

Chapter 4: Construction: Two Thousand Days and Nights to Forge a Masterpiece Project

The construction of the Beijing-Shanghai HSR adhered to the principle of “A Century Project, Quality First,” supported by world-class technologies and management expertise. The project implemented a comprehensive quality control system through all phases from design and construction to final acceptance, with clearly defined responsibilities for all participating entities, including construction, design, contracting, consulting, and supervision teams. A robust quality management framework was established, featuring strict compliance with standardised constraints from sub-projects to individual work packages, real-time digitalised monitoring through advanced data systems, and expert-driven quality assurance protocols. This meticulous approach forged what is now recognised as a world-class infrastructure benchmark.

4.1 How Many Years Did It Take to Build the Beijing-Shanghai HSR?

How long was the construction period of the Beijing-Shanghai HSR? At first glance, the construction timeline appears to be 3 years—commencing with the groundbreaking ceremony on April 18, 2008, and concluding with full operation on June 30, 2011. However, a comprehensive review reveals the actual duration was 5 years, as documented in official records. According to the 2007 approval of the feasibility study for the Beijing-Shanghai HSR, the construction was to be completed in 5–5.5 years. At the end of 2007, the guiding construction organisation plan prepared by the Beijing-Shanghai HSR Company also specified 5 years, comprising 4 years for physical construction and 12 months for integrated testing and trial operation.

However, this 5-year period was calculated based on construction commencing in early 2008, with all construction works to be completed by early 2012 and operations commencing in early 2013. In reality, the opening of the railway was advanced by 1.5 years. So how was this 1.5-year acceleration achieved? Originally, the groundbreaking ceremony for the Beijing-Shanghai HSR was scheduled for early January 2008. However, coinciding with this time, a severe ice and snow disaster struck southern China, causing the ceremony to be postponed until April. Nevertheless, construction teams had already mobilised and commenced work in January 2008, with nearly 100,000 construction personnel deployed along the entire route. Among the sixty-eight prioritised preliminary projects identified in the construction plan, all were fully underway by April of that year. By September, all forty-eight beam fabrication yards had been completed. Against this backdrop of a strong start, the Leading Group Office convened a meeting in September 2008 to analyse and study the progress. Based on optimised construction planning and design, it was proposed that

the overall project timeline could potentially be shortened by 1 year. This marked the first adjustment requirement to the Beijing-Shanghai HSR construction plan.

In late January 2009, the MoRs conducted a comprehensive inspection of the entire project and, observing smooth progress, proposed another acceleration, targeting full line opening by early October 2011. This marked the second adjustment to the Beijing-Shanghai HSR's construction plan. While schedule adjustments, either advancement or delay, represent normal occurrences in major construction projects, modifications to the construction organisation plan demand rigorous treatment. Such changes must be grounded in scientific demonstration and undergo strict decision-making procedures. The adjustment to the Beijing-Shanghai HSR's construction plan was implemented only after obtaining approval at the third meeting of the Construction Leading Group, following due process.

The Beijing-Shanghai HSR is the world's longest trunk HSR line constructed in a single phase. At that time, although China had previously built the Wuhan-Guangzhou and Zhengzhou-Xi'an HSR lines, insufficient experience in constructing the Beijing-Shanghai HSR still presented unprecedented challenges. Therefore, the initial project timeline design intentionally incorporated buffer periods. Thanks to exceptionally thorough preparations, the project progressed remarkably smoothly in practice—this became the fundamental rationale behind the adjustability of the construction organisation plan.

Beyond these, two primary factors critically influenced the project timeline: one is land acquisition and relocation, and the other is key engineering challenges.

In many construction projects, delays often occur due to unsatisfactory progress in land acquisition and resident relocation. As early as 2001, at the request of the MoRs, the NDRC and the Ministry of Land and Resources issued notices to provinces and cities along the Beijing-Shanghai route regarding reserving land for the Beijing-Shanghai HSR construction. By the end of 2007, to ensure priority commencement of key projects, the Ministry of Land and Resources pre-approved land use quotas exceeding 6,000 mu (approximately 400 hectares). Regarding soil and water conservation, the Ministry of Water Resources approved the comprehensive soil and water conservation plan for the entire route in 2006. With support from various ministries and local governments, the land acquisition and relocation process proceeded exceptionally smoothly. Meanwhile, as previously mentioned, the preparatory work for the Beijing-Shanghai HSR was exceptionally thorough—whether in scientific research, engineering experiments, or design document optimisation. Notably, 90% of the full route's design documents had been delivered by the project's commencement, a remarkable achievement.

The other critical factor is the key and challenging projects, also known as critical-path projects. The term “critical-path projects” refers to bottleneck components that determine whether the entire project can be completed on schedule. If these sections are delayed, the entire project will be delayed. For the Beijing-Shanghai HSR, the foremost critical-path project was the Nanjing Dashengguan Yangtze River Bridge.

By 2005, all technical and decision-making preparations for the Beijing-Shanghai HSR were essentially complete, though the project had not yet received official approval for initiation due to certain reasons. To ensure smooth progress once construction began, the HSR Office of the MoRs and the Preparatory Group of the Beijing-Shanghai HSR Co Ltd. proposed in 2005 that the Nanjing Dashengguan Yangtze River Bridge be approved as a standalone project. With strong support from relevant authorities, the bridge was granted independent project approval on December 22, 2005. By June 2006, its feasibility study report was approved, and authorities greenlit early-phase construction, allowing work to begin 1.5 years ahead of the full-line commencement.

Another independently approved project for the Beijing-Shanghai HSR was the reconstruction and expansion of Beijing South Station. This project was initiated to coordinate with the construction of the Beijing-Tianjin Intercity Railway, and thus received approval from the NDRC as early as May 2005, with construction commencing in late December 2005. If using the Nanjing Dashengguan Yangtze River Bridge's start date as the benchmark, the total construction period was 5 years, but if counting from Beijing South Station's reconstruction, the duration extends to 5.5 years.

Several critical milestones during the construction of the Beijing-Shanghai HSR are particularly noteworthy.

On April 18, 2008, Premier Wen Jiabao of the State Council attended the groundbreaking ceremony for the Beijing-Shanghai HSR in Beijing, officially announcing the full-line commencement of construction. During the ceremony, Premier Wen also unveiled the plaque for the Beijing-Shanghai HSR Co., Ltd., marking the formal establishment of the entity responsible for the project's implementation.

On June 12, 2008, the Dadian Beam Yard successfully completed the pouring of the first 900-tonne, 32-m ballastless box girder. By June 20, 2010, the installation of all 29,251 prefabricated 900-tonne box girders along the Beijing-Shanghai HSR mainline was fully completed.

On September 28, 2009, the Nanjing Dashengguan Yangtze River Bridge achieved structural closure.

On July 19, 2010, track-laying commenced on the entire Beijing-Shanghai HSR. By November 15, 2010, track-laying was fully completed across the entire Beijing-Shanghai HSR.

On December 3, 2010, the "Harmony" CRH380A new-generation high-speed EMU set a record speed of 486.1 km/h on the Zaozhuang-Bengbu pilot section. Test data demonstrated that all infrastructure components of the pilot section—including subgrade, bridges, and track works—fully met the requirements for high-speed operation, with the overhead catenary system achieving world-leading quality standards.

On February 20, 2011, integrated testing and commissioning began on the sections from Dezhou East to Zaozhuang and Bengbu South to Hongqiao. On March 20, 2011, integrated testing and commissioning commenced on the section from Beijing South

to Dezhou East. From May 11 to June 10, 2011, the Beijing-Shanghai HSR conducted full-line through-running and operational trials.

On May 31, the Beijing-Shanghai HSR passed preliminary acceptance inspection. The MoRs invited thirty academicians and experts to inspect and evaluate the Beijing-Shanghai HSR Project. The experts unanimously concluded that the track achieved high smoothness and stability; the communication signals and traction power supply systems were stable and reliable; the passenger service systems met the operational requirements; the CRH380 high-speed EMUs fulfilled all high-speed and high-comfort specifications; operational safety facilities were fully equipped and reliably functional. Through technological innovation and standardised management, the project's engineering technology and quality control attained world-class standards, fully meeting all conditions for commercial operation.

On June 12, the Beijing-Shanghai HSR passed the safety assessment. The entire line is ready for trial operation.

On June 14, the then Minister of Railways led an inspection team aboard a test train to examine the entire Beijing-Shanghai HSR line. Subsequently, an on-site operational meeting was convened in Shanghai to finalise all preparatory work prior to the line's official opening.

On June 16, leaders from the NPC Financial and Economic Affairs Committee, Education, Science, Culture and Public Health Committee, and the Budgetary Affairs Commission of the Standing Committee received a briefing in Beijing on the construction and operational preparations for the Beijing-Shanghai HSR. Subsequently, they conducted an on-site inspection of the HSR and trains by boarding a high-speed EMU.

On June 23, the Ministry of Water Resources convened the final acceptance meeting for the water and soil conservation facilities of the Beijing-Shanghai HSR in Beijing, approving the project's soil and water conservation infrastructure for operational use.

On the same day, the fifth meeting of the Beijing-Shanghai HSR Construction Leading Group was held in Zhongnanhai. The meeting summarised achievements in the railway's construction, deliberated and arranged operational launch preparations, fully affirmed the project's accomplishments, and finalised pre-opening arrangements.

At 15:00 on June 30, 2011, the Beijing-Shanghai HSR officially commenced operation. Standing Committee Member of the CPC Central Committee Political Bureau and Premier of the State Council, Wen Jiabao, attended the opening ceremony at Beijing South Station and inspected operational conditions aboard the inaugural G1 train.

On February 25, 2013, the Beijing-Shanghai HSR successfully passed the inspection by the National Acceptance Committee, becoming the first HSR and passenger-dedicated rail project in China to receive national-level certification.

4.2 Constructing Civil Engineering with Mechanical Standards

From its inception, the Beijing-Shanghai HSR was designed to be a model project and exemplary engineering achievement in China's railway construction, with overall quality meeting world-class standards for high-speed rail, capable of withstanding the test of both operational demands and time. To this end, a series of specific benchmarks were established, including: zero tolerance for major design or construction flaws, structural perfection in main works, with >100 years service life for bridge and tunnel concrete structures, >60 years lifespan for ballastless track systems, 100% first-pass acceptance rate for all unit projects, infrastructure performance fully achieving designed speed targets, achieving full operational readiness upon initial launch, etc. A case in point is that while conventional railways may tolerate >10 cm of subgrade settlement without impairing operations, HSR mandated millimetre-level precision—essentially applying mechanical engineering standards to civil infrastructure.

