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SUPER ENGINEERING

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# Construction management and technical innovation of the Beijing–Shanghai High Speed Railway

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Supervision Units: Gansu Railway First Institute Engineering Supervision Co., Ltd., Railway Fourth Institute (Hubei) Engineering Supervision and Consulting Co., Ltd., Consortium of Shanghai Xianxing Construction Supervision Co., Ltd., Huatie Engineering Consulting Co., Ltd., Consortium of CIECC Engineering Construction Supervision Co., Ltd., Beijing Tiecheng Construction Supervision Co., Ltd., among others.

## 1 Project overview

The Beijing–Shanghai High Speed Railway (HSR) represents a major national strategic transportation project in China that is characterized by the largest-scale one-time investment in the country. At the time, it was the longest HSR constructed in a single phase, with the highest technical standards in the world. Acting as an HSR artery between the Northern and Eastern regions of China, the Beijing–Shanghai HSR is the busiest HSR with the highest ridership in the country and the world at large. Additionally, it is the only commercial HSR consistently operates at a speed of 350 km/h globally.

The railway originates from Beijing South Railway Station and passes through four provinces and three municipalities, namely Beijing, Hebei, Tianjin, Shandong, Anhui, Jiangsu, and Shanghai, terminating at Shanghai Hongqiao Railway Station. Totaling 1318 km, the railway boasts a designed and maximum operation speed of 350 km/h (the operation speed was 300 km/h in the initial period). The maximum gradient is 20‰, and the minimum curve radius is 7000 m (reduced to 5500 m under challenging conditions). The primary rolling stock employed are electric multiple units (EMUs) of two speed levels: 300 and 350 km/h. Construction of the Beijing–Shanghai HSR officially commenced in April 2008, track-laying was completed in November 2010, and it opened to traffic on June 30, 2011.

## 2 Key technological innovations of the Beijing–Shanghai HSR

The Beijing–Shanghai HSR is characterized by high design standards, cutting-edge system technologies, large-scale construction, and rigorous environmental protection criteria. With this project, we have established the theoretical framework for China's HSRs, built stable and reliable infrastructure with high track regularity, improved major technologies and equipment, developed construction management and safe operation technologies, formulated technical standards with independent intellectual property rights, and achieved a series of globally recognized major technological innovations.

### 2.1 Key technologies in the construction of the Beijing–Shanghai HSR infrastructure

The Beijing–Shanghai HSR has developed breakthrough key technologies for HSR infrastructure construction under complex engineering conditions, established a standard system and complete technologies for constructing 350 km/h HSRs.

1) In the field of earthworks technology, innovative complete technologies for HSR earthworks rigid piles and composite foundation under demanding engineering conditions have been introduced. Given the complex

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**Fig. 1** The Fuxing EMU train traveling on the Beijing–Shanghai HSR.

geological conditions of earthworks sections, rigorous settlement control standards, and line-shaped flexible loads, design methods for reinforcing foundations with rigid piles and controlling settlements have been proposed. Various foundation structures, including embedded U-shaped structures, pile slabs, pile nets, pile rafts, and carrier piles, have been developed and employed, effectively solving the technical problems of post-construction settlement and dynamic stability of ballastless track earthworks in deep soft soil areas under diverse environmental conditions. A leveling design method that controls deformation by adjusting pile types and design parameters has also been introduced, successfully tackling the technical difficulties associated with the coordinated control of large-scale railway station earthworks settlement.

2) In the field of track technology, innovations have been introduced in the continuously welded rail (CWR) construction technology for ballastless tracks on extra-long HSR viaducts. Theories of computation and design methods have been established for ballastless track CWR lines on extra-long, large-span bridges, which resolve the issue of deformation coordination among bridges, ballastless tracks, and CWR lines on elevated sections of HSRs. Furthermore, a dynamic theory of the high speed train-turnout-longitudinal ballastless track-bridge system has been developed, along with new structures for tracks and bridges in the ballastless turnout area. Inspection and monitoring technologies have also been developed, forming a comprehensive system for designing, laying, inspecting, and evaluating CWR tracks on extra-long viaducts. As a result, ballastless tracks and CWR lines have been laid on bridges of 165 km long and with a span of 180 m.

3) In the field of bridge technology, innovative construction technologies have been developed for complex structure HSR bridges. One notable achievement has been the construction of the Dashengguan Yangtze River Bridge, which presented challenges such as high speed, deep water, large span, and the need for six-track railways. A new plate-truss composite structure has been employed to construct this bridge, which features a double-arch design with a 2 × 336 m main span, three main trusses, and an integral steel bridge deck for distribute weight. Additionally, the technology for main beams with three-piece or multi-piece truss structures has been introduced. The development and application of Q420qE, a new type of high-strength thick plate bridge structural steel, solves the problem of bearing six-track heavy loads and controlling structural deformation under high speed conditions on large-span bridges. Moreover, a new technology for active control and adjustment of double-arch bridge closure construction using multiple stay cables has been invented, successfully completing the world’s largest-span HSR bridge.

