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Assessment of Existing Railroad Bridges to Accommodate a Higher Speed Considering Chinese Practices

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TECHNICAL SUMMARY

Title: Assessment of Existing Railroad Bridges to Accommodate a Higher Speed Considering Chinese Practices

Introduction

As the country continues to grow, the USDOT understands that the transportation system will continue to evolve to meet the opportunities of the future. A balanced use of all modes of public transportation of individuals and freight will be required to meet the country's future transportation needs. An underutilized mode of public transportation is the nation's rail system. Rail transportation of passengers is safer than highway travel, generates less emissions per unit transported than highway or air, is more energy efficient than any other transportation mode, and inherently has a lower transportation cost per unit mile.

Recently, the USDOT has sponsored the formulation of the National University Rail (NURail) Center. The NURail consortium has selected shared rail corridors as the central theme of its proposed research program. Currently, the rail systems in the U.S. are designed to support heavy freight train traffic. As High-Speed Rail (HSR) becomes a more vital asset to our nation's infrastructure, there are many elements of the existing rail network that need to be tailored to address safety concerns as well as the maintenance of way of dual purpose assets that service both HSR passenger traffic and shared revenue service lines. However, development of incremental HSR lines in the U.S. poses a number of new challenges related to existing railroad bridges. On the other hand, China has gone through similar upgrades and accumulated many experiences. The proposed research takes the advantage of the research team's strong research collaborative relationship with one of the leading research schools in China (Southwest Jiaotong University). The objectives of this study are (1) to conduct a scanning tour of China; (2) to evaluate the Chinese railroad bridge system and the issues identified in China when their railroad speed was increased six different times; and (3) to identify the most significant technologies for possible implementation in the United States in order to accommodate a higher speed for the nation's shared rail corridors.

Approach and Methodology

The research team has conducted a scanning tour of China, and had meetings with government agencies, academia, and private sector organizations in China. Specifically, the following activities were undertaken:

1. Visited the China Academy of Railway Science and consulted several experts on the general experience and achievement of speed upgrade of China's existing railways.

2. Visited the China Railway Publishing House and gathered books, technical papers, and codes which explain the theoretical analysis and practical technology developed during speed upgrade of existing Chinese railways.

3. Conducted a field survey of several railway bridges in the Jingguang Railway with assistance of the Zhengzhou Bureau. Jingguang Railway connects Beijing and Guangzhou, and is essentially the artery of Chinese railway traffic in the north-south direction.

4. Had a symposium with Zhengzhou Design Institute of China Railway Engineering Consulting Group Co., Ltd to learn the decision-making principles and design methods of strengthening and retrofitting bridges in existing railways to accommodate the needs of speed upgrade.

5. Discussed with China Major Bridge Engineering Co., Ltd about construction technology developed for strengthening and retrofitting existing railway bridges to meet the requirements of speed upgrade.

Conclusions

Railroad speed in China was increased six different times. Experiences and lessons learnt in the speed-upgrade for existing railways in China were summarized in this report based on the interviews and on-site investigations. The major conclusions are summarized below:

1. To gain experiences in their existing railway speed upgrades, engineers in China first selected a few main lines to conduct field tests of existing infrastructure with the objective of understanding the impact of speed upgrade on existing lines. Before the speed upgrade, railway research institutions carried out lots of research projects.

2. In terms of bridge structures, the main line is controlled by stiffness, not controlled by strength when the train speed is increased, especially for the high speed railway. When the speed is increased four times faster than the current speed on existing lines, bridges demonstrate an insufficient lateral stiffness, especially for steel bridges. Most steel girder bridges on existing lines in China were replaced with concrete girder bridges. If the replacement is not feasible, the train speed is limited when crossing steel bridges.

3. In the process of long-term operation of the upgraded rail lines, a monitoring system of bridge structures is implemented in China to observe the vertical and lateral accelerations and deflection.

4. Adding transverse prestress in the diaphragm between the beams of the existing bridges can effectively increase the transverse stiffness of the bridge. When the bridge superstructure needs to be reinforced, investigation should be made at the same time on the possible impact on bridge piers and foundations.

Recommendations

After completing the scanning tour, the team proposes the following recommendations concerning speed upgrade of existing railway bridges in the U. S.

1. In terms of the feasibility study of speed upgrade in the U.S., investigation on the current and future demands of passenger and freight transportation of the existing railways in the U. S. is necessary. Identify the railway corridors that need speed upgrade and the degrees of speed upgrade for these railway corridors. Then survey several existing railways in the U.S. based on the requirements for several degrees of speed upgrade. Determine if the speed of existing railways should be upgraded to the desired degrees at one time or over several times. Classify the bridges on the existing railways according to their materials and structural types, since different kinds of bridges may encounter unique problems. Gather the information about the quantity of bridges on the existing railways and choose the bridges representative of each material and structural type for further study. Conduct a field survey of the bridges identified. Investigate how bridge components influence one another if the operating speed on a railway bridge is upgraded. Identify if bridge strengthening and retrofitting should be applied to both bridge superstructures and substructures.

2. In terms of bridge strengthening and retrofitting for speed upgrades in the U. S., relevant Chinese experience may be considered when speed upgrades of existing railways are conducted in the U. S. When the railway line on a bridge needs to be altered, and the original piers and foundation are in good condition, it is not necessary to change the piers and foundation. It is suitable to widen and strengthen their sides to accomplish the modification of the railway line. For short-span bridges with good structural integrity, it is not necessary to retrofit them when on-site testing and evaluation indicates that they can satisfy the requirements for speed upgrades. The experience of bridge speed upgrades in China shows that it is expensive and not very effective to retrofit steel girders. When speed upgrades are carried out in the U. S., it is important to evaluate the cost and actual effects of strengthening and retrofitting of steel bridges. The fast construction method used in China may be helpful to reduce the impacts of construction on the normal operations of existing railways during speed upgrades in U.S. When bridge speed upgrades are conducted, the responsible technicians should have construction experience and understand the corresponding technology and construction equipment. It is important to reduce the effects of train operation on the construction quality of bridge strengthening and retrofitting. This report suggests that train speeds should be decreased when travelling on the bridges under construction. When bridge strengthening and retrofitting are completed, the train speeds should be gradually increased over a period of time.