Throughout the construction of the Beijing-Shanghai HSR, critical technical challenges were successively overcome, achieving exceptional stability in bridges, tunnels and subgrade works, ultra-smoothness in track and overhead catenary systems, and uncompromising reliability in train control systems. These advancements propelled China's HSR construction technology to unprecedented heights. The project pioneered China's HSR technical standards and compiled the *Provisional Design Specifications for HSR*, establishing China as the standard-setter for 350 km/h high-speed rail systems worldwide.

4.2.1 Subgrade Engineering

Throughout the history of China's railway construction, it was not until the Qinhuangdao-Shenyang Passenger Dedicated Line era that the fundamental subgrade structure took shape, establishing the concepts and standards for the subgrade body, subgrade bottom layer, and subgrade surface layer, as well as the “three-stage,” “four-section,” and “eight-process” subgrade filling techniques. During the Eighth and Ninth Five-Year Plan periods, the MoRs initiated scientific and technological research on post-construction settlement control of subgrades. The Beijing-Shanghai HSR traverses the North China Plain and the Middle and Lower Yangtze River Plain, where soft soil and loose soil are widely distributed and deeply deposited. After the project's groundbreaking ceremony on April 18, 2008, ballastless track was adopted as the primary track structure, imposing a stringent post-construction subgrade settlement control standard of ≤ 15 mm. To achieve this, extensive research and testing were conducted, culminating in a comprehensive set of deep soft soil foundation treatment and settlement control technologies.

(1) Comprehensive Treatment Technology for Rigid Pile Composite Foundation in Deep Soft Soil

In the initial phase of the project, the Liyao and Fengyang sites with thick-layer soft and loose soils were selected as test sections. Through laboratory simulation tests and mechanism analysis, the calculation method for vertical resistance and horizontal friction in CFG pile composite foundations with reinforced mesh cushions was validated and refined. The study established the settlement deformation patterns of CFG pile-net and pile-raft foundations and proposed design principles for pile-net and pile-raft foundations, settlement calculation methods, structural strength design and stability analysis methods for pile-net systems. The research also developed construction techniques and quality control systems for CFG pile composite foundations tailored to HSR and a flexible load-testing method better suited to the stress-deformation characteristics of railway pile-net composite foundations. For the soft soil subgrade (4–13 m thick) of the Nanjing Hub Xianxi Connecting Line, which had poor mechanical strength and high compressibility, a new Precast Concrete Casing (PCC) pile composite foundation technology was employed. The PCC pile-raft structure offered high rigidity, load-bearing capacity, and structural integrity. This integrated pile-raft technology effectively resolved localised stress concentrations, prevented lateral deformation and controlled post-construction settlement in high-fill deep soft/loose soil foundations.

(2) Transition Section Filling and Modified Concrete Treatment Technologies

While ensuring effective control of post-construction settlement, the critical issue of transition zones in HSR has garnered global attention. The Beijing-Shanghai HSR features more than 2,400 transition zones between embankments and bridges, culverts, tunnels, as well as cuts and fills. To ensure uniform track stiffness, deformation, and surface smoothness during transitions, an inverted trapezoidal reinforced structure was primarily adopted. Concurrently, a modified graded crushed stone and its construction method were developed for the backfill zone behind abutments. This innovation enhanced construction controllability and ensured tighter integration between abutments and subgrades, effectively preventing the formation of voids at the junction, a common issue when using cement-stabilised crushed stone in inverted trapezoidal structures.

(3) Selection, Improvement and Compaction Technology of HSR Subgrade Fill

To reinforce the deep soft soil foundation of low-height embankments, a bored pile system integrated with C40 reinforced concrete continuous slab beams was adopted, using the silty sand layer as the bearing stratum. Combined with surcharge preloading and other techniques, this effectively improved the stress conditions of the embankment subgrade. Dynamic parameters, including vibration acceleration, dynamic displacement, dynamic stiffness, and natural frequency, all met HSR specifications. This solution overcame the limitations of CFG piles (limited reinforcement depth) and pipe piles (difficulty penetrating thick silty sand/clay layers, inability to reinforce underlying soft soil, failure to eliminate post-construction

settlement, and adverse effects on adjacent structures). It successfully controlled total and post-construction settlement of low embankments in deep soft soil areas. A novel technique of large-area vacuum preloading, long plastic drainage boards, and short mixing piles to reinforce soft soil was applied to address large-area surcharge preloading and post-construction settlement control in the Shanghai Hongqiao EMU Depot, where soft soil exceeds 30 m in depth.

Regarding infrastructure settlement monitoring, a high-precision measurement network-based settlement observation system was established along the entire line. The proposed residual analysis-based high-reliability prediction method not only provided a basis for controlling foundation settlement and structural deformation but also was used to determine the optimal construction timing for ballastless track installation, ensuring compliance with predefined deformation control requirements.

4.2.2 Bridge Engineering

The Beijing-Shanghai HSR crosses four major water systems—the Haihe, Yellow River, Huaihe, and Yangtze River—and traverses 215 existing railways, highways, and navigable waterways. Bridges account for 80.4% of the total route length. The Danyang-Kunshan Grand Bridge, the longest on the line at 164.7 km, is divided into thirteen segments and features more than 130 specially designed bridge structures. To protect the ecological environment of Yangcheng Lake, the lake-crossing bridges primarily use prefabricated 32-m simply supported box girders, with piers constructed using a “double-row pile cofferdam” method. Bridges constitute 79.8% of the line’s key projects. The design and construction of these bridges involved pioneering key high-speed rail bridge technologies, resulting in a series of advanced innovations.

(1) Design and Construction Technology of Nanjing Dashengguan Yangtze River Bridge

In 2003, the MoRs initiated the research on deep-water long-span bridges, organising institutions including the CARS, Beijing Jiaotong University, Southwest Jiaotong University, and Central South University. Using dynamic simulation methods, they conducted computational analyses of typical bridge configurations along the entire line, with a maximum simulated speed of 420 km/h. In 2004, the MoRs launched nine research projects to tackle key challenges in the construction of the Nanjing Dashengguan Yangtze River Bridge. The Nanjing Dashengguan Yangtze River Bridge serves as a crossing for the Beijing-Shanghai HSR, the Shanghai-Wuhan-Chengdu Railway, and the Nanjing Metro, making it the world’s first six-track railway bridge. The bridge spans 9.273 km, with its main steel structure over the Yangtze River measuring 1.615 km. It consists of two (84 + 84)-m continuous steel truss girders and one (108 + 192 + 2 × 336 + 192 + 108)-m continuous steel truss girder with three main trusses and a double-arch integrated deck. The construction of the bridge consumed

80,000 tonnes of steel girders, 1.4 million m³ of concrete, and 360,000 tonnes of steel structures, with more than 5,000 workers on-site during peak periods.

Nanjing Dashengguan Yangtze River Bridge overcame numerous technical challenges in design, fabrication, and construction. To meet the demands of long spans, high speeds, heavy loads, and integrated joints for bridge steel quality and thickness, the project pioneered the use of Q420qE-grade steel—a new material specifically developed for this project. For high-speed train operation, the superstructure adopted a three-truss, double-arch continuous steel truss design, with an orthotropic steel deck rigidly connected to box-shaped lower chords to form an integrated through-truss system. The main trusses featured welded monolithic joints. To suppress wind-induced vibrations, the bridge innovatively employed octagonal closed-section hangers with high sectional stiffness and superior aerodynamic performance. To accommodate track forces, bridge expansion, and bearing loads, the design incorporated 1,000 mm-expansion rail temperature adjusters, 800 mm-expansion beam-end displacement devices, and 18,000-tonne spherical bearings. For construction efficiency, the deep-water foundations used a “combined drilling platform and cofferdam” method, resolving challenges in launching, floating, and sinking mega-cofferdams for the main piers. For alignment control, the main steel arch truss employed a three-tier cable-stayed cantilever method with pier-side brackets and horizontal tie cables, enabling precise closure of the three-truss structure—a feat unachievable with conventional jacking methods. These innovations in materials, structural systems, equipment, and construction techniques established the bridge as a global benchmark for HSR bridges. The MoRs designated it as the “most technologically complex and constructional challenging critical project” on the Beijing-Shanghai HSR.

(2) Design and Construction Technology of Jinan Yellow River Bridge

The Jinan Yellow River Bridge, the second most critical control project on the Beijing-Shanghai HSR after the Nanjing Dashengguan Yangtze River Bridge, features a (112 + 3 × 168 + 112)-m continuous steel truss girder with rigid beams and flexible arches. This design achieves long spans, high speeds, and extra-wide trusses. During construction, it successfully addressed numerous challenges in designing and building long-span, multi-track HSR bridges in sediment-laden riverbeds. On the basis of the main structural design featuring two main trusses for four railway tracks, the Jinan Yellow River Bridge adopted a new integrated deck structure combining the orthotropic steel deck with lower chords, transverse bracing with K-struts and hangers, and monolithic joints for the main trusses. This design ensured the required stiffness for both the deck and the entire bridge structure. To reduce negative skin friction in sediment-prone areas, steel casings were installed around pile foundations, and emulsified asphalt coatings were applied to casing exteriors. The “top-mounted gantry crane with unidirectional retreating erection” method enabled stress-free precision closure at arch springing, elimination of safety risks associated with crown closures, and resolution of workspace constraints.

(3) Tied Arch Bridge Represented by Zhenjiang Grand Canal Bridge on the Beijing-Shanghai HSR

Tied arch structure bridges were widely used on the Beijing-Shanghai HSR, with more than ten such structures along the line. These tied arch structures included both simply-supported tied arches (internally statically indeterminate, externally statically determinate) and continuous tied-arched (internally and externally statically indeterminate). Designs featured both steel-concrete composite and all-steel structures, serving both double-track and quad-track configurations. The primary technical challenges varied significantly across these different bridge types. Among them, the Zhenjiang Grand Canal Bridge, a (90 + 180 + 90) m prestressed concrete continuous beam-arch hybrid structure, holds the national record as the longest span and highest operational speed (350 km/h) among CRTS II slab ballastless track bridges in China.