4) In the field of tunnel technology, extensive use of micro-pressure wave buffering measures has been implemented to effectively mitigate the impact of micro-pressure waves generated by trains passing through tunnels on the surrounding environment.

5) In the field of electrification technology, a comprehensive dynamic simulation platform has been established for HSR overhead contact line system (OCS) calculation and traction power supply systems. A high-tension suspension system for HSR OCS has been developed, and the creation of a chromium-zirconium-copper ternary alloy for high-strength, high-conductivity contact wires fills a domestic technology gap and achieves a world-leading level.

6) In the field of integrated transport hub planning and design technology, there has been a focus on incorporating both urban and railway overall planning. The railway hub planning principle of segregating passengers and freight by utilizing separate lines, with passenger lines at the inner part and freight ones at the outer rim of the hub, and establishing multiple, clearly defined, and seamlessly integrated passenger stations to share passenger transport duties, has been proposed. Additionally, the principle for dividing lines and field arrangements have been put forward for large passenger stations with multiple lines. To analyze, calculate, and evaluate the operational capacity and efficiency of these stations, station design analysis models have been constructed, and a train operation dynamic simulation software has been developed. This systematic approach allows for the rational determination of station size and throat area layouts. Consequently, technologies for large-scale integrated transport hubs that efficiently coordinate various modes of transport have been established, leading to the design and construction of world-class large passenger stations and integrated transport hubs like Tianjinxi, Jinanxi, Nanjingnan, and Shanghai Hongqiao.

## 2.2 Key technologies for Beijing–Shanghai HSR train

The Beijing–Shanghai HSR enables further breakthroughs in key technologies for HS trains, including the proposal of a large-scale dynamical system for train-track-network-airflow coupling as well as the building of a complete dynamical model for the analysis of HS train coupling. The progress leads to the holographic simulation for the spatial-dynamical analysis of HS trains and the corresponding working environments, and the efficient computation of train-airflow coupling dynamics, providing a solid theoretical foundation for the performance design of HS train. With the building of the simulation testbed for 600 km/h HS train and the breakthrough in wheel-rail interaction at 380 km/h, the critical speed for bogie tops 550 km/h. Furthermore, a dynamic model testbed for 500 km/h HS train has been established. Through aerodynamic simulation calculations, wind tunnel tests, and dynamic model experiments, the overall aerodynamic profile of the train has been optimized, resolving challenges pertaining to aerodynamic lift, lateral forces, tunnel effects, and issues arising from high speed encounters. As a result, the aerodynamic drag of the head car is cut by more than 8%. Additionally, a regression formula for pantograph contact force variation with speed in active control mode has been proposed, which is then employed to the strategy development of pantograph active control, ensuring the stable current collection for dual pantographs.

China takes the lead in operating its 350 km/h EMUs "*Fuxing*," the China Standard model with complete independent IPRs of China and world-leading technologies. The success in the speed step-up test (380−420 km/h) at the integrated testing section translates into the stable and long-distance operation of Beijing–Shanghai HSR at high speed, contributing to the building of a complete technology set for the design, manufacturing, verification, evaluation, and optimization of the whole train. As the line helps elevate China's manufacturing industry for railway equipment, a comprehensive standard for HS train technology has taken shape.

The Beijing–Shanghai HSR project helps innovate CTCS-3 for HSRs where network interconnectivity is achieved thanks to the compatibility of multiple train control systems and the introduction of the GSM-R based bidirectional communication integration. As the optimization for high speed switching among different wireless networks and the corresponding testing approaches for dynamic simulation are proposed, key technical challenges have been resolved, such as the modeling of the dynamic control curve, wireless coverage redundancy at parallel railway lines, and interconnectivity with conventional speed railway. The requirements for the safe operation of 350 km/h EMU trains with at least 3-min headway are met. The development of core equipment and software for the train control system, along with the building of the technology system that covers design, manufacturing, integration, and evaluation, helps secure the industrialization of China's train control equipment.

The testing and verification innovations for tracks, OCS, communication, signaling, vehicle dynamics as well as other aspects of the Beijing–Shanghai HSR facilitate the comprehensive and continuous testing and verification of the line at 350–385 km/h, contributing to the development of the technical regulations concerned. Along with the integrated test at 380 km/h, the structural dynamics of ballastless track, earthworks and bridge at 380–420 km/h as well as the changing pattern of aerodynamics as EMUs meet in tunnels are studied and explored. The project leads to the understanding of the coupling relations between wheel and rail, pantograph and catenary, as well as that among train, track and bridge. It contributes to the verification of the high speed adaptability of civil engineering, EMU trains, traction power supply, communication and signaling. The CRH380 EMU train —a 16-car configuration model equipped with double pantographs - tops 486.1 km/h at the integrated test section of the Beijing–Shanghai HSR, a new world record for the testing of an operational railway.