3. For speed upgrades of existing railway bridges in the U.S., it is important to consider carefully in terms of the train operation time-table before making decision on the reconstruction plans and corresponding construction methods. This suggestion can lower the effect of on-site construction on the normal operation of a railway line. When on-site construction is performed on the bridges of an existing railway, structural types of the

bridges, the methods of reconstruction, the actual conditions of other infrastructures on this railway, of the constructors' experience level, and their familiarity with construction technology and equipment, should be considered to make the detailed on-site construction plan. The on-site construction of a bridge requires the cooperation of other components in a railway transportation system, including: electric power lines, communication devices, route, rail, transportation equipment and so on. It is necessary to coordinate different departments to ensure the punctual completion of the on-site bridge construction and normal operation of the railway. Before a portion of railway is closed, make all the necessary preparations and take full advantage of the closed time period to accomplish the planned construction.

4. Field investigation should be conducted to understand the current situation of the United States existing railroads considering Chinese practices and experience in speed upgrades of existing railroads, to compare US railroad bridge systems with Chinese railroad bridge systems and to identify the most significant technologies for implementation in the United States, and propose strategies to accommodate a higher speed for the nation's shared rail corridors. An on-site survey of the Crescent Corridor between Memphis and Harrisburg in Crescent Corridor routes is recommended. The report developed a series of amplifying questions to help focus the discussion with engineers and to show them the topics of interest.

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SECTION 1: INTRODUCTION

1.1 Background

As the country continues to grow, the USDOT understands that the transportation system will continue to evolve to meet the demands of the future. A balanced use of all modes of public transportation, for both individuals and freight, will be required to meet the country's future transportation needs. An underutilized mode of public transportation is the nation's rail system. Rail transportation of passengers is safer than highway travel, generates less emissions per unit transported than either highway or air, is more energy efficient than any other transportation mode, and inherently has a lower transportation cost per unit mile.

Recently, the USDOT has sponsored the formulation of the National University Rail (NURail) Center. The NURail consortium has selected shared rail corridors as the central theme of its proposed research program. Currently, the rail systems in the U.S. are designed to support heavy freight train traffic. As High-Speed Rail (HSR) becomes a more vital asset to our nation's infrastructure, there are many elements of the existing rail network that need to be tailored to address safety concerns as well as the maintenance of dual purpose assets that service both HSR passenger traffic and shared revenue service lines. However, development of incremental HSR lines in the U.S. poses a number of new challenges related to existing railroad. On the other hand, China has gone through similar upgrades and accumulated many experiences.

1.2 Objectives and Focus Areas

The purpose of the tour was to investigate and document the applications and experiences with shared rail corridors in China, especially regarding China's six different rail speed upgrades. The team conducted meetings with government agencies, academia, and private sector organizations to evaluate the Chinese railroad bridge system and issues identified in China when their railroad speed was increased six different times. This will be done so as to compare US railroad bridge systems with Chinese railroad bridge systems and to identify the most significant technologies for implementation in the United States, and propose strategies to accommodate a higher speed for the nation's shared rail corridors.

The following activities were undertaken:

1. Visited the China Academy of Railway Science and consulted with several experts on the general experience and achievement of speed upgrade of existing railways. The research team (RT) discussed the technical problems encountered in railway bridges during speed upgrade and the corresponding solutions to these problems.

2. Visited the China Railway Publishing House and gathered books, technical papers, and codes which explain the theoretical analysis and practical technology developed during the speed upgrade of existing Chinese railways.

3. Conducted a field survey of several railway bridges in the Jingguang Railway with the assistance of the Zhengzhou Bureau. Jingguang Railway connects Beijing and Guangzhou, and is essentially the artery of Chinese railway traffic in the north-south direction. RT visited the sites of several railway bridges to understand how they were strengthened and retrofitted to accommodate the needs of a speed upgrade Our objective was aiming to understand the impacts of speed upgrade on different types of railway bridges, the technical problems and corresponding solutions in the strengthening and retrofitting of these railway bridges, and the realistic effects of the technical solutions on the railway bridges. RT collected photographs of the sites of the railway bridges.

4. Had a symposium with Zhengzhou Design Institute of China Railway Engineering Consulting Group Co., Ltd to learn the decision-making principles and design methods of strengthening and retrofitting bridges in existing railways to accommodate the needs of speed upgrade. RT's goal was to obtain the knowledge and experience concerning the most economic and effective strengthening and retrofitting methods of different types of railway bridges.

5. Discussed with China Major Bridge Engineering Co., Ltd about construction technology developed for strengthening and retrofitting existing railway bridges to meet the requirements of speed upgrade.

1.3 Locations Visited

The team visited China Academy of Railway Sciences, China Railway Publishing House, Zhengzhou Railway Bureau, Beijing-Guangzhou Railway, Zhengzhou Design Institute of China Railway Engineering Consulting Group Co., Ltd, and the China Zhongtie Major Bridge Engineering Group Co., Ltd from November 05 to 09, 2012. These institutions were selected because of their knowledge of theories, regulations and standards, technologies and experiences. The contacts in each institution are listed in Appendix A. The locations, specific dates, and activities are given in **Table 1.1**.