The main bridge of the Zhenjiang Grand Canal adopts a rigid continuous beam with a flexible arch structural system, where the main girder serves as the primary load-bearing component. The self-weight of the girder is entirely borne by the main beam, while secondary dead loads and live loads are shared between the beam and arch. The load distribution ratio depends on factors including the stiffness of the main beam and arch ribs, and the cross-sectional area of hangers. Therefore, the critical design challenges involved optimally matching the main beam with the arch ribs and determining appropriate hanger forces. Through structural calculations varying parameters, including main girder height, arch rib chord tube diameter, arch rib height, arch axis configuration, and hanger forces, the design team analysed and compared internal forces, stresses, strength, stability, and deformations in both the main girder and arch ribs. This process established the relationship between beam-arch stiffness and load distribution, ultimately determining the final dimensions: main girder height: 4.5 m at mid-span, 10.0 m at intermediate supports; arch ribs: 1.1 m chord tube diameter, 3.1 m rib height. The total hanger forces at the completion of the bridge were 14,688 kN, accounting for 80.0% of the secondary dead load in the main span. When the entire bridge is under full-span train live load, arch ribs bear 38.4% of the vertical train live load. Under double-track live load, the main girder exhibited a maximum vertical deflection of -38.6 mm, yielding a deflection-to-span ratio of 1/4,663. Compared to a continuous girder bridge of equivalent span, this design reduced the main girder height by approximately 5 m.

(4) Non-Standard Structural Bridges and Turnout Beams

The Beijing-Shanghai HSR employed various non-standard bridge structures, including spatial rigid frames, steel portal piers, U-shaped continuous girders, and long-span continuous beams. These configurations proved highly effective for minimising oblique crossings over existing infrastructure, optimising vertical alignment to reduce line elevation, and mitigating construction impacts on adjacent roads and environments. Multiple stations on the Beijing-Shanghai HSR were constructed on viaducts, requiring the installation of diverse turnout systems.

High-speed turnouts impose unique structural demands on bridges, necessitating specialised designs distinct from conventional bridge engineering. The project pioneered design criteria, theoretical principles, and calculation methods for integrating seamless turnouts with elevated station bridges, establishing a technical framework subsequently adopted by other passenger-dedicated lines.

To address the construction challenges of long-span bridges along the entire line, a new carbonate-admixed concrete material was developed to enhance the efficiency of the cantilever casting method. This innovation maintains durability while significantly improving the early-strength and elastic modulus of concrete, reducing the prestressing curing period to just 3 days/segment. The total construction time for a continuous girder was cut by one-third.

4.2.3 Tunnel Engineering

The tunnel design of the Beijing-Shanghai HSR comprehensively considered requirements, including tunnel clearance gauge, safety operation space, emergency evacuation passages, and maintenance access. By adopting a 5-m track spacing and ensuring a minimum clear cross-sectional area of 100 m² above the rail level, the project effectively mitigated the aerodynamic effects on train safety and passenger comfort during high-speed operation. Based on tunnel length and portal terrain conditions, diversified buffer structures were installed at tunnel entrances. These structures significantly reduced micro-pressure waves generated during train entry/exit, minimised impacts on surrounding buildings, and enhanced passenger comfort.

(1) Tunnel Portal Buffer Structure Design Technology

The Beijing-Shanghai HSR operates at a speed of 350 km/h with ballastless track installed in tunnels. When high-speed trains pass through tunnels, they generate a series of aerodynamic effects, primarily including micro-pressure waves at tunnel portals and pressure waves inside tunnels. The former affects the environment near tunnel exits, while the latter directly impacts passenger comfort and causes fatigue damage to tunnel linings and structures. The main strategy to solve these problems is to reduce the pressure gradient of compression waves at the tunnel entrance by optimising portal designs, adding buffer structures at portals, and increasing tunnel cross-sectional area. After implementing improved portal designs and buffer structures on the Beijing-Shanghai HSR, micro-pressure waves were significantly mitigated. When EMUs pass through the tunnel at a speed of 350 km/h, the minimum reduction value of micro-pressure waves is at the Fenghuangtai Tunnel exit, with a reduction value of about 25.1%. The largest reduction value of micro-pressure waves is the Xikema No. 1 Tunnel exit, with a reduction value of about 41.5%.

(2) Construction Technology of Hanfushan Tunnel Group in Weak Surrounding Rock

The Hanfushan Tunnel Group on the Beijing-Shanghai HSR comprises four parallel tunnels: Hanfushan No. 1, No. 2, No. 3, and No. 4. Tunnels No. 1, No. 2, and No. 3 are closely spaced with a clearance of approximately 6–8 m, classifying them as small-clearance tunnels. The tunnel group is located in predominantly Class V surrounding rock, characterised by highly fractured rock mass, shallow burial depth, and severe asymmetric pressure. Conventional blasting methods for portal construction could easily cause partial or complete collapse of the rock mass between tunnel portals, compromising the stability of the surrounding rock and leading to safety incidents. To address this, the construction sequence adopted for the Hanfushan Tunnel Group followed simultaneous construction of No. 1 and No. 3 tunnels first, and then the construction of No. 2 tunnel, maintaining a face distance of about 10 m between No. 3 and No. 1 Tunnel faces, and no less than 50 m between No. 2 and No. 3 Tunnel faces. Grouting reinforcement was applied to the intermediate rock pillars between No. 1 & No. 2 tunnels and No. 3 & No. 2 tunnels, covering the area from the arch foot to the arch waist. During construction, sonic testing measured blast-induced damage depth in the inter-tunnel rock mass. Field data confirmed the damage depth was effectively controlled within 0.8–1.0 m—significantly less than the minimum 6 m clearance between tunnels. Blast vibration monitoring recorded controlled vibration velocities of 1.1–5.6 cm/s, well below the design limit of 10 cm/s, demonstrating excellent blasting control.

(3) Construction Technology for Jinniushan Tunnel under passing High-class Highway

The Jinniushan Tunnel on the Beijing-Shanghai HSR passes under the Beijing-Fuzhou (Jingfu) Expressway at two locations. At location one, the clearance between the tunnel crown and road surface measured 9.280 m, and at the other location, the clearance between the tunnel crown and road surface measured 12.045 m. The Jingfu Expressway carries heavy traffic (one vehicle every 3–5 s) with numerous heavily-loaded trucks, posing significant challenges for the underpass construction. To ensure the construction quality, three-dimensional numerical simulation analysis was carried out on the bench cut method, CD method, and double-side-drift method before tunnel construction. Multiple blast vibration tests were performed on the road surface to assess blasting impacts during undercrossing operations. After a comprehensive evaluation, the project adopted the three-bench centre drift method for the main excavation and large pipe roof support as an auxiliary measure. Field monitoring results showed the maximum surface settlement is <12 mm, which is under control standard, and the road vibration is <3 cm/s, meeting control requirements.

4.2.4 Track Engineering

The rails are a crucial component of the track system. After being laid and welded together, they form a continuous rail stretching from Beijing to Shanghai. Beneath

the rails are individual track slabs—more than 400,000 pieces from Beijing to Shanghai—marking their first application in China. During the construction of the Beijing-Shanghai HSR, three major challenges in track slab production were overcome, and three core technologies for slab laying were resolved, establishing integrated manufacturing and installation systems. Furthermore, for the construction of ballastless tracks, more than ten technical breakthroughs have been conducted, including reinforced concrete durability research and transition zone end anchorage tests.

(1) Manufacturing and Installation Technology for CRTS II Slab Ballastless Track

The Beijing-Shanghai HSR pioneered the use of CRTS II track slabs, overcoming three major production challenges. First, production lines. Through extensive testing and research on manufacturing equipment and processes, including optimisation of various production line configurations, issues, such as uneven stress distribution in tensioning beds, formwork displacement during prestressing, and steel reinforcement rebound during cutting, were resolved, key technologies were developed for measurement of prestress and friction losses, mid-span deflection control of tensioning beams, equipment configuration optimisation and production workflow management. This enabled the successful implementation of 120 m-long production line beds. Second, concrete materials. After systematic theoretical studies, lab/field tests, and engineering validation, a new material system was established using ordinary Portland cement, conventional admixtures, and non-retarding water reducers. This formulation met structural requirements, simplified construction, and reduced costs, with corresponding technical standards codified. Third, the track slab grinding software. A proprietary grinding software with independent intellectual property rights was developed, which resolved key technical challenges, including 3D spatial geometric calculations for precise track slab profiling, data interaction management between grinding machines, motion control and electrical system operation. The software increased grinding head movement speed, optimised engraving processes, achieved a manufacturing precision of 0.3 mm for track slabs, and broke foreign technology and pricing monopolies.

The installation of track slabs also overcame three critical technical challenges. First was the development of track slab layout software. Second was the development of an automatic fine-adjustment device for track slabs based on a six-axis parallel mechanism, which increased installation efficiency by more than 100%. And third involved key research into the formation mechanism of CA mortar, which was crucial for the success of the slab track system. By preparing the mortar considering the distinct molecular interactions of asphalt and cement, its stability was significantly enhanced.

(2) Longitudinally Connected Slab Ballastless Track Technology for Bridge Turnout Zones

The Beijing-Shanghai HSR pioneered the application of longitudinally connected slab ballastless track technology for turnout zones on bridges. This innovation established interaction mechanisms between connected baseplates and bridge structures as well as the design principles and standards, which filled the technical void for installing large numbers of ballastless turnouts on bridges. The technology defined interface requirements between the track and bridge, including beam arrangement specifications, technical criteria for bridge design and necessary widening for switch machines. It introduced a limit state design method for continuous baseplates and determined load combination coefficients. The project successfully constructed 350 km/h CRTS II slab turnout zones on viaducts, resolving compatibility issues between high-speed turnouts and elevated structures and achieving seamless ballastless track installation across elevated stations.

(3) Long Rail Welding and Laying Technology

The laying and welding technology of long rails is crucial for ensuring track smoothness. The Beijing-Shanghai HSR employs 500-m long rail welding, which integrates joint misalignment control technology, rail cross-section verticality control technology, weld joint inspection technology, and post-weld heat treatment technology. This comprehensive approach prevents grinding wheel bouncing and damage to parent rail material, eliminates grinding burns and surface bluing at weld joints. Contour grinding machines are used to precisely finish the running surface of rail heads and the working edges of rail head sides. This ensures perfect rail head profile geometry and prevents mechanical or thermal damage.

The Beijing-Shanghai HSR has successfully developed a complete set of long rail laying technologies. The rail-transporting vehicle carries 500-m-long rails from the storage yard to the laying site. The WZ500-TY ballastless track long rail laying unit then drags and positions the rails. After the long rails are pulled into place, the roller is removed, the rails are lowered into track grooves, and the track is preliminarily locked. To ensure uniform stress distribution and minimise rail temperature locking errors, the “continuous connection method” is used for stress release and locking between rail sections; and within a single rail section, when rail temperature is within the design locking range, “Roller method” is applied, and when rail temperature is outside the locking range, “Tensioner-roller combined method” is employed.

