet noise limits, requiring low-noise machinery or sound barriers, which add cost and complexity. For bridges crossing water bodies, construction platforms are affected by current and water level changes. During flood seasons, high water and strong flow threaten platform stability; during dry seasons, shallow water may block ships, delaying material transport.

(3) Tunnels crossing under rivers face high water pressure, requiring excellent waterproofing. Poor sealing of segment joints can cause leakage, threatening safety. Extreme weather also affects construction. High heat or freezing conditions disrupt concrete setting and asphalt paving, while heavy rain or typhoons can stop outdoor work, delaying schedules^[1].

2.3 Complex Structural Stresses

When revising, the structural types should be presented in the order of roads, bridges, and tunnels, employing

professional terminology to explain the load-bearing mechanisms and associated risks. By appropriately substituting vocabulary and adjusting sentence structures, the logical coherence and academic rigor of the content can be enhanced. During both construction and operation, road, bridge, and tunnel structures are subjected to multiple types of loads, and their complex stress states place extremely high demands on design accuracy and construction precision. In road engineering, pavement structures are subjected to dynamic vehicle loads. The transient impact acting on the surface layer is transmitted through the base course to the subgrade, and long-term repeated loading tends to cause fatigue damage of the surface and reflective cracking in the base course. In special sections where both lateral and vertical loads are increased, the mechanical properties of pavement materials must meet stricter requirements. Moreover, deformation induced by thermal stresses should not be overlooked; if expansion joints in bridges or portal sections of tunnels fail to effectively release thermal stress, localized structural damage may occur. In bridge construction, the structural load-bearing system is in a state of dynamic change. For long-span continuous girder bridges constructed by cantilever casting, the sequential casting of segments alters the distribution of bending and shear forces, while the movement of the form traveler changes the support points. Improper load control may easily cause alignment deviations or consolidation damage. In cable-stayed bridges, the accumulation of tensioning errors in stay cables may lead to excessive displacement of the main girder, while deviation or misalignment of the main towers can further compromise stability. In tunnel construction, excavation disturbs the original rock stress field, leading to stress redistribution and the formation of loosened zones and plastic regions. If the support system does not match the deformation of the surrounding rock, instability is likely to occur. In sections with composite strata, the uneven distribution of pressure often leads to stress concentration at the junctions, making these areas prone to cracking.

3. Technical Measures to Address Construction Challenges

3.1 Geological Survey and Treatment Technologies

(1) In the early stage of construction, a multi-

technology survey system should be established. Geological drilling, seismic reflection, and ground-penetrating radar are combined to build a 3D data network, enabling accurate analysis of faults, karst development, and weak interlayer distribution. Core sampling with in-situ testing provides reliable mechanical parameters of the rock mass, supporting later technical planning. Geophysical methods significantly improve efficiency: high-density electrical surveys can locate groundwater with meter-level accuracy, while surface wave testing quickly identifies stratification.

(2) Different geological conditions require targeted treatments. In fault fracture zones, advanced grouting with small-diameter pipes, combined with pipe shed support, can increase rock integrity by more than 30% and improve deformation resistance. In karst areas, double-fluid grouting is used, with cement–sodium silicate ratios adjusted according to cave fillings; in water-rich zones, it forms rapid sealing curtains with a diffusion radius of 5–8 m. In weak surrounding rock, hollow grouting bolts combined with lattice girders transfer load, while shotcrete protects the rock surface and prevents weathering.

(3) For bridge foundations, cement-soil mixing piles can form composite foundations, increasing bearing capacity by 1.5–2.5 times. Drilled cast-in-place piles integrated with inclinometer systems allow real-time trajectory monitoring and correction, keeping vertical deviation within 1%, thus ensuring foundation quality and overall bridge stability^[2].