Table 1.1 Schedule of Activities

Location	Date	Activities
Beijing, China	Monday, November 05, 2012	Group discussion with experts from China Academy of Railway Sciences
Beijing, China	Monday, November 05, 2012	Visited China Railway Publishing House
Zhengzhou, China	Tuesday, November 06, 2012	Group discussion with experts from Zhengzhou Railway Bureau
Zhengzhou, China	Wednesday, November 07, 2012	Site visits to bridges on Beijing-Guangzhou Railway.
Zhengzhou, China	Thursday, November 08, 2012	Meeting with Zhengzhou Design Institute of China Railway Engineering Consulting Group Co., Ltd, and site visits to bridges on Beijing-Guangzhou Railway.
Wuhan, China	Friday, November 09, 2012	Meeting with China Zhongtie Major Bridge Engineering Group Co., Ltd

1.4 Amplifying Questions

RT developed a series of amplifying questions to help focus the discussion with the Chinese experts and to show them the topics of interest. The amplifying questions addressed several topics related to speed upgrade of existing railway bridges: the working procedure of bridge strengthening and retrofitting according to the upgraded speed， the requirements for railway bridges based on the grades of speed upgrading (such as dynamical responses and other structural behavior indices), the methods of their state evaluation, experimental study of construction technology, the design methods and practical and effective approaches of bridge strengthening and retrofitting, the influences of different locomotives on speed upgrade, typical problems during operations after speed upgrade, the diagnosis of these problems, the reasons for these problems, and the corresponding technical measures to solve these problems. The questions provided to the hosts before the scanning study are included in Appendix B.

SECTION 2: FINDINGS ON ASSESSMENT OF
EXISTING RAILROAD BRIDGES TO ACCOMMODATE A HIGHER SPEED AT
DIFFERENT VISITING SITES

2.1 <u>Southwest Jiaotong University</u>

Southwest Jiaotong University, a key university supervised by the Center and the Education Department, was established in 1896. It is one of the top '211 Engineering' universities and National '985 Engineering' innovation platforms within the country. It has a national dynamic lab and 27 provincial or departmental labs. Its Transportation Engineering major has been ranked No.1 in China. It is one of the universities with a long history, named as "Producer of Engineers Majoring in Railway Engineering". The portal of the University is shown in **Figure 2.1.1**.

Figure 2.1.1 Southwest Jiaotong University
(http://tieba.baidu.com/)

The National Driving Dynamic Lab in Southwest Jiaotong University was established and approved by the National Planning Department. It was supervised by the Railway Department, but now is supervised by the Education Department. The research conducted in the lab focuses on the high-speed and heavy-loaded train. Because of the railway transportation development trend and its characteristic, the research is mainly on the structural design of the railway vehicles and their driving apparatus, dynamic and strength analysis, inspection and testing. There are six research interests: train design theory and structural reliability, dynamic characteristic and response of vehicles, suspension train technology, theory of friction and its application, electrical, transformable and controllable properties of driving apparatus, and inspection and testing techniques. As an engineering lab, the lab emphasizes testing equipment; it designed a set of vehicle testing equipment including a vehicle locomotive rolling vibration test rig, rolling stock vehicle integrated parameter measurement units, a 12-channel fatigue test rig, vehicle virtual prototyping platform software (VirtualMBS), the train line system with dynamic simulation and safety evaluation device TTIS-1, damping device R & D systems, a high-speed wheel-rail friction test rig, a traffic safety detection system, a wireless detection system, and pantograph mixed simulation test bench test equipment. Some of the testing platforms are shown in **Fig. 2.1.2 to 2.1.5.**

Figure 2.1.2 Traction Power State Key Laboratory Test Equipment
(http://news.swjtu.edu.cn/epaper/shownews)

Figure 2.1.3 Digital Simulation Platform for High-speed Trains
(http://news.swjtu.edu.cn/)

Figure 2.1.4 Overall Test Platform Locomotives

Figure 2.1.5 Research Experiment Platform (highest 600 km/h)
(http://news.swjtu.edu.cn/epaper/shownews)

2.2 China Academy of Railway Sciences (CARS)

RT met with two specialists, Mr. Xiaxin Chen and Mr. Suoting Hu, from the China Academy of Railway Sciences. The two specialists first summarized the six speed upgrades of existing railways in China. Then, they introduced the overall planning and implementing procedure of the speed upgrades. Finally, they discussed the technical problems related to railway bridges in their speed upgrades. They also provided their experiences concerning the investigation methods, the corresponding solutions, and the effectiveness of these solutions in practice to address these technical problems.

China Academy of Railway Science (CARS) was founded on March 1, 1950. It is the only research institute to perform interdisciplinary scientific and engineering research in the China Railway Industry. It has conducted extensive experiments and developed significant technology for Chinese railways. CARS has won 176 state-level awards and 649 province-level awards. CARS is essentially the leading organization in developing railway technology and contributes significantly to the progress of the China Railway Industry.

Recently CARS investigated several topics related to speed upgrades, heavy freight transportation, intercity passenger railways, high speed railways, and railways subjected to environmental effects of plateaus. The achievement of the research includes upgrading the speeds of existing railways to 250 km/h (155 mph), the technology of transporting 20,000 tons of heavy loads, traction, brake and network control systems of high speed trains, unballasted rail tracks for passenger transportation, advanced operation scheduling systems, and high speed testing trains for 400 km/h (248 mph) traveling. CARS has successfully accomplished all the coordinated scheduling and testing work of the operational high speed railways in China. CARS has the National Railway Test Center and owns over 40 laboratories of different specialties. The facilities in CARS include 6991 pieces of equipment. Recently, CARS has established six state-level platforms for technology innovation, such as the National Research Center of System Engineering of Railway Intelligent Transport, State Key Laboratory for Track Technology of High-Speed Railway, National Engineering Laboratories for System Test of High-Speed Railway, Equipment Testing Line of Urban Rail Transit, State Key Laboratory for Traction and Control System of Locomotive and EMU, Service Platform for Technological Innovation of High-Speed Train. In 2011, CARS became an official member of the International Union of Railways or UIC (*CARS website:* http://home.rails.com.cn/en/). The main building of CARS is shown in **Fig. 2.2.1 and 2.2.2**.