(4) Measurement and Fine Adjustment Technology for Ballastless Track

Rail and turnout fine-tuning constitute the final critical step in ensuring high track smoothness. To enhance fine-tuning efficiency and quality, the Beijing-Shanghai HSR adopted a relative + absolute measurement technology. Using the HSR fine-tuning instrument, it automatically measures track slab level and elevation data via the CPIII control network. This system establishes a conversion model from spatial curve to line waveform, determining the data conversion calculation method corresponding to the spatial curve and the line sleeper, and directly uses the relative measurement data for fine-tuning of the track plate, significantly improving the efficiency of fine-tuning. After initial adjustment of the track was completed, the dynamic test results

showed that all Class I and geometric deviations had been eliminated, the TQI lower than 3.0 mm was achieved, and all dynamic parameters met the specifications. Upon completing system integration testing, zero Class I deviations remained, TQI improved to 2.5 mm, and all dynamic parameters reached “excellent” grade, thus ensuring ultimate track smoothness.

4.2.5 Passenger Station Engineering

As a passenger transfer hub integrating multiple transport modes (high-speed rail, conventional rail, urban rail transit, road transport, long-distance coach, and aviation), the mega comprehensive transport hub adopts an integrated design philosophy to maximise same-station transfers and short-distance transfers. It fully utilises the rapid distribution functions of urban rail and road networks to achieve convenient and efficient passenger transportation.

The construction follows integrated planning principles to optimise land use, implement three-dimensional layouts, and maximise shared building structures through multi-level designs.

The coordination system enhances transport integration to jointly respond to emergencies, address climate change impacts, and establish a stable and reliable comprehensive transport network.

(1) Technology for Integrating Mega Station Construction and Urban Transportation

Conventional transportation planning divides areas according to industries, creating isolated architectural islands that were disconnected from one another. For the sake of streamlined industry management, the facilities of various transportation modes were intentionally separated, resulting in significant inconvenience for passengers during travel and transfers. To maximise the convenience of passenger transfers, the Beijing-Shanghai HSR proactively coordinated with local authorities, innovating the design philosophy for large passenger stations. They adopted an integrated approach to plan and holistically design major transportation hubs, such as Beijing South, Tianjin West, Jinan West, Nanjing South, and Shanghai Hongqiao. These hubs incorporated high-speed rail, intercity rail, urban rail transit, and ground public transportation within the same architectural complex, forming comprehensive urban passenger transportation hubs centred around high-speed rail stations. To address the challenges of architectural structural design, a multi-level, three-dimensional overpass station layout was employed. This design spatially overlapped the facilities and spaces of different transportation modes as much as possible while interconnecting their passageways. It achieved a three-dimensional integration of various transportation modes within large railway stations, optimising land use efficiency and constructing the most efficient transfer pathways. This approach broke

down the traditional industry barriers between different transportation modes and significantly enhanced the convenience of passenger transfers.

(2) “Station-Bridge Integration” Innovative Structural Technology at Nanjing South Railway Station

The design of Nanjing South Station adopts an elevated platform structural system featuring the “integration of station and bridge,” where the station building and bridge structures form a unified framework. High-speed trains passing through the station at speeds of 300 km/h or higher, as well as during stopping and starting, exert dynamic impacts on the building. The structural layer at a relative elevation of 10.3 m serves as both the track-bearing layer of the bridge and the structural layer of the station building, while also functioning as the foundation for the upper waiting hall and roof space truss structure. The bridge and station structures are integrated into an indivisible whole. The design must account for two key factors: on the one side, the dynamic impact of trains on the building structure may induce vibrations that directly affect structural integrity and lifespan; on the other side, the influence of structural vibrations may affect train operational stability and safety, potentially compromising both running safety and passenger comfort. Through specialised research and simulation tests on the structural stability of Nanjing South Station’s “Station-Bridge Integration,” an in-depth analysis was conducted on critical areas and nodes, including vertical excitation pressure on the track-bearing structure during train operation, maximum vibration levels in key zones, such as the underground floor ceiling, waiting hall, and mezzanine, peak vibration levels in the platform slab area, maximum velocity responses of the main station structure and canopy under various operating conditions, and stress levels in structural components, such as frame columns and beams. The results confirmed that stress levels at all key points remained within safe allowable limits. For locations with relatively low safety margins, structural reinforcement measures were implemented to enhance stability.

(3) Design and Construction Technology for Steel Structure Roofs of Ultra-large Passenger Stations

The elevated waiting floor structure of large passenger stations is located directly above the platform track layer, serving as an important space for passengers waiting for their trains. To achieve the large-space effect of the platform, the column grid spans are designed to be exceptionally large, with multiple sections of the elevated structure exceeding spans of 40.5 m. Moreover, to ensure structural safety and mitigate the impact of high-speed train vibrations, no structural columns are installed along the main track lines. This design approach significantly increases the complexity and difficulty of both the structural design and construction processes.

The station buildings of major passenger hubs, such as Beijing South, Tianjin West, Jinan West, Nanjing South, and Shanghai Hongqiao, feature expansive spaces. To achieve optimal interior spatial quality and visual effects, large-span spatial steel structures were adopted, integrated with roof and curtain wall designs, ensuring excellent natural lighting and aesthetic appeal. The design technology for these large-

span spatial steel structures addressed complex challenges, including intricate load-bearing conditions, diverse structural configurations, and substantial spans. Through comprehensive modelling tailored to engineering requirements, the solutions ensured both structural stability and visually striking architectural forms. Due to the large spans in the waiting halls, traditional hoisting methods are not applicable. Instead, innovative construction techniques were employed, including unit assembly, sliding into position, and composite forming. High-precision spatial positioning equipment and sliding control systems were developed to overcome difficulties in high-altitude component alignment and assembly accuracy, which were critical to meeting design specifications. Through systematic research on construction methodologies, a specialised sliding and composite installation technique for large-span station roofs was established. This advancement provided a reliable foundation for ensuring construction safety and quality control in the assembly of these monumental transportation hubs.

4.2.6 Traction Power Supply Engineering

There are three interfaces involved in train operation: aerodynamics, wheel-rail interaction, and pantograph-catenary contact. The catenary system acts as the “wings” of a train, serving as the energy supply channel that powers its movement. The tension of the contact wire and its electrical conductivity are critical performance factors, with the wire material being the primary constraint in improving both. To address limitations in traditional contact wires, a high-strength, high-conductivity material was developed. This advanced wire achieves tensile strength of 84 kN and maximum operational tension of 38 kN, with an electrical conductivity of 86 S/m. The new wire was first deployed on the Zaozhuang–Bengbu line (>100 km) and subjected to rigorous testing. Trials were conducted at four tension levels (31.5, 33, 36, and 40 kN)—all exceeding the highest international standard (27 kN)—with successful results. The system demonstrated stable and efficient power transmission, ensuring reliable high-speed train operation even under extreme conditions.

(1) 2×27.5 kV Large-capacity Gas-Insulated Switchgear (GIS)

The 2×27.5 kV GIS, known for its high integration, compact footprint, exceptional reliability, and minimal-to-zero maintenance, has been widely adopted in electrified railways—especially high-speed rail—overseas. However, due to technical limitations, large-capacity 2×27.5 kV GIS products were previously monopolised by foreign companies. In 2008, under the joint scientific and technological support programs of the MoRs and the Ministry of Science and Technology, Chinese engineers tackled this challenge to meet the traction power supply demands of the Beijing-Shanghai HSR. They conducted research and development in six key areas, that is, component structure, modular configuration, cable connection methods, environmental adaptability, manufacturing processes, and operation and maintenance protocols.

The breakthrough achievement was a highly integrated, high-sealing-performance HV power distribution system, combining seven critical components into a single unit, that is, circuit breaker, busbar, disconnecter, current transformer, voltage transformer, surge arrester, and bushing. Not only does it possess independent intellectual property rights, but it also fulfils all critical requirements for power distribution equipment: compact structure, minimal space occupation, high safety and reliability, flexible configuration, and reduced maintenance workload. This system has been extensively deployed in the Beijing-Shanghai HSR project, demonstrating excellent operational performance in real-world applications.

(2) Traction Power Supply System Technology Featuring High-Strength, High-Conductivity Catenary System for 380 km/h Operation

Globally, the wave propagation speed of the catenary system serves as the foremost criterion for assessing whether a catenary system meets HSR performance requirements. According to wave propagation theory, reducing the linear density of the contact wire and increasing its rated working tension are the two primary methods to enhance this critical parameter. In China's HSR mainlines, the contact wire cross-section is standardised at 150 mm². Given this fixed geometry, the most effective approach to boost wave propagation speed is to increase the rated working tension of the contact wire.

The Beijing-Shanghai HSR employs high-strength, high-conductivity copper alloy contact wires with technical performance that meets international leading standards. These contact wires have a tensile strength of 560 MPa or higher and a conductivity ranging from 75% IACS to 82% IACS. Additionally, their wear resistance is significantly better than that of copper-magnesium and copper-tin alloy contact wires.

To meet the requirements of the maximum operating speed and test speed of the Beijing-Shanghai HSR, a systematic experimental approach was implemented in the down-direction pilot section, testing four distinct tension configurations, with the messenger tension set at 20 kN and contact wire tension at 31.5 kN, 33 kN, 36 kN, and 40 kN, respectively. Through actual train tests, the optimal tension configuration for the 380 km/h sections of the Beijing-Shanghai HSR was ultimately determined. Practical experience has shown that when EMUs operate at speeds exceeding 350 km/h with dual pantographs, the vibration of the overhead catenary becomes significantly more intense. Without measures applied to the pantographs, simply increasing the tension of the catenary alone does not notably improve the current collection quality of the trailing pantograph. Therefore, all next-generation EMUs deployed on the Beijing-Shanghai HSR are equipped with new active-control pantographs, marking the first use of such technology on domestic EMUs. Under the condition of using active-control pantographs, all three proposed catenary tension systems met the requirements for stable and continuous current collection at 380 km/h with dual pantographs. Key performance indicators, including average contact force, maximum contact force, uplift displacement, and arcing rate, all fell within expected ranges. Among these, the

(20 kN + 36 kN) tension configuration demonstrated the best performance, followed by (20 kN + 33 kN), while (20 kN + 31.5 kN) remained viable.