3.2 Construction Environment Optimization Technologies

The systematic optimization of construction environments should be advanced through technological innovations across three dimensions: spatial utilization, pollution control, and adaptation to special environments. At the level of site planning, Building Information Modeling (BIM) is employed to generate three-dimensional models of construction sites, enabling precise delineation of machinery operating radii and material storage zones. By dynamically simulating construction workflows, site utilization efficiency can be improved by 20%–30%. Modular construction equipment designed for confined spaces incorporates foldable operating devices that reduce the footprint

by more than 50%, while hydraulic drive systems achieve millimeter-level operational precision, thereby meeting the requirements of construction in complex environments. For the protection of underground pipelines, multi-frequency electromagnetic detection technology is adopted, capable of identifying both metallic and non-metallic pipelines with a positioning error controlled within 10 cm. When combined with static excavation equipment, the risk of pipeline damage can be minimized. The pollution control system addresses noise, dust, and water pollution management. Low-noise hydraulic breakers, integrating vibration-damping devices with soundproof enclosures, can reduce operational noise by 15–20 dB, meeting the acoustic requirements for nighttime construction. A three-dimensional dust suppression network composed of mist cannons and perimeter spray systems effectively maintains PM10 concentrations below 0.5 mg/m³ on construction sites. Permeable pavement subgrades facilitate natural rainwater infiltration, thereby reducing surface runoff pollution. In cross-water construction, the use of caisson-type working platforms ensures the isolation of the working zone from the water body through sealed steel box structures. A slurry recovery system installed at the base of the platform enables wastewater recycling after treatment, achieving a reuse rate of more than 80%. For tunnel waterproofing, the principle of “prevention first with a rigid-flexible combination” is adopted. Pre-applied self-adhesive waterproof membranes, consisting of polymer materials and composite adhesive layers, accommodate tensile and shear deformations while hot-melt welding of joints ensures continuity of waterproofing. The drainage system is designed with three filtration stages: circumferential blind drains collect seepage, which is directed via longitudinal drains to a central water channel and then discharged by pumps. Single-cycle drainage capacity reaches 100 m³/h, satisfying the requirements of high water pressure environments. Under extreme climatic conditions, intelligent temperature-control systems are employed for concrete works, adjusting mixing water temperatures and pre-cooling aggregates to maintain placing temperatures within 5–30 °C. For asphalt paving, infrared temperature monitoring equipment tracks the thermal profile of the mixture to ensure compaction quality and compliance^[3].

3.3 Structural Design and Construction Control Technologies

(1) In structural design, stress simulation and parameter optimization are essential. Finite element analysis with material and geometric nonlinearities enables multi-condition stress evaluation. Topology optimization reduces self-weight by 10–15% in long-span bridges. Cable force optimization in cable-stayed bridges balances bending moments and reduces tower stress by 8–12%. Tunnel support systems use load–structure models to match stiffness of primary and secondary linings, achieving balanced stress distribution and avoiding concentration.

(2) During construction, precise control relies on automated monitoring. In cantilever bridge construction, total stations and sensors record elevation, alignment, and stress hourly. Data automatically adjust formwork elevation, keeping closure segment deviations under 5 mm. Cable tensioning with intelligent hydraulic systems maintains errors within ±1%, with data transmitted wirelessly for closed-loop control.

(3) Tunnel construction applies the “three-step, seven-bench” excavation method to control deformation rates. Monitoring frequency is adjusted by rock grade (every 2 days for grade III, daily for grade V). Advanced geological prediction combines radar and infrared water detection to locate anomalies within 30 m ahead, producing 3D models to guide construction. Concrete quality is ensured by rebound hammer testing combined with core drilling, confirming strength compliance^[4].

Conclusion

Road, bridge, and tunnel projects face multiple difficulties, including complex geology, restricted environments, and complicated structural stresses. However, with geological survey and treatment, adverse conditions can be effectively managed. Environment optimization technologies reduce external impacts, while structural design and control ensure safe and precise construction. Together, these measures provide strong support for overcoming challenges in transportation infrastructure projects.

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