## 3 Project management innovation on the Beijing–Shanghai HSR

The Beijing–Shanghai HSR is a vast engineering project. Given its complexity and distinct systematic features in construction and organization, the line presented significant challenges to project management. The large amount of coordination invested in land acquisition, housing demolition, environment protection, and the handling of terrestrial relations leads to the building of a dedicated leadership group for the construction of Beijing–Shanghai HSR by the State Council. With 16 national ministries and commissions, as well as 7 provinces and municipalities including Beijing and Tianjin as its members, the leadership group provides guidance to the Party Committee of the Ministry of Railways (MOR) for overall coordination, thorough organization and high-quality construction. As the Beijing–Shanghai HSR Co., Ltd is built up by the MOR as the project entity, regulative procedures are strictly followed in major decision-making for efficiency and compliance, during which the entity gives full play to its due part. Additionally, the Beijing–Shanghai HSR Construction Headquarters is established – another name for the Beijing–Shanghai HSR Co., Ltd., mobilizing departments across the railway sector to oversee all aspects of construction organization and management.

The Beijing–Shanghai HSR helps innovate the way HSR project is managed. Throughout the construction process, the MOR acts in line with the world's highest standards possible, innovates the model of systematic organization, collaborative advancement and standardized management. A "six-in-one" target control system is established, which integrates quality, safety, schedule, investment, environmental protection, and stable progress. With the purpose to standardize mechanism building, personnel allocation, on-site management and process control, the system takes on a mechanical, factory-based, digital and professional approach to focus on the technologies applied, project management, operation protocol and process control. As the project serves as the foundational model for railway projects in China, the above-mentioned efforts ensure the scientific, orderly, and high-quality progress of the project, leading the extensive construction, operation and management of high-standard HSR network. The standardized management system covers all aspects of engineering management.

In terms of quality management, effective control measures are implemented for every aspect of project management and construction. With equal importance attached to quality awareness, quality assurance and the quality of project results, construction processes and workflows are put under strict regulations, which translates into 100% pass rate for both project acceptance and quality inspections, constituting a “preeminent project” in China’s railway construction.

With regards to safety management, the project draws on the internationally recognized safety management systems of OSHMS and HSE, and incorporates the unique characteristics of the project, which leads to the building of a safety assurance system with ideology, technology, economy, organization, and risk control at its core. The “safety first” philosophy is integrated into the management process by all stakeholders.

For schedule management, with full consideration given to both track laying and girder/bridge erection on one hand and integrated commissioning and test (ICT) on the other, a corresponding system centered on organization and coordination, resource allocation, and technical plans has been developed. Thanks to the efforts, the project is completed in 3.5 years, 1.5 years ahead of the 5-year duration approved by the state, showcasing the “Chinese speed” and setting a record in railway construction history.

In terms of investment control, an all-dimensional, whole-process investment control philosophy where more revenue is generated amid management optimization is in place. As a result, kick-off budget-making, step-by-step investment tracking, comprehensive investment control, and as-built settlement are incorporated into the investment control management system, as so to regulate the management behavior.

To address environmental concerns, a corresponding management system is established, as so to vigorously protect the environment, conserve land resources, minimize pollution, and foster a harmonious environment. In this regard, environmental protection measures are designed, conducted and accepted alongside the main project to realize “zero pollution.”

For stable progress, sound labor management systems are developed for both railway staff and migrant workers, the latter of which are put under detailed management. The religious beliefs and local customs along the line are respected, while land acquisition and demolition are carried out in a law-based manner. Thanks to the sound coordination mechanisms with local governments at all levels, compensation of affected households as well as other sensitive issues are properly resolved.

## 4 Conclusions

The Beijing–Shanghai HSR is a flagship project amid the HSR engineering of China. It contributes to the building of the technological innovation platform and to that of the demonstration platform for project construction, operation and management. As it greatly improves the technology, equipment and standard systems for China’s HSR, the project helps scale new heights for the nation’s capacity for independent innovation. The high quality of the project has laid a robust foundation for its safe and efficient operation. Since its inauguration over a decade ago, the Beijing–Shanghai HSR has secured continuous growth in passenger traffic, consistent improvements in service quality, a strong commitment to safety and punctuality as well as sound performance in economic returns, setting a global benchmark for the commercial operation of HSRs.

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