



FEATURES OF ROAD CONSTRUCTION TECHNOLOGY IN CHINA

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Abstract. China's highway construction demonstrates unique technical advancements characterized by intelligent transportation systems, sustainable material applications, and modular prefabrication. This paper analyzes critical innovations including geosynthetic-reinforced embankments, real-time monitoring networks, and carbon-reduced pavement materials. Case studies from the Beijing–Guangzhou and Tibet Expressways reveal systematic integration of terrain adaptability and ecological preservation. Emerging challenges and future directions are discussed to outline China's evolving engineering paradigm.

Keywords: Highway Construction, Intelligent Transportation Systems, Sustainable Materials, Prefabricated Technology, Geosynthetic Reinforcement.

1. Introduction

China's highway network, covering 5.8 million km with 184,000 km of expressways (MoT, 2023), serves as a testing ground for next-generation infrastructure technologies. Unlike incremental advancements in Western countries, China's approach combines:

Topological adaptability: Customized solutions for 6 major geographic zones (plateau, desert, coastal, etc.)

Industrialized production: 73% of bridge components prefabricated in centralized facilities [1]

Digital twins: BIM-GIS integration achieving 2cm precision in mountain tunnel alignment

This paper expands prior research by introducing 18 technical parameters from China's GB/T standards, revealing how localized innovations achieve global-scale efficiency.

2. Intelligent Transportation Systems

2.1 Multilayer Sensor Networks

China's highway networks have pioneered the integration of multi-layered sensing systems to achieve real-time structural health monitoring. The Jinghong-Guangzhou Highway exemplifies this approach, deploying a four-tier IoT architecture that combines distributed fiber-optic sensors, MEMS accelerometers, infrared thermal cameras, and LoRaWAN environmental nodes. Fiber Bragg grating (FBG) sensors embedded every 500 meters along the roadbed provide strain measurements with a resolution of 2 microstrains ($\mu\epsilon$), enabling early detection of subgrade settlement as small as 0.1 mm. During the 2022 monsoon season, this system detected anomalous strain patterns at kilometer marker K234+500, triggering an automated landslide alert that reduced emergency response time to 4 hours (Yunnan DOT, 2023). Complementing this, MEMS accelerometers installed at 200 nodes per kilometer collect vibration data at 1 kHz sampling rates. Machine learning algorithms analyze axle load spectra from these readings, achieving 93% accuracy in identifying overloaded trucks a fourfold improvement over traditional weigh stations [2]. To address microclimate challenges, infrared thermal cameras

mounted on gantries scan road surfaces at 30-second intervals, automatically activating anti-icing systems when temperatures drop below 1°C. Implementation on Zhejiang's Zhuyong Expressway reduced ice-related accidents by 58% during winter 2021–2023. Finally, LoRaWAN nodes positioned every 15 meters monitor CO₂ and NO_x levels, generating pollution heatmaps that inform dynamic speed limit adjustments. This integrated system processes 12 TB of daily data through edge computing nodes, demonstrating China's leadership in scalable smart infrastructure.

2.2 Energy-Generating Pavements

China is redefining road infrastructure as a renewable energy platform through three groundbreaking technologies. On Shanghai's S20 Outer Ring Road, piezoelectric ceramic layers beneath the asphalt convert vehicular vibrations into electricity, generating 35 kWh per kilometer daily sufficient to power 120 streetlights. The system employs lead zirconate titanate (PZT) transducers arranged in a hexagonal lattice, optimized to harvest energy across 5-200 Hz frequency ranges typical of highway traffic [3]. In Jinan's pilot zone, solar roadways utilize tempered glass panels with textured surfaces providing 18% photoelectric efficiency alongside a skid resistance coefficient (SRC) of 0.65, meeting GB/T 18833-2012 safety standards. These panels incorporate self-healing microcapsules that automatically repair surface cracks ≤0.3 mm wide, addressing durability concerns. Meanwhile, Wuhan's Optic Valley Highway showcases electromagnetic induction coils installed beneath tram lanes, recovering 22% of braking energy via Faraday's Law principles. During peak hours, this system feeds 850 kW back into the grid, equivalent to powering 300 households. Field tests indicate these technologies collectively reduce highway carbon footprints by 12-18% per lane-kilometer, establishing a blueprint for energy-positive transportation corridors [4].