(3) Joint Construction Technology for 220 kV Traction-Power Substation (Nanjing South and Shanghai Hongqiao)

The traction substation and power substation of the Beijing-Shanghai HSR are both located at Hongqiao Hub. To achieve power resource sharing, the two substations were co-constructed. To harmonise the overall layout of the integrated substation with the hub's landscape, a fully indoor substation design technology was proposed. The fully indoor, jointly constructed substation is housed within a single building, marking the first application of mature technical equipment including 220 kV indoor SF6 GIS, 220 kV power cables, plug-and-play cable connection technology for the 220 kV side of traction transformers, etc. This integration has significantly elevated the overall equipment standards while facilitating operation and maintenance. The design not only fully ensures but also enhances power supply reliability and safety to a certain degree.

The Ningnan Traction Substation of the Beijing-Shanghai HSR and the Sunjiawa Traction Substation (including the 220/10 kV Nanjing South Power Substation) are both located in the Nanjing Hub area. As part of the project in “Nanjing Hub Dashengguan Yangtze River Bridge, Nanjing South Railway Station and Related Projects,” Sunjiawa Traction Substation is responsible for supplying traction power for the Beijing-Shanghai HSR, the Nanjing Railway Hub, the Shanghai-Wuhan-Chengdu Corridor and the Ningjing-Anqing Intercity Railway, as well as meeting the general power load of the Nanjing hub. To optimise 220 kV power utilisation, minimise land use, and reduce construction costs, the substations were co-constructed into the largest integrated substation in China's railway network, featuring ten 220 kV transformers (including eight traction transformers and two power transformers), traction and power distribution equipment for the two projects, and other auxiliary facilities. In the co-constructed substation, except for the traction transformers and power transformers, which adopt an outdoor low-profile arrangement, all other distribution equipment and related facilities are housed within a single building. For the 220 kV side distribution equipment, mature indoor SF6 GIS is adopted. The 2×27.5 kV side distribution equipment utilises indoor compact insulated switchgear (CIS). Inter-equipment connections employ cable connections, with cable layout and routing arranged in separate trenches according to different voltage levels and power supply ranges. Indoor cable terminations adopt plug-and-play connections, while outdoor connections use cable terminals transitioning to overhead lines. This configuration significantly simplifies equipment layout, reduces building footprint and site area requirements, facilitates construction/installation and operation/maintenance, while also improving overall equipment standards.

4.2.7 Communication Signal Engineering

Since the 1990s, under the unified arrangement of the MoRs and relying on the preliminary technical research for the Beijing-Shanghai HSR, China has initiated systematic research and demonstration work on communication and signalling systems for its HSR systems. Through comprehensive analysis and comparison of various foreign train control systems, and combined with the wireless communication requirements for China's HSR operations, specialised investigations were conducted on two technological standards—GSM-R and TETRA. It was ultimately decided to adopt GSM-R as the wireless communication solution for China's HSR, while establishing Chinese Train Control System (CTCS) with Chinese characteristics as the train control standard. This led to the development of CTCS-3, an autonomous train control technology with independent Chinese intellectual property rights. Through the engineering implementation on the Beijing-Shanghai HSR, both GSM-R digital mobile communication and CTCS-3 train control technologies were successfully applied to HSR operating at 350 km/h and above. This achievement laid a solid foundation for the rapid and sustainable development of train control technologies for China's HSR network.

(1) Communication, Transmission, and GSM-R Networking Technology

The Beijing-Shanghai HSR pioneered the adoption of a chain-type MSP 1 + 1 inter-station networking architecture for its communication transmission system. This innovative design features a dual-optical-cable, dual-node network architecture design, which utilised the existing aggregation nodes as secondary station nodes, significantly reducing the construction costs and effectively eliminating single-point failure risks inherent in traditional transmission systems. This design can prevent system-wide communication outages from node failures and enhance overall subsystem reliability. The chain-type MSP 1 + 1 inter-station networking plan for the Beijing-Shanghai HSR communication transmission network has later been established as the benchmark transmission solution for subsequent high-speed rail lines and passenger-dedicated railways.

The GSM-R network design for the Beijing-Shanghai HSR introduced an innovative solution by proposing that “two base stations be configured as primary and backup at divergence points in parallel sections, with multiple directional antennas providing separate coverage for each line direction.” This design effectively addressed the requirements for GSM-R signal redundancy coverage, system capacity, frequency planning, quality of service, reliability, etc. in the parallel sections between the Beijing-Shanghai HSR and other CTCS-3 lines, including Shanghai-Nanjing Intercity Railway, Shanghai-Hangzhou Passenger Dedicated Line, and Hefei-Bengbu Passenger Dedicated Line. The solution successfully resolved the conflict between system capacity and frequency planning in GSM-R networking, while establishing valuable implementation experience for GSM-R network design in parallel sections of subsequent HSRs and passenger dedicated lines.

(2) CTCS-3 Train Control Technology Compatible with CTCS-2

The Beijing-Shanghai HSR has established a CTC system with distinctive Chinese characteristics, adopting the domestically developed CTC-3 technology. This achievement has realised optimal matching between the vehicle control curves of onboard equipment and EMU braking parameters, significantly enhancing the adaptability and reliability of train control technology under high-speed conditions. The ground equipment for train control on the Beijing-Shanghai HSR was uniformly designed according to the CTCS-3 standard while maintaining compatibility with CTCS-2. Both levels share common equipment, including track circuits, balises, and temporary speed restriction servers. The onboard train control subsystem accommodates application requirements for both levels, enabling automatic seamless transition between CTCS-3 and CTCS-2 control modes without stopping at designated transition points or during wireless communication timeouts.

Real-time and reliable bidirectional transmission of train control information between the train and the ground has been achieved. Through the GSM-R digital mobile communication network, the CTCS-3 onboard equipment can receive in real-time movement authorities, temporary speed restrictions and line data for the upcoming route. Simultaneously, ground systems utilise the interface between Radio Block Centre (RBC) and CTC equipment to provide dispatchers with real-time monitoring of train speed, position, and operational status of CTCS-3 level trains, providing a strong safeguard for the safety of the train operation.

The Beijing-Shanghai HSR has established a unified CTCS standard framework that fulfils interoperability requirements across different control levels and system types. The line incorporates multiple major hubs, including Beijing South, Tianjin West, Nanjing South, and Shanghai Hongqiao. The design of hub signalling systems must fulfil the requirements for interoperability with adjacent lines and cross-line operations. Through a comprehensive consideration of each hub's cross-line operational needs and route characteristics, a coordinated design approach was implemented. This included balise arrangement, grade transition point configuration, and software modifications for adjacent systems: RBC, TCC(Train Control Centre), TSRS(Temporary Speed Restriction Server), CBI(Computer Based Interlocking). These measures achieved seamless interoperability between the Beijing-Shanghai HSR and connecting lines, fully meeting cross-line operational demands.

Direct communication between adjacent RBC has been achieved. This facilitated enhanced data exchange between neighbouring RBCs. By utilising the CTCS-3 level train position information recorded by RBCs, it continuously tracks and records train movement positions. This functionality ensures proper train separation intervals for CTCS-3 level trains and enhances operational safety during train tracking operations.

(3) Train Control High-Speed Adaptation Technology

To evaluate the comprehensive performance of the train control system under 300–350 km/h operational conditions and explore its adaptability at higher speeds, the Beijing-Shanghai HSR conducted field tests in its pilot section, focusing on train-

ground information transmission performance (GSM-R wireless transmission, balise message transmission, and cab signal reception), electromagnetic compatibility characteristics and braking characteristics of onboard equipment, and adaptability of train control functions. For the first time, with trains operating at speeds exceeding 400 km/h, several key breakthroughs were achieved:

1. Established a GSM-R radio wave propagation model for plain viaduct sections;
2. Proposed GPRS data transmission characteristics under high-speed conditions;
3. Clarified the transmission properties of GSM-R short messages during high-speed operation;
4. Mastered the reliable transmission patterns of balise messages under different speeds and with various installation methods;
5. Optimised the CTCS-3 onboard train control model.

These advancements have provided critical technical support for the further development of train control technology.

4.3 Exploring Modern Railway Construction Management Models

During the construction process, the project innovatively addressed the management objectives of “quality, safety, schedule, investment, environmental protection, and technological innovation” through a series of breakthroughs in “organisational models, financing approaches, and management systems,” ultimately establishing an advanced management framework. Funding was secured through market-oriented financing approaches that actively attracted social capital through market-based financing channels, establishing a diversified investment structure led by government authorities. The project adopted an organisational model combining the project legal entity responsibility system with an engineering command department structure. An “owner management + professional consulting” approach was implemented, with supervisory personnel working alongside owners on project oversight. A standardised construction management system was established, featuring the “Four Standardisations” as the core content and “Four Modernisations” as the support. This system enhanced work efficiency through mechanised construction, standardised product quality via industrialised production, ensured engineering quality by building specialised teams, promoted precision management with information systems, and advanced standardised management through standardised operations. These measures strongly facilitated the safe, high-quality, and efficient construction of the Beijing-Shanghai HSR, achieving the goals of building a technologically innovative project, a quality excellence project, a resource-efficient project, an environmentally friendly project, and a socially harmonious project.

“One Entity, Dual Identities”—Integrated Project Legal Entity and Engineering Command Department Management Model. Under the leadership and strategic

decisions of the CPC Central Committee and the State Council, the Beijing-Shanghai HSR project adopted an innovative hybrid management model combining project legal entity responsibility with engineering command department systems, structured as follows:

1. The national construction leading group provided overarching organisational guarantees;
2. Member units of the leading group delivered coordination and support;
3. A dedicated company is responsible for fundraising and ensuring capital assurance;
4. The general command headquarters oversees the implementation of construction and project management.

The highly complex construction management of the Beijing-Shanghai HSR required strengthened national-level leadership to ensure smooth project implementation. Following the project's approval, the CPC Central Committee and the State Council established the Beijing-Shanghai HSR Construction Leading Group to provide overarching guidance for the construction, coordinate solutions for major challenges, and address difficult issues, including land acquisition and resettlement along the route. After construction commenced, the Leading Group convened a series of key meetings on April 24, 2009; March 23, 2010; December 14, 2010; and June 23, 2011. These meetings served as platforms to review progress reports on the HSR's construction and to issue directives and arrangements for major challenges encountered during the construction process.

The construction of the Beijing-Shanghai HSR implemented the project legal entity responsibility system, with the specialised establishment of the Beijing-Shanghai HSR Co Ltd. responsible for the project's construction and management. The company adopted a corporate governance structure, adhering to strict procedures for major decision-making, and assumed comprehensive responsibility for the entire process, including financing, construction, operation, debt repayment, and asset value preservation and appreciation. This ensured efficient and legally compliant decision-making. To leverage the MoRs' strengths in construction management, the Ministry established the Beijing-Shanghai HSR Construction Headquarters, which shared the same organisation with the Beijing-Shanghai HSR Co., Ltd under "one entity, two identities," enabling the mobilisation of resources across all railway departments for construction management.