Figure 2.2.1 China Academy of Railway Science

Figure 2.2.2 PI arrived at CARS

(http://home.rails.com.cn)

During the six-round speed upgrade of the existing railways in China, CARS was the main institute in charge of technology and participated in a lot of projects. CARS was responsible for compiling technology plans, establishing technical specifications and testing regulations, for tackling the encountered technical difficulties, and conducting comprehensive testing and inspections. CARS has already mastered the technology of speeding up the existing railways to 250 km/h (155 mph). (*CARS website:* http://home.rails.com.cn/en/). A discussion about the experience of the six-round speed upgrade between representatives and the research team was carried out at CARS, as shown in **Fig. 2.2.3**.

Figure 2.2.3 Photo after Seminar in China Railway Research Institute

2.2.1 Background for the Six-round Speed Upgrade of the Existing Railways in China

In the middle of the twentieth century, railways started to revive through the high-speed passenger transportation. The invention of high-speed trains has renovated the railway industry, which used to be regarded as a “sunset industry”. In order to fully utilize the potentials of the existing railways, a few countries that have strong interests in the development of high-speed rails, have sped up their existing railways on a large scale and fulfilled rapid railway transportation. Especially in the 1980s, more countries paid attention to the retrofitting of existing railways for their speed upgrade. The retrofitting of existing railways and the improvement of trains' speeds has the characteristics of short construction periods, less investment and more efficiency. They allow many high-speed trains to be operational in a short time period and enhance the productivity and transportation efficiency. It has become a worldwide trend to develop the railway industry by increasing trains' speeds, and high-speed railways represent one of the future directions for transportation.

In the 1990s, the highest train speed for passenger transportation in China was 110 km/h (68 mph). The average train speed, however, was only 48.3km/h (30 mph). The speed of railway transportation could not accommodate the needs of economic and social development in China. Therefore, it was essential to increase the speeds of existing railways. The significance of speed upgrade is also related to the maximization of the railway resources available and enhancement of their transportation capability. With respect to these backgrounds, China has updated its fixed installation and mobile equipment on existing railways, launched the projects of speed upgrade, improved its original transportation modes, and promoted the development of railway industry.

2.2.2 Summary of Chinese Six-round Speed Upgrade of Existing Railways

Between 1997 and 2007, China has accomplished speed upgrade of existing railways six times. After all the speed upgrade, the speed of the trains for passenger transportation has increased from 80-90 km/h (50-56 mph) to 200-250 km/h (124-155 mph). Because of the utilization of the new bogies, the speed of the trains for freight transportation has increased from 80 km/h (50 mph) to 120 km/h (75 mph). The details concerning the six-round speed upgrade of existing railways are illustrated in **Fig. 2.2.4 to Fig. 2.2.6** and explained in **Table 2.1** (http://baike.baidu.com/ and http://news.xinhuanet.com/ziliao/).

Figure 2.2.4 Schematic of the Fifth Speed Upgrade
(http://www.meizhou.cn/news)

Figure 2.2.5 Schematic of the Sixth Speed Upgrade
(http://shjt.shfamily.com.cn/tbch)

Figure 2.2.6 Summary of the Existing Railways after the Sixth Speed Upgrade
(Green line: >120 km/h, total 22000 km; Blue line: >200 km/h, total 6003 km;
Red line: >250 km/h, total 846 km)
(http://news.huochepiao.com)

Table 2.1 Summary of Six-round Speed Upgrade

Date	Achievements
Not available	The first speed upgrade mainly focused on three main corridors: Jingguang or Beijing-Guangzhou Corridor, Jinghu or Beijing-Shanghai Corridor, and Jingha or Beijing-Harbin Corridor. Length of railways with a speed post of 120 km/h (75 mph): 1398 km (868 miles) Length of railways with a speed post of 140 km/h (86 mph): 588 km (365 miles) Length of railways with a speed post of 160 km/h (100 mph): 752 km (467 miles)
October 1, 1998	The second speed upgrade still focused on the three main rail corridors mentioned above. Length of railways with a speed post of 120 km/h (75 mph): 6449 km (4007 miles) Length of railways with a speed post of 140 km/h (86 mph): 3522 km (2188 miles) Length of railways with a speed post of 160 km/h (100 mph): 1104 km (685 miles)
October 21, 2000	The third speed upgrade was mainly conducted on the Longhai or Lianyungang-Lanzhou Corridor, Lanxin or Lanzhou-Urumqi Corridor, Jingjiu or Beijing-Kowloon Corridor, Zhegan or Hangzhou-Zhuzhou Railway. Length of railways with a speed post of 120 km/h (75 mph): 9581 km (5953 miles) Length of railways with a speed post of 140 km/h (86 mph): 6458 km (4012 miles) Length of railways with a speed post of 160 km/h (100 mph): 1104 km (685 miles)
October 21, 2001	The fourth speed upgrade included the Jingjiu or Beijing-Kowloon Corridor, Wuhan-Chengdu Railway, the southern part of Jingguan Corridor, Zhegan Railway, and Hada or Harbin-Dalian Corridor. Length of railways with a speed post of 120 km/h (75 mph): 13161 km (8177 miles)