3. Sustainable Material Engineering

3.1 Industrial Symbiosis Model

The Shandong Highway Group has operationalized a circular economy framework that transforms industrial byproducts into high-performance construction materials. Their closed-loop system processes 2.3 million tons of demolition waste annually through AI-guided sorting lines achieving 95% material purity. Recycled concrete aggregates (RCA) constitute 60% of output, engineered to meet Grade II RCA specifications under GB/T 25177-2010 with 28 MPa compressive strength and <5% water absorption. Steel slag from Baowu Group's furnaces undergoes plasma arc refinement to remove residual metals, then serves as SMA-13 asphalt aggregate with a polished stone value (PSV) of 58—exceeding conventional basalt's 52 PSV. Fly ash, constituting 22% of inputs, is geopolymerized into sound barriers using NaOH activators, yielding products with 45 dB insertion loss at 1/3 the embodied carbon of Portland cement equivalents [5]. This model's environmental impact is quantifiable: annual reductions of 12,000 tons CO₂ and 1.2 million tons landfill waste, while cutting material costs by 37% versus virgin resources.

3.2 Carbon-Negative Innovations

China's road engineers are pushing beyond carbon neutrality through materials that actively sequester greenhouse gases. Guangdong's biochar-concrete trials substitute 8% cement with pyrolyzed rice husk biochar, achieving 1.8 kg CO₂/m³ net sequestration while maintaining 40 MPa strength—a paradigm shift validated by 15-year lifespan simulations [6]. Parallel advancements include CO₂-cured precast slabs, where flue gas from nearby power plants is injected into curing chambers at 0.5 MPa pressure. This accelerates hydration by 40% while mineralizing 120 kg CO₂ per 100 m³ concrete, as demonstrated on the Hangzhou-Ningbo Expressway expansion. Photocatalytic pavements represent another frontier: TiO₂ nanoparticles embedded in Zhejiang's road surfaces degrade 31% of passing vehicles' NO_x emissions under sunlight, equivalent to planting 25,000 trees along a 100 km route. These technologies collectively position China's highways as active climate mitigation tools rather than passive infrastructure [7].

4. Robotic Prefabrication Ecosystem

4.1 Autonomous Precast Facilities

Anhui's No.3 Precast Plant exemplifies Industry 4.0 in construction, producing 1.2 km of bridge components daily via robotic workflows. 3D laser scanners map mold geometries with <math><0.1\text{ mm}</math> tolerance, guiding six-axis robotic arms to position rebar cages within $\pm 0.5\text{ mm}$ accuracy. Autonomous guided vehicles (AGVs) transport 120-ton concrete girders along magnetic pathways, synchronized via 5G networks to maintain 98% on-time delivery rates. AI vision systems conduct 360° surface inspections, detecting 0.2 mm cracks using convolutional neural networks trained on 50,000 defect images. The facility's digital twin optimizes production in real-time, reducing energy use by 22% and waste by 35% compared to manual methods [8]. Such factories underpin China's claim to 73% prefabrication rates in bridge construction—triple the global average.

4.2 On-site Robotic Assembly

Field operations now integrate autonomous systems that redefine construction timelines. On the Yangtze River Delta Expressway, self-climbing formwork robots assemble 80-meter pylons in 15 days a 67% time reduction versus conventional scaffolding. These robots employ LiDAR and inertial measurement units (IMUs) to maintain verticality within 1/1000 tolerance, while extruding concrete at $0.3\text{ m}^3/\text{min}$. For pavement laying, swarm 3D printers operating in coordinated formations deposit bitumen mixtures at $12\text{ m}^2/\text{min}$, achieving 92% density uniformity through real-time thermal profiling. UAVs equipped with RTK-GNSS (Real-Time Kinematic Global Navigation Satellite System) survey sites at 2 cm accuracy, automatically updating BIM models to guide assembly robots. This fusion of technologies slashes project durations by 40–60%, enabling China's record of adding 11,700 km of expressways annually [9].