Beijing-Shanghai HSR Co., Ltd. has established five departments, including the General Administration Department, Planning & Finance Department, Engineering Management Department, Safety & Quality Department, and Materials & Equipment Department, specifically responsible for the construction management of the entire line. It set up five regional headquarters in Tianjin, Jinan, Bengbu, Nanjing and Suzhou, while delegating the construction of four major hubs (Tianjin West, Jinan West, Nanjing South, and Shanghai Hongqiao) to Beijing, Jinan and Shanghai

Railway Bureaus, respectively, with four corresponding construction headquarters established for these delegated projects. Each headquarters was responsible for organising and managing the construction activities within its designated section, promptly coordinating and resolving on-site construction issues, and overseeing process control of schedule, quality, safety, investment, environmental protection and technological innovation during project implementation. The construction organisation model is shown in Figure 4-1.

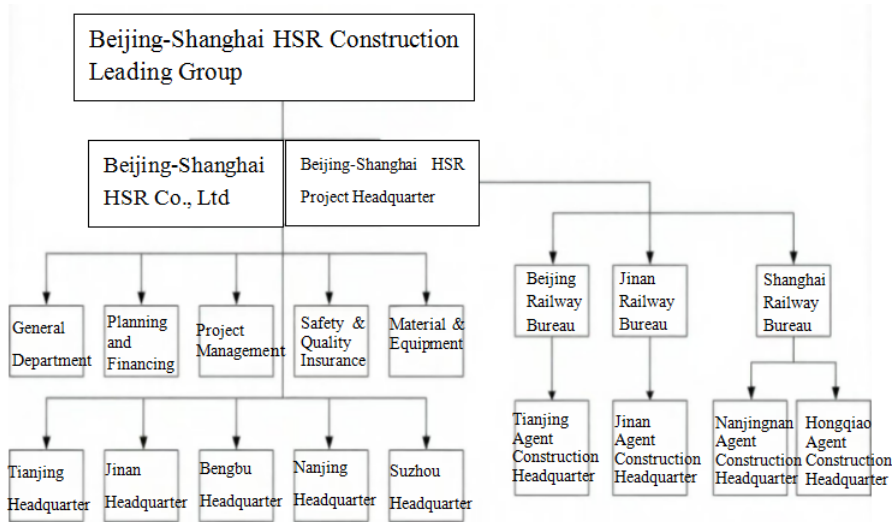


Figure 4-1. Organisational Framework for the Construction of Beijing-Shanghai HSR. HSR, high-speed railway.

4.3.1 “Owner Management with Professional Consulting” Management Model

Given the massive scale and high technical standards of the Beijing-Shanghai HSR project, traditional engineering management approaches proved inadequate to meet its construction management needs for achieving both technological and managerial innovation. To ensure effective construction management, the Beijing-Shanghai HSR Co., Ltd. pioneered a new “Owner Management with Professional Consulting” model. Under this model, Beijing-Shanghai HSR Co., Ltd. retained decision-making authority and other essential powers, while delegating relevant construction management tasks to specialised consulting agencies with strong professional and technical expertise. These consulting agencies took on responsibilities in surveying, design, construction, procurement of equipment and materials, etc., ensuring professional oversight and guidance throughout the project lifecycle. A detailed overview of the consulting

organisations involved, their respective consultation types, and the specific content of their services is provided in Table 4-1. The project employs various methods to establish specialised consulting bodies. Notable examples include forming joint consultation teams for technical guidance, engaging materials procurement agencies for supply chain management, and adopting an integrated Chinese-foreign consulting-supervision model for the construction of the Nanjing Dashengguan Yangtze River Bridge. This integrated team was responsible for supervising the entire project.

Table 4-1: Professional Consultation for Beijing-Shanghai HSR.

NO.	Consultation Body		Consultation Type	Consultation Contents
1	Technical Consultation Consortium	Chinese Consultation	Technical Consultation	Individual technical consultation, review design documents, construction details, review design changes, and participate in design pre-review.
		International Quality Representative	Technical Consultation, Key Project Consultation	On-site supervision of key projects (or processes), special quality supervision, inspection, and providing training for supervisors across the line.
2	Designing Consultation Consortium		Designing Consultation	Survey demonstration, construction details designing, construction details changing, and construction site guidance.
3	Supervision Consortium		Project Supervision	Design review, construction bidding, and construction supervision.
4	Quality Inspection Agency of Third Party		Technical Consultation	Quality inspection of materials and equipment.
5	Materials Commission Providers		Management Consultation	Materials procurement, supply, product testing, quality monitoring, and management services.
6	Research Institutions of Colleges		Topic Consultation	Technical R&D services.

HSR, high-speed railway.

4.3.2 Government-led, Diversified Investment, Market-oriented Operation

The total investment in the construction of the Beijing-Shanghai HSR exceeded CNY 200 billion. To secure enough funding, the preparatory team of the Beijing-Shanghai HSR adopted a financing strategy of “government leadership, diversified investment, and market-oriented operation” as directed by the MoRs. Following a market-oriented

financing approach, the team actively sought to attract social capital, corporate capital, and foreign investment. Their goal was to establish a diversified investment structure and explore multiple funding channels to support the project's construction.

Clarifying the State's Controlling Stake. The sponsors' agreement explicitly stipulates that the registered capital would be initially set at CNY 115 billion, to be fully subscribed by the sponsors in a single commitment with payments made in instalments. Acting as the investment representative of the MoRs, China Railway Construction Investment Corporation contributed CNY 64.707 billion, holding a 56.267% equity share and becoming the largest shareholder.

Actively introducing local government funding. Through coordination of the MoRs and local governments, the seven provinces/municipalities along the Beijing-Shanghai HSR route designated the following as their respective government investment representatives: Beijing Infrastructure Investment Co., Ltd., Tianjin Infrastructure Investment Group Co., Ltd., Hebei Transportation Investment Group Co., Ltd., Shandong High-speed Group Co., Ltd., Jiangsu Communications Holdings Co., Ltd., Nanjing Railway Construction Investment Co., Ltd., Anhui Provincial Investment Group Holding Co., Ltd., Shanghai Shentie Investment Co., Ltd. The land acquisition and resettlement compensation costs incurred by each locality for the railway project were capitalised as equity investment.

Introducing strategic investors. On January 26, 2006, the MoRs and the China Insurance Regulatory Commission (CIRC) signed a strategic cooperation framework agreement on indirect insurance funds investment in railways. On March 16, 2006, the MoRs and the CIRC held talks on indirect investment of insurance funds in railway construction projects. On June 28, 2006, the MoRs and the CIRC reached a preliminary cooperation agreement. On August 23, 2006, the MoRs and the CIRC held a coordination meeting on the promotion of insurance funds invested in the Beijing-Shanghai HSR Project. From September 5 to October 23, 2006, the MoRs Working Group on the Investment of Insurance Funds in the Beijing-Shanghai HSR Project held comprehensive talks with the Coordination Group on the Investment of Insurance Funds in the Beijing-Shanghai HSR Project.

After negotiation, the insurance team represented by Ping An Asset Management Co., Ltd. and the National Council for Social Security Fund of the PRC finally subscribed for shares of CNY 16 billion and CNY 10 billion, respectively. The capital contribution ratio of each shareholder of Beijing-Shanghai HSR Co., Ltd. is shown in Table 4-2.

After the construction of the Beijing-Shanghai HSR commenced, the shareholder composition of Beijing-Shanghai HSR Co., Ltd. underwent adjustments. In accordance with relevant national policies, the company gradually increased market financing share by replacing or swapping the MoRs' capital contribution under the premise of appropriate transfer prices, while progressively reducing the proportion of state-owned funds in the registered capital, on the precondition of maintaining the relative controlling stake of China Railway Construction Investment Corporation. In April 2009, Bank of China Group Investment Limited (Hong Kong) proposed investing

in the Beijing-Shanghai HSR project by acquiring part of the equity held by China Railway Construction Investment Corporation. Through relevant procedures, Bank of China Group Investment Limited purchased 5.217 billion shares (representing 4.537% of the total shares of the Beijing-Shanghai HSR Co., Ltd.) held by China Railway Construction Investment Corporation for CNY 6 billion via a transaction at the Beijing Equity Exchange. Consequently, the shareholding of China Railway Construction Investment Corporation decreased from 56.267% to 51.73%.

Table 4-2: Shareholders' Contribution Ratio for the First Financing of Beijing-Shanghai HSR.

No.	Shareholders	Contribution Ratio (%)
1	China Railway Investment Co., Ltd.	56.267
2	Ping An Asset Management Co., Ltd.	13.913
3	National Council for Social Security Fund of the PRC	8.696
4	Shanghai Shentie Investment Co., Ltd.	6.564
5	Jiangsu Communication Holding Co., Ltd.	3.803
6	Beijing Infrastructure Investment Co., Ltd.	3.334
7	Tianjing Railway Construction & Investment Holding (Group) Co., Ltd.	2.751
8	Nanjing Railway Construction Investment Co., Ltd.	1.903
9	Shangdong Railway Investment Holding Co., Ltd.	1.615
10	Hebei Transportation Investment Group Co., Ltd.	0.591
11	Anhui Provincial Investment Group Holding Co., Ltd.	0.563
Total		100

HSR, high-speed railway; PRC, People's Republic of China.

Financing through Debt Capital. The Beijing-Shanghai Passenger Dedicated Line Preparatory Group actively negotiated with major state-owned banks and essentially secured sources of debt financing in 2006. Key milestones included: on March 2, 2006, China Construction Bank issued a loan commitment letter for CNY 33.7 billion to the Beijing-Shanghai HSR Project; on March 7, 2006, Industrial and Commercial Bank of China granted a loan commitment letter for CNY 110 billion to the Beijing-Shanghai HSR Project; on June 2, 2006, Agricultural Bank of China granted a loan commitment letter for CNY 30 billion to the Beijing-Shanghai HSR Project. Additionally, the Preparatory Group signed a technical assistance loan agreement worth several billion yuan with the China Development Bank.

4.3.3 “Six-in-One” Integrated Target Management Innovation

The Beijing–Shanghai HSR project pursues the vision of building a world-class railway, with five overarching objectives: quality excellence project, technological innovation project, resource efficiency project, environmentally friendly project and social harmony project. These targets were operationalised through a “Six-in-One” management system focusing on: quality targets, safety targets, investment targets, schedule targets, environmental protection targets and technological innovation targets.