	Length of railways with a speed post of 140 km/h (86 mph): 9779 km (6076 miles) Length of railways with a speed post of 160 km/h (100 mph): 1104 km (685 miles)
April 18, 2004	The speeds of both passenger transportation and freight transportation were simultaneously upgraded for the first time. The speed limits of parts of several corridors had been increased to 200 km/h (124 mph). The total length of the upgraded railways was more than 16500 km (10252 miles). The achievements included: Length of railways with a speed post of 160 km/h (100 mph): 7700 km (4784 miles) Length of railways with a speed post of 200 km/h (124 mph): 1960 km (1218 miles) The increase of freight transportation capacity: 3%
April 18, 2007	Large-scale speed upgrade had been conducted on the Jingha Corridor, Jinghu Corridor, Jingguang Corridor, Longhai Corridor, Lanxin Corridor, Jiaoji or Qingdao-Jinan Railway, Wujiu or Wuhan-Jiujiang Railway. The speed limits of passenger trains had been increased to 200 km/h (124 mph). In certain parts of these corridors, passenger trains were allowed to travel at the speed of 250 km/h (155 mph). The heavy-duty freight trains which could transport 5000 tons (11023 kip) and travel at the speed of 120 km/h (75 mph) were operational after the speed upgrade. The achievements also included: Length of railways with a speed post of 120 km/h (75 mph): 22000 km (13670 miles) Length of railways with a speed post of 200 km/h (124 mph): 6003 km (3730 miles) Length of railways with a speed post of 250 km/h (155 mph): 846 km (526 miles)

After the six-round speed upgrade, the capacity of passenger transportation of Chinese railways has increased by 18%. The capacity of freight transportation of Chinese railways has increased by 12%. The speed upgrade has mitigated the bottleneck condition of the railway transportation in China. The speed upgrade of existing railways is especially beneficial to freight transportation. The worldwide trend of freight transportation through railways is to develop specialized, centralized and rapid railway systems. During freight transportation, the time of its travel on trains is only about 30% of the total time. Other operations, such as loading, organization, transfer, and unloading, take about 70% of the total time. The speed upgrade of existing railways can facilitate the organization and transfer of freight and pave a way for the leapfrog of railway transportation development. In fact, the speed upgrade of existing railways can not only improve the railway infrastructures, but also expedite the technology advancement and enhance the service quality.

2.2.3 The Overall Planning of Speed Upgrade of Existing Railways in China

At the beginning of the speed upgrade, railways in China had the following characteristics: the most intense transportation, a high degree of utilization close to their transportation capacities, dual purposes for both passenger and freight transportation, and the mixture of different types of trains. Different types of trains possess different speeds, densities, and weight. For the intense railway transportation, they have distinct requirements for transportation organizations, rail systems, information systems, and traction power. At the same time, the existing railways had different ages and were not designed according to the same code or specification. As a result, it was very complex to perform the speed upgrade, and it was necessary to understand the actual conditions of the railways' infrastructures, including rails, switches, road foundation, bridges and tunnels, locomotives, trains, signal equipment, communication equipment, and equipment of information technology.

After understanding the actual conditions of the railway infrastructure, engineers in China began to determine the reasonable target values for the new increased speed. According to previous research, when the transportation distance is less than 300 km (186 miles), railways cannot compete with highways if the railways' speed is less than 100 km/h (62 mph). When the transportation distance is between 500 km (310 miles) and 800 km (497 miles), railways cannot compete with airways if railways' speed is less than 250 km/h (155 mph). The existing railways in China were shared by passenger transportation and freight transportation. In order to upgrade the speed of existing railways, it is essential to have realistic predictions about the future demands of passenger and freight transportation, proper evaluation of equipment conditions, reasonable estimation about required investment and a good understanding of the trains' allowable speeds considered in the original design. Once the information mentioned here is available, the reasonable target values for new speeds can be determined. Then, it is possible to retrofit or upgrade lines, road foundations, bridges and culverts, and communication signals. The reasonable target values for new speeds are also significant to create feasible design and construction plans which can minimize investment and yet meet the comfort and safety requirements for the trains after a speed upgrade.

For the first several times, speed upgrade in China was conducted on a few major corridors. The actual conditions of railways' infrastructures were investigated by collecting materials documented in field construction and field speed upgrade tests of several railways including Huning or Shanghai-Nanjing Railway, Jingqin or Beijing-Qinhuangdao Railway, Jingguang or Beijing-

Guangzhou Railway and Guangshen or Guangzhou-Shenzhen Railway. Studies were also conducted to understand the impact of speed upgrade on the infrastructure. Several institutes including CARS conducted extensive research studies before the speed upgrade was carried out. The research focused on many engineering problems, such as retrofitting and/or new construction of the railways' line plane (vertical section), retrofitting and/or new construction of road foundations, strengthening of the road foundation, increasing the spans of existing bridges and culverts, retrofitting of bridges and culverts, the replacement of rails, the replacement of ballast, the replacement of sleepers or crossties, and overhead lines. The construction caused disruption to the normal operations of the railways. The construction transition was also complicated. It was vital to coordinate the operations and construction to minimize the disruption and finish the construction on time. Therefore, communications with the departments of railway operations and construction protection were prepared before construction was started. The safety of operations and construction was provided by cooperating with the departments of railway operations and taking necessary safety measures. **Fig. 2.2.7 to Fig. 2.2.33** show the field construction for speed upgrade of existing railways.

Figure 2.2.7 CRH5 EMU in the Loop Line Test

Figure 2.2.8 Loop Line Trucks Carried 120 km/h Speed Reliability Test
(Photo from http://home.rails.com.cn/)

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(http://www.railcn.net/news/railway-building/3126.html)

Figure 2.2.30 Bridge Girder Erection Site for 6th Speed Upgrading
(Courtesy of Jianping Du   http://news.china.com.cn/)

Figure 2.2.31 Upgrading of a Frame Bridge Girder Next to an Existing Lines

Figure 2.2.32 Overloaded Trains Passing the New Bridge
(http://www.chnrailway.com/)

Figure 2.2.33 Trains under Normal Operation during Bridge Reconstruction
(http://www.bstcc.com.cn/zxjs/bstccnews/news/104677.shtml)

Before the speed of an existing railway was officially increased to its new limit, a section of the railway that was considered representative of its overall conditions was chosen for comprehensive tests to evaluate the effects of retrofitting and identify potential safety problems. Practical problems and corresponding solutions encountered during the process of speed upgrade were summarized into several technical specifications and standards. The accumulated experience and technology were then applied to other parts of the same railways or other railways. The experience and technology were also improved during their application. The speed upgrade of existing railways was achieved in a stage-by-stage process. The impact of speed upgrade on bridges was highlighted as an example below.