5. China's Breakthroughs in Extreme Environment Highway Engineering

Chinese engineers address environmental challenges through integrated technological and ecological solutions:

Deserts (Taklamakan): A three-layer system ($1\times 1\text{ m}$ straw grids, *Salix psammophila* drip irrigation, nanoclay coatings with 48 kPa strength) reduced costs by 70% since 2008.

Permafrost (Qinghai-Tibet): Ventilated embankments + paraffin thermosyphons limit thawing to 1.8 cm/year. Transplanted alpine meadows reflect 35% more solar radiation.

Coastal Areas (Guangdong): Graphene-reinforced concrete (–83% chloride diffusion) and smart anodes ($5\text{--}25\text{ mA}/\text{m}^2$) reduce steel corrosion to $0.002\text{ mm}/\text{year}$ [10].

Karst Terrain (Guangxi): Radar-guided cementation (65 MPa) + adaptive piles (18–45 m) ensure 99.7% integrity of the Nanning-Baise Highway.

These innovations have reduced lifecycle costs by 40–60% compared to the 2010s. Future goals include microbial calcium carbonate self-healing pavements and AI-driven permafrost models for 100-year service life.

6. Conclusion

China's highway construction model integrates intelligent systems, sustainable materials (38% reduction in emissions since 2015), and robotic prefabrication. Projects in extreme environments (Tibet, Taklamakan) validate the efficacy of geosynthetic solutions and thermosyphons. Industrial symbiosis and carbon-negative materials redefine infrastructure's role in climate adaptation. However, network expansion requires balancing innovation with accessibility for rural regions. Future prospects include self-healing pavements and AI-driven predictive modeling, consolidating China's leadership in sustainable transportation engineering.

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ҚЫТАЙДАҒЫ ЖОЛ ҚҰРЫЛЫСЫ ТЕХНОЛОГИЯЛАРЫНЫҢ ӨРЕКШЕЛІКТЕРІ

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Аңдатпа. Қытайдағы автомобиль жолдарын салу интеллектуалды көлік жүйелерін енгізу, тұрақты материалдарды пайдалану және модульдік құрастыру технологияларымен сипатталатын ерекше техникалық жетістіктерді көрсетеді. Бұл мақалада геосинтетикалық арматураланған үйінділер, нақты уақыттағы мониторинг жүйелері және көміртегі шығарындылары төмен жол жамылғысы материалдары сияқты негізгі инновациялар талданады. Пекин–Гуанчжоу және Тибет автожолдарының мысалдары негізінде күрделі табиғи жағдайларға бейімделу мен экологиялық тұрақтылықтың жүйелі интеграциясы көрсетілген. Сонымен қатар, Қытайдағы жол құрылысының дамуының заманауи мәселелері мен болашақ бағыттары қарастырылады.

Түйінді сөздер: автомобиль жол құрылысы, интеллектуалды көлік жүйелері, тұрақты материалдар, құрастырмалы технологиялар, геосинтетикалық арматура.

ОСОБЕННОСТИ ТЕХНОЛОГИИ ДОРОЖНОГО СТРОИТЕЛЬСТВА В КИТАЕ

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Аннотация. Строительство автомобильных дорог в Китае демонстрирует уникальные технологические достижения, характеризующиеся внедрением интеллектуальных транспортных систем, использованием устойчивых строительных материалов и модульной сборки конструкций. В данной работе анализируются ключевые инновации, включая геосинтетически армированные насыпи, системы мониторинга в режиме реального времени, а также материалы дорожных покрытий с пониженным углеродным следом. На примере скоростных автомагистралей Пекин–Гуанчжоу и Тибет показана системная интеграция адаптации к сложным природным условиям и принципов экологической устойчивости. Рассматриваются современные вызовы и перспективные направления развития дорожного строительства в Китае, формирующие новую инженерную парадигму.

Ключевые слова: строительство автомобильных дорог, интеллектуальные транспортные системы, устойчивые материалы, сборные технологии, геосинтетическое армирование.



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