The overall goals are:

- (1) **Quality Excellence Project:** The project follows the principle of “a century-long endeavour, with quality as the top priority.” Leveraging world-class technologies and management practices, it implements comprehensive, full-cycle quality control throughout the construction process.
- (2) **Technological Innovation Project:** With a high starting point and strict standards, the project targets globally advanced benchmarks. Through a combination of original innovation, integrated development, and introduction-digestion-absorption-reinnovation, it has developed a high-speed rail technology system with independent Chinese intellectual property rights.
- (3) **Resource Efficiency Project:** The project promotes efficient use of resources by optimising investment control, incorporating land-saving strategies, and applying energy-efficient design principles.
- (4) **Environmentally Friendly Project:** Strict compliance with national ecological and environmental protection policies is enforced. Preserving the ecological environment along the route is treated as a key responsibility throughout the construction process.
- (5) **Social Harmony Project:** Efforts are made to safeguard the legal rights and interests of affected residents, while land acquisition, resettlement, and the relocation of infrastructure—including communication, broadcasting, and power lines (known as the “three-electricity” facilities)—are handled in accordance with laws and regulations. The project also works closely with local governments to maintain public order and social stability along the railway corridor.

“Six-in-One” Management Goals:

Guided by overarching project objectives, the MoRs and Beijing-Shanghai HSR Co., Ltd. placed strong emphasis on environmental protection and technological innovation. Accordingly, they developed an integrated “Six-in-One” management framework, which embodies the principles of environmental sustainability and technological advancement, as illustrated in Figure 4-2.

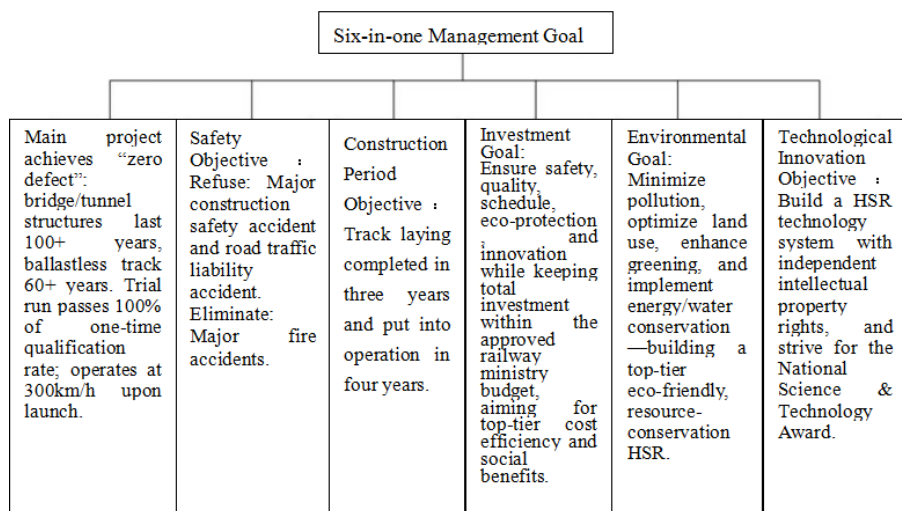


Figure 4-2: "Six-in-One" Management Goal System.

During the construction of the Beijing-Shanghai HSR, the project adhered to the guiding principles of "overall planning, scientific organisation, prioritising key projects, phased implementation, balanced production, and orderly progress." Based on a master construction plan for the entire line, the project was systematically decomposed and refined at each level according to the actual conditions of individual subprojects. Key progress milestones were clearly defined, responsibilities assigned at all levels, and implementation closely monitored to ensure that all schedule targets remained under effective control.

4.3.3.1 Modularised Management

Based on the work breakdown structure (WBS), the guiding principle of implementing modularised management for the Beijing-Shanghai HSR construction was established.

The project adopted approximately 20-km segments of bridges and ballastless tracks as standard construction units, with systematic planning for rational layout.

4.3.3.2 Focusing on Critical Paths

The master construction plan for the Beijing-Shanghai HSR clearly identified the project's critical paths. During the construction process, key components, including priority projects, critical construction processes, and pilot parallel sections, were treated as the core elements of schedule management. A hierarchical progress

management model was implemented along the entire line: overall control is achieved through milestone-based schedule management; milestones are controlled through the progress of modular units; unit progress is managed through work procedure tracking; and work procedures are controlled through real-time construction monitoring.

4.3.3.3 Tiered Implementation Plan

A strict change management procedure was established to ensure that the construction organisation designs of all participating units remained aligned with the master construction plan. For example, after the overall plan was revised, each regional headquarters developed updated construction plans for their respective sections. These plans were submitted to the Beijing–Shanghai HSR Co., Ltd. for review and consolidation. Following this, all participating units were required to study and incorporate the feedback received.

Finally, the company worked closely with each unit to align the detailed implementation plans for each contract section, specifying key milestones, construction methods, and technical measures—ensuring full coordination and consistency across all levels of construction planning.

4.3.3.4 Phased Target Fulfilment

To meet the overall construction schedule, priorities and objectives were refined for each phase of the project. Major milestones, key control sections, and special structural bridges were assigned specific deadlines. Tasks were broken down to individual work zones, responsibilities were assigned to specific personnel, schedules were detailed down to the day, and progress was managed to the exact point of execution.

HSR construction projects are characterised by extensive mileage, large scale, stringent standards, substantial investment, numerous participating units, and prolonged construction periods. Throughout the construction process, unified standardisation is required in areas including establishing sound rules and regulations, improving personnel competency, enforcing strict process control, and implementing rigorous supervision and inspection. This has progressively formed a standardised construction management system and methodology (as shown in Figure 4-3), using standardised management as the means to fully implement the “Six-in-One” integrated management requirements.

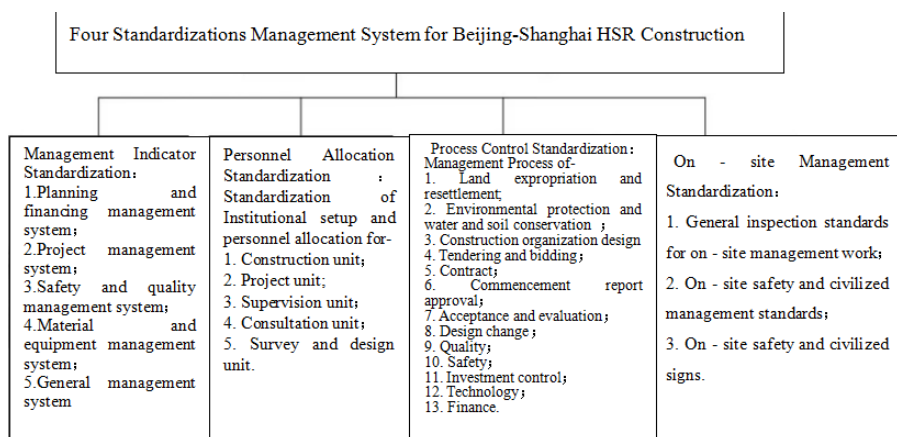


Figure 4-3: Standardised Management System for Beijing-Shanghai HSR Construction. HSR, high-speed railway.

4.3.3.5 Standardisation of Management Systems

Based on the establishment of comprehensive rules and regulations, the standardisation of management systems is embodied in the concept of “all-encompassing.” Beijing-Shanghai HSR Co., Ltd. has formulated relevant management procedures and systems, while encouraging participating units to develop their own standardised management protocols. This has created a top-down, coordinated effort to advance management standardisation across the project, thereby achieving scientific, systematic, and standardised management.

4.3.3.6 Standardisation of Personnel Allocation

With targeted training as the core approach, the personnel allocation emphasised a “high-calibre” (“强”) approach. The Beijing-Shanghai HSR Co., Ltd. formulated and implemented the *Beijing-Shanghai HSR Standardised Construction Management Manual—Personnel Allocation Standardisation* across the entire line. All participating units are required to adopt the “Four Fixations” model in human resource management for building on-site management teams, which includes: fixed organisational structure, fixed organisational functions, fixed position duties, and fixed qualification requirements. By implementing this method, each unit established organisational structures in line with national and industry standards, clarified roles and responsibilities, refined workflows, and quantified work standards, while also strengthening training, supervision, and inspection.

4.3.3.7 Standardisation of Process Control

Centred on refined management, process control reflects the principle of “strictness.” It is divided into two parts: standardisation of technical processes and standardisation of management processes.

- (1) **Standardisation of Technical Process Control:** This focuses on construction operations of the same category and type. The process begins by creating model works that fully comply with design standards. These include model mixing stations, model laboratories, model girder fabrication yards, model piers, model beams for special structures, model track slabs, and model small components. Upon acceptance and verification, these models are used to establish mature construction techniques, which are then applied to full-scale production.
- (2) **Standardisation of Management Process Control:** Based on the guiding construction plan, the Beijing-Shanghai HSR Co., Ltd. systematically managed all processes, including land acquisition and resettlement, bidding and tendering, financial management, technical supervision, safety control, quality assurance, and material management. Every phase was strictly controlled in accordance with established procedures and standards, including organising quality acceptance inspections for unit projects. Construction contractors refined the process control targets (such as quality and safety objectives) determined by the project owner and incorporated into contracts, implementing them across every task, construction procedure, and the entire project execution.

4.3.3.8 Standardisation of On-site Management

With standardised regulations as the foundation, on-site management emphasised a “meticulous” approach. The Beijing-Shanghai HSR Co., Ltd. pioneered the extension of the MoRs’ standardised management framework to construction site operations, formulating the “Beijing-Shanghai HSR Standardised Construction Management Manual—On-site Management Standardisation.” All headquarters, construction and supervision units refined workflows, establishing operational standards for both site management and safe/civilised construction, while implementing supervision and inspection to enforce standardised practices on-site.

The comprehensive implementation of standardised management in railway construction must be supported by industrialisation, mechanisation, informatisation, and specialisation. Industrialisation serves as a reliable guarantee for quality and safety, mechanisation provides an effective means to improve operational efficiency, informatisation offers a powerful tool to enhance management effectiveness, while specialisation forms the essential prerequisite for implementing accountability.

4.3.3.9 Industrialised Production

The project established an industrialised production concept, boldly explored industrialised production models, developed sound organisational systems and mechanisms for industrialised production, and formulated and optimised processes and standards. Implementing the principle of “maximising industrialisation where possible and utilising existing social production capacity where available,” it conducted thorough demonstrations of engineering measures, technical solutions, layout of major temporary facilities, and equipment configuration, while meticulously planning each production process and product.