2.2.4 Summary of Encountered Problems, Corresponding Solutions and Relevant Experience in Bridges

The railway bridges in China are complicated due to the differences in design standards, ages, load ratings, and infrastructure conditions. During the speed upgrade, field tests and evaluations were conducted on several bridges according to the actual conditions of their infrastructures and the target values for their new speeds. These tests and evaluations were useful in understanding the structural types and characteristics of the bridges on the existing railways and the influences of speed upgrade on these bridges. Theoretical investigations on typical bridges were conducted to analyze the effects of various strengthening and retrofitting methods. Then, strengthening and retrofitting plans were made according to the type of bridge structures. Finally, the actual effects of bridge strengthening and retrofitting were evaluated through comprehensive experimental studies before the speed upgrade of these bridges was officially carried out. The successful experience concerning bridge strengthening and retrofitting was summarized and then applied to other bridges of the same types. For the problems encountered during the practice of speed upgrade, the corresponding solutions were obtained through a lot of theoretical investigation and experimental verification. Some of the relevant experience shared by CARS is briefly explained as follows:

(1) When trains' speeds are upgraded, the dynamic response of a bridge should be evaluated considering three aspects: dynamic strength, safety against train derailment, and riding comfort. Generally speaking, when the speed of a train is increased, especially for that traveling on a high-speed railway, the behavior of a bridge should be controlled by stiffness instead of strength. During the first four speed upgrades, it was found that a few types of girders had insufficient lateral stiffness. These girders are typically over 32 m (105 ft.) long and include: prestressed concrete girders and steel girders in single-track bridges with the structural forms of top plate, bottom plate, top truss, bottom truss, and half through truss. During field tests, bridges with the girders mentioned above experienced a noticeable swaying. The derailment and excessive lateral amplitudes were observed in a few bridges. Train derailment was observed three times during the tests of Luanhe Bridge on the Jingshan Railway (shown in **Fig. 2.2.34**) which had deck steel plate girders. During the fifth speed upgrade, the problems concerning increased vertical impacts and insufficient vertical stiffness were also identified. When trains with increased speeds moved on the bridges, the vertical deflections of the bridges were so pronounced that large vertical accelerations were observed and the smoothness of the rails was compromised. Because of the large accelerations, track detection gauges in the locomotives indicated Level-3 amplitudes which caused severe problems concerning the comfort and stability of trains. Speed upgrade could also cause cracking in abutments and piers, damages on bridge bearings, large deformation of light piers, and exacerbating the damage of masonry abutments and piers. It was concluded that light-piers were problematic in meeting the requirements of speed upgrade. To sum up, speed upgrade amplified the impacts of trains on bridges. Damages on bridge abutments, piers and bearings were also intensified.


Figure 2.2.34 Luanhe Railway Bridge
(http://www.changli.ccoo.cn)

In order to solve the problems above, the MOR, CARS and several universities performed a lot of theoretical investigation and field tests. Most of the research was related to steel bridges which seemed to have the most problems and the problems could occur at very early stages. Dozens of strengthening and retrofitting methods were invented to enhance the stiffness and frequencies of steel bridges. The methods include using diaphragms at a smaller spacing, using top bracing at a smaller spacing, and enhancing the distances between the major beams. Nevertheless, previous experience showed that all the strengthening and retrofitting methods for steel bridges were not economical. When railway paths needed to be adjusted, the required changes of steel girders were difficult to be implemented and bridge sleepers should also be altered. When bridge sleepers were enlarged, the moments on bridge sleepers were also increased. When a theoretical strengthening and retrofitting method is utilized in practice, it is effective to some extent based on field testing results. However, few methods were able to completely solve the problems above. As a consequence, most of the steel bridges on the existing railways were either replaced by concrete bridges or had reduced speed limits.

The main problem with concrete bridges is the insufficiency of lateral stiffness. For the bridges whose girders were not laterally connected and those which are over 12 m long and had only two girders, the effective methods of increasing their integrity and lateral stiffness are to add more diaphragms at their midspans and at abutments and to provide lateral prestressing forces through the diaphragms. For short or medium span slab-type bridges with rubber bearings, the lateral displacements at their bearings should be controlled to increase their lateral stability. If the superstructures are severely damaged, they should be replaced. For a culvert, when the path of an existing railway is widened, one side of the culvert needs to be spread and its side walls and wing walls may be removed. Attention should be given to the protection of subgrade slopes. When side walls and wing walls are removed, sheet piles or dug piles are needed at the shoulder.

(2) During the process of several speed upgrades, there were many existing bridge structures which satisfied the requirements for speed upgrades in the theoretical analysis but encountered practical problems during rail operation with higher speeds. On a couple of concrete bridges with the span length of 32 m (105 ft.), the effect of resonance was observed due to the low natural frequencies of these bridges. Because of their long-time service, connections have degraded enough to cause the operation problems during speed upgrades.

(3) Field testing demonstrated that freight trains generally caused more lateral vibration than passenger trains. In order to mitigate the unfavorable effects of locomotives and freight trains on infrastructures like bridges, the MOR has developed the cross-braced bogies K4 and K5 shown in **Fig 2.2.35 and Fig. 2.2.36**, and installed them in freight trains. Compared to the original freight trains with the 8A bogies, the new freight trains reduced the dynamical responses in the transverse direction and increased the operation speed of freight trains on the existing railways from 80 km/h (50 mph) to 120 km/h (75 mph). However, the requirements

of superselevation for freight trains are different from those for passenger trains. At the same time, the axle weights of freight trains are heavier than those of passenger trains. If the operation speed is too high, the braking of the locomotives for freight trains will become a significant problem. These factors are the challenges of further enhancement of operation speeds and transportation capacity of freight trains on the Chinese existing railways.

Figure 2.2.35 K4 Bogie
(http://wuhanonhtie.i.sohu.com/blog/view/128244484.htm and http://image.baidu.com)

Figure 2.2.36 K5 Bogie

(http://www.csrgc.com.cn/cns/cpyfw/lbj/2008-05-26/134.shtml)

(4) Field construction on the existing railways should be planned to minimize the disruption to rail operation. The construction procedure, techniques, equipment and materials should be carefully selected to perform the field construction under the normal operation of a bridge. The following instance is illustrated to explain the strengthening and retrofit of an existing concrete bridge under its normal operation.

When the girder replacement was performed on an operational railway, key crossing closure is generally utilized in the field construction. In order to minimize the influence on rail transportation, the girders are replaced and simply connected to other bridge members during the closure time. Prestressed concrete diaphragms and other secondary components can be constructed after the railway is opened.

When construction is conducted on an operational railway, it is difficult to seal the posttensioned anchorage of the prestressed concrete diaphragms. First of all, the work should be done high above the ground with trains traveling on the bridges. Construction safety should be a concern under this circumstance. Also, the construction quality cannot be easily controlled. The concrete used to seal the posttensioned anchorage cannot be consolidated well due to the vibration caused by the traveling trains. After the construction, the concrete may experience hollowing and spalling and results in the corrosion of anchor head and the loss of prestress. As a result, prestressed concrete diaphragms may not achieve their desired effect. The problem discussed here was quite severe during the replacement of the girders in Minghe Bridge on the Beijing-Guangzhou railway.

During the replacement of concrete girders in the Shahe Bridge on the Bejing-Shanhaiguan railway, several improved measures were implemented to solve the problem above. Shahe Bridge located between Maliu Town and Yangge Town. Its superstructure consists of prestressed concrete T-beams and reinforced concrete. Because of the design deficiencies, their cambers have exceeded the design limit and caused the posted speed limit of this bridge to be only 80 km/h (50 mph). According to the requirement for the speed upgrade of the Bejing-Shanhaiguan railway, those girders whose cambers were much larger than the design limit should be replaced. The construction of the girder replacement was carried out in January 2000. After the girder replacement, the operational speed was temporarily 80 km/h (50 mph). The construction of prestressed concrete diaphragms was performed between May and August 2000. After all the construction was accomplished, the operational speed of this bridge was increased to a higher value. In order to eliminate the concrete problem at the anchorage ends, a new construction method was implemented in this project which is briefly explained as follows:

- Use high-pressure water to clean the laitance the inside anchorage ends and to expose the anchor plates;
- Weld two 4 mm-diameter rebars to the anchor plates. The spacing of the rebars should be about 170 mm, and the rebars should extend 20 mm beyond the anchorage end;
- Cut a piece of steel plate as a form. Its in-plane dimension should be close to that of anchorage ends. Two holes should be drilled on the steel plate. The diameter of the hole should be 6 mm. The spacing of the holes should also be 170 mm;
- Pass the rebars through the holes and cover the anchorage ends with the steel plate. Then fasten the steel plate by bolts. Use proper dimensions when casting steel plate to leave around 50 mm space for concrete grouting (shown in **Fig. 2.2.37**);

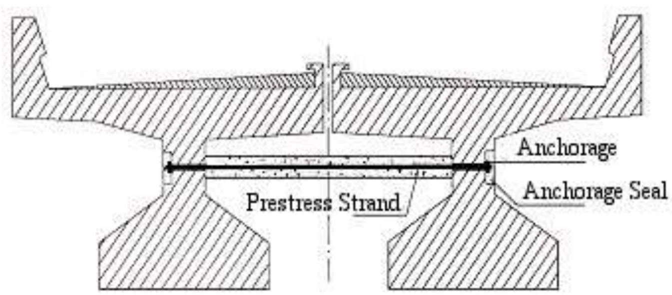

Figure 2.2.37 Transverse Prestress Connection

- Cast concrete through the grout hole and vibrate it. The concrete strength for the anchorage ends sealing should be 7.25 ksi (50 MPa with a slump of 30 mm to 50 mm);
- Make a simplified vibrator vibrate the concrete.
- Remove the form after 24 hours. Then repair and cure the concrete.

(5) China has extensively conducted many comprehensive speed upgrade tests to investigate the conditions of bridges, locomotives, electric power systems and several other components in the rail transportation systems. CARS has set up specialized institutes, designed the outlines of experiments, proposed the standards for various parameters, and determined the contents and safety measures of the on-site experiments. After conducting comprehensive tests, the data concerning all the infrastructures can be obtained.

The following parameters of concrete bridges were collected during the field tests:

- Dynamic deflections at midspan (including dynamic factors);

- Dynamic strains at the extreme bottom fibers at midspan (including dynamic factors);
- Vertical and transverse vibration at midspan (including the amplitudes, forced vibration frequency, natural frequency, and damping ratios);
- Transverse amplitudes at the top of piers;
- Displacement of the supports in the vertical direction and transverse direction;
- Vertical accelerations at midspan, quarterspan, and ends of bridge girders;
- Transverse accelerations at midspan;
- Vertical and horizontal forces between wheels and tracks (including derailment coefficients, rate of wheel load reduction);
- Train's speeds and positions.