4.3.3.10 Mechanised Operations

In the guiding construction design of the Beijing–Shanghai HSR, comprehensive arrangements were made for the use of mechanical equipment. These included the selection of machinery and construction methods, planning the number and mobilisation schedule of large-scale construction equipment, allocating workloads, formulating transportation plans for oversized equipment, and scheduling mechanised construction processes. In addition to employing a wide range of conventional machinery, a series of large-scale, specialised, and intelligent equipment—along with dedicated experimental, testing, and measuring devices—were developed and deployed to ensure control over technical indicators, enhance construction capacity, and improve production efficiency.

4.3.3.11 Informatisation Management

Beijing–Shanghai HSR Co., Ltd. established clear objectives in advancing informatisation management, achieving visual chart displays for construction progress diagrams and quality inspection reports, developing electronic quality acceptance forms, creating linkages between contract management and electronic progress payment modules, implementing a paperless electronic document circulation system, and adopting electronic signature technology and geographic information system platforms. To ensure quality traceability, construction and supervision units implemented dual video and written documentation for concealed works, establishing comprehensive video archives.

4.3.3.12 Professional Organisation

Beijing-Shanghai HSR Co., Ltd. adopted a series of meticulous and effective measures, including unified command, full authorisation, and dynamic management, to ensure professional supervision from the outset. Specialised teams, professional staff, and expert technical guidance were deployed to effectively manage all participating entities in design, construction, and supervision.

In organisational development, the project prioritised contracting construction enterprises with outstanding expertise and strong management capabilities through competitive bidding, allocating engineering tasks based on each unit's specialised strengths, to leverage their technical advantages and ensure rational professional deployment.

In terms of technical management, the company entrusted several domestic specialised technical institutions to provide expert consultation, conduct targeted research, and solve a number of key technical challenges. Moreover, foreign quality representatives were engaged, fully leveraging the experiential advantages of international experts, thereby maximising the professionalism and standardisation of on-site quality management.

All construction contractors prioritised the improvement of quality, safety, schedule, and cost control as the focus of their specialised management, equipping projects with fully-staffed and highly-qualified technical and construction management personnel, and establishing comprehensively-staffed, lean and efficient project headquarters or management departments; For workforce organisation at the operational level, they actively implemented the “frame team” employment management model, and implemented specialised division of labour for frame teams and work crews.

To achieve the overarching goal of building the Beijing-Shanghai HSR into a world-leading HSR, Beijing-Shanghai HSR Co., Ltd. decomposed and quantified all requirements of the “Six-in-One” integrated control system by project phase, construction year, and implementing unit, forming a target control network characterised by “top-down deployment, tiered implementation, level-by-level assurance, full-staff participation, comprehensive execution, and whole-process control,” which enabled the “Six-in-One” control system to yield substantial results in the construction of the Beijing-Shanghai HSR.

4.3.3.13 Design Management

The overall design of the Beijing-Shanghai HSR adhered to first-class standards, upholding the construction principle of “systematic design, integrated construction, high-quality efficiency, and one-time completion.” Throughout the entire design phase, from establishing design concepts, preliminary preparations, phased design

work and document reviews, to continuous optimisation and on-site coordination during construction, a comprehensive full-process tracking management system was established. For construction drawing schedule control, Beijing-Shanghai HSR Co., Ltd. established a Construction Drawing Supervision Group and implemented an Owner-Resident-at-Design-Institute System to ensure timely drawing delivery.

To strictly manage design changes during construction, the company formulated the “Design Change Management Procedure” and established a design change leadership group to implement categorised, batched, and tiered management of all changes based on impact level, covering joint review, decision-making, implementation, accountability and feedback.

Land Acquisition and Resettlement. The Beijing-Shanghai HSR adopted an innovative land acquisition model, where the seven provincial and municipal governments along the route organised implementation based on current national and local compensation policies to provide land for construction, with audit-confirmed acquisition costs converted into equity stakes for respective provinces and cities.

As land acquisition involved an extensive scope and complexity, multiple ministries, including Natural Resources, Transport, Human Resources and Social Security, Water Resources, Ecology and Environment, and Public Security, provided coordinated support. To expedite the land acquisition process, ensure the timely provision of construction land, and complete formal land approval procedures, Beijing-Shanghai HSR Co., Ltd. established a Land Expropriation and Resettlement Coordination Group and a Promotion Leading Group. Multiple training sessions were held to educate all involved parties on relevant policies and regulations, thereby creating favourable conditions for the smooth progress of construction. By January 31, 2008, construction land for twenty-three initial work sites was delivered; by March 31, 2008, the remaining preliminary land was provided; and by June 30, 2008, all formal land was fully allocated.

4.3.3.14 Materials Management

The Beijing-Shanghai HSR project involved large-scale material procurement with numerous categories, stringent standards, and concentrated supply requirements, all managed by a relatively small material management team. Under full-line construction conditions, materials management adhered to the principle of “serving construction organisation, prioritising site needs,” while innovatively implementing the management approach of “categorised management, tiered accountability, professional service, and coordinated supply.” Beijing-Shanghai HSR Co., Ltd. integrated traditional management practices with modern concepts, balancing the general principles of railway material supply with the unique requirements of the Beijing-Shanghai HSR construction. An emergency supply protocol emphasising

“responsiveness, speed, and practicality” was established, proactively addressing potential supply chain disruptions to ensure project completion.

4.3.3.15 Quality Management

To achieve the goal of building a world-class HSR, Beijing-Shanghai HSR Co., Ltd. established a comprehensive quality assurance system that integrates the company headquarters, project command centre, design institutes, consultants, supervision agencies, and construction contractors. To strengthen leadership in quality excellence and ensure premium engineering quality, the Beijing-Shanghai HSR Co., Ltd. set up a Quality Excellence Leadership Group for the construction project. To achieve quality management objectives, the company implemented the following measures:

1. a material qualification system for strict raw material quality control;
2. pilot testing to optimise construction techniques;
3. first-article approval to standardise processes; and
4. demonstration projects with observation sessions to disseminate quality standards and control measures project-wide, thereby enhancing overall effectiveness.

4.3.3.16 Safety Management

The Beijing-Shanghai HSR has developed a unique “12332” safety management approach tailored to the project’s characteristics: establishing “one system” (safety assurance system), focusing on “two keys” (pre-incident preparedness and post-incident response), integrating “three phases” (preparation, implementation, and acceptance), implementing “three safeguards” (ideological, organisational, and institutional), and strengthening “two means” (technical support and economic assessment). Beijing-Shanghai HSR Co., Ltd. set up dedicated safety management departments, with safety responsibilities clearly assigned at every level to ensure effective organisational safeguards. For institutional safeguards, it implemented the “Detailed Rules for Safety Production Management” to standardise safety protocols for all participating units. During construction, a complete safety contingency management system was established, covering hazard identification, plan development, review, and execution. The integrated safety management framework comprised systematic hazard identification with tiered emergency plan approval, optimised management of specialised construction methodologies, full compliance with On-site Safety and Civilised Construction Standards, intensified “red-line” safety management to ensure effective hazard identification and rectification, and upgraded safety management information system for technical safeguards.

4.3.3.17 Progress Management

Beijing-Shanghai HSR Co., Ltd. implemented a comprehensive progress control system through coordinated planning, scientific organisation, and meticulous execution. The design of the construction organisation was adopted as the framework, with resource allocation and on-site management as the foundation, land acquisition/resettlement and drawing delivery as lead factors, and advanced technologies as means to ensure project progress. For schedule planning, bridge and track works were designated as the main construction line, while pilot sections and parallel works are treated as priority projects. Construction schemes and organisation designs were dynamically adjusted based on project progress, site conditions, and engineering characteristics to ensure the timely completion of critical works.

4.3.3.18 Investment Management

The Beijing-Shanghai HSR adopted a whole-process investment control model. Investment control targets were set in phases based on project characteristics, with investment management integrated throughout the entire construction process. Responsibilities for investment control were clearly defined, and performance management was implemented. Drawing on the specific nature of the project and the overall requirements for cost control, Beijing-Shanghai HSR Co., Ltd. established a distinctive investment control system featuring “one goal, two controls, three-level management, and four-in-one integration.” During construction, the company scientifically formulated construction standards, continuously optimised engineering designs and technical measures, strictly standardised contract management, and ensured all participating units effectively implemented investment control practices. These efforts jointly ensured the successful achievement of the project’s investment management goals.

4.3.3.19 Environmental Protection and Water Conservation Management

Under the leadership of the MoRs and with guidance from the Ministry of Ecology and Environment and the Ministry of Water Resources, Beijing-Shanghai HSR Co., Ltd. incorporated environmental protection into its comprehensive “six-in-one” project management objectives. The project consistently adhered to the “Three Simultaneities” principle (simultaneous design, construction, and operation of environmental protection facilities with main works), strengthened process control, and fully implemented all requirements specified in the environmental impact assessment (EIA) and its approval documents. During construction, environmental protection measures were implemented through a three-phase process control (preparation,

construction, and completion stages), including thorough environmental awareness campaigns, strict implementation of EIA and water impact assessment reports, effective joint supervision by railway and local authorities, and continuous innovation in railway environmental management practices. Through technological innovation, ecological protection was ensured, ultimately building the Beijing-Shanghai HSR into an environmentally friendly railway.

4.3.3.20 Technological Innovation Management

The management of scientific research and technological innovation for the Beijing-Shanghai HSR was strictly divided into two phases: pre-construction and post-construction. Before construction, research project approval was mainly managed by the MoRs' Department of Science and Technology. Since the establishment of the MOR Beijing-Shanghai HSR Preparatory Office in 1994, it has taken over the daily management and review of research projects. In 2003, the MoRs reorganised the HSR Construction Leading Group Office ("High-Speed Office") and established an expert group to coordinate preliminary work and manage research projects related to HSR. After the project was approved, the MoRs formulated the "Beijing-Shanghai HSR Technological Innovation Plan." Accordingly, the company established a Technological Innovation Management Committee to oversee experimental research and technological innovation during construction. During construction, the project incorporated existing innovations, adopted a new government-industry-university-research collaboration model, conducted advanced research and prioritised key innovation projects. It implemented hierarchical management to leverage each unit's strengths, established major research programs for core technologies, and focused on the three key links of research, experimentation and application. These efforts significantly advanced technological innovation, strengthened innovation management, and perfected China's independent HSR technology and standard systems.