For steel bridges, field tests were conducted to measure:

- Dynamic stresses and factors at the top and bottom flanges (or bottom chords and inclined chords) of longitudinal girders, transverse girders, and main girders at midspan;
- Transverse and vertical vibration of the top and bottom flanges (or bottom chords) of the main girders at midspan and quarterspan (including the amplitudes, forced vibration frequency, natural frequency, and damping ratios);
- Transverse amplitudes at the top of piers;
- Transverse and vertical accelerations of the bottom flanges (or bottom chords) of the main girders at midspan and quarterspan; Transverse and vertical accelerations of railroad ties; Vertical accelerations of longitudinal girders at midspan;
- The relative transverse displacements between ties and longitudinal girders at midspan;
- Static deflections of bridge girders;
- Dynamic transverse displacements at girder ends;
- Dynamic deflections of end floor beams;
- Vertical and horizontal forces between wheels and tracks (including derailment coefficients, rate of wheel load reduction);
- Train's speeds and positions.

The determination of bridges to be tested is based on the feedback information concerning the status of bridge structures provided by on-site engineers and the categorization of the bridges on the existing railways for speed upgrades provided by research institutes. By conducting on-site speed upgrade tests, it is possible to understand the structural problems of various bridges caused by speed upgrades under different loading conditions and speeds. Extensive field tests are beneficial to experimental data accumulation and problem identification. They are also helpful to study the speed upgrade requirements for static and dynamic responses of various bridges and codify specifications to provide guidelines for bridge retrofit and reconstruction. During the speed upgrades on the existing railway in China, most of the structural problems of bridges were discovered through field tests. **Fig. 2.2.38 to 2.2.41** show a few examples of field tests.

Figure 2.2.38 Jiaoji Truck Line Speed 120 km/h Test

Figure 2.2.39 Comprehensive Test of 23 tons Axle Load of Freight Trains

Figure 2.2.40 200 km/h Speed Passenger Intersection Test

Figure 2.2.41 200 km/h Speed Passenger and 120 km/h Speed Truck Intersection Test
(Photo from http://home.rails.com.cn/)

2.3 Zhengzhou Railway Bureau, Beijing-Guangzhou Railway

At the Zhengzhou Railway Bureau (ZRB), the scanning team met with two representatives: Mr. Yajun Gong, a project engineer in ZRB and Mr. Xiaolin Yang who is the chief of HSR bridge construction section. **Figure 2.3.1** shows Dr. Ma with the two representatives. The scanning team together with the two representatives conducted field surveys of several bridges which are on the Beijing–Guangzhou railway and administered by ZRB. The bridges have been strengthened and retrofitted for speed upgrades. After inspecting a bridge numbered "K796+803"， the team learned the methods of bridge strengthening and retrofitting when the speeds of bridges are upgraded to different levels. At the same time, the team obtained the principle and arrangement approach of transverse caging devices. After inspecting a bridge numbered "K751+758"， the team learned that short-span bridges with integrally precast elements have sufficient vertical and transverse stiffness to satisfy the requirements for dynamic responses at different speed levels. After conducting a field survey of the old Zhengzhou Yellow River Major Bridge, the team investigated the problems and technical solutions of steel bridges during their speed upgrades. Finally, the team also obtained the information concerning the practical problems of on-site construction and the corresponding technical solutions.

Figure 2.3.1 On-site Investigation of Jingguang Line

2.3.1 Background

Zhengzhou Railway Bureau (ZRB) is located in Zhengzhou which is the capital of the Henan Province. It administers sixteen operational railways which form a sophisticated network. The network plays a vital role in the transportation of coal from the provinces of Henan, Shanxi, and Shaanxi. It is also a hub of rail transportation of the Beijing-Guangzhou railway and Jiaozuo-Liuzhou railway and water transportation of the Yangtze River and the Han River.

Beijing–Guangzhou Railway (also known as Jingguang Line), as shown in **Fig. 2.3.2 and 2.3.3**, is a significant rail corridor connecting the north and south of China. It is a rail artery connecting the capitals of six provinces and several major cities. It is also the longest and busiest rail in China and possesses a vital strategic position. It starts from Beijing West Railway Station and ends at Guangzhou West Railway Station. Its length is 2284 km. The part of this railway administered by ZRB is between a place numbered as K485+800 in the north and a place numbered as K807 in the south. K485+800 is between Baizhuang and Anyang. K807 is between Xishangqiao and Mengmiao.

Since 1996, the Ministry of Railway conducted speed upgrade tests on the existing electrified busy line between Guanting and Mengmiao and performed the highest speeds of the existing railways 185km/h and 240km/h then.

Beijing–Guangzhou Line was the major corridor in the fifth nationwide speed upgrade of the existing railways. The 723 km region between Anyang and Wuchang was especially important. For the sake of train safety, ZRB has invested a lot in large-scale upgrades of infrastructures like rails and bridges in the fifth speed upgrading. As a prototype railway, Beijing – Guangzhou Railway developed a new passenger-cargo pattern at a speed of 250 km/h, without existing specifications or experience. In the project of six-time acceleration for Guanting-Changtai railway of Beijing–Guangzhou Railway, 300 bridges or culverts were built or strengthened. Since the opening of the railway on April 18th 2007, these bridges have been in good condition, satisfying the requirements of trains at speeds of 200-250 km/h.

Figure 2.3.2 On-site of Beijing-Guangzhou Railway Line
(http://image.baidu.com)

Figure 2.3.3 Route Schematic of Beijing-Guangzhou Railway Line
(http://baike.baidu.com/)

2.3.2 Findings from on-site Investigation of bridges under the Jurisdiction of Zhengzhou Railway Bureau

(1) Bridge “K796+803” in Jiangguang Line

The first bridge that was inspected on the old Beijing-Guangzhou line is located near the Zhengzhou Bureau under the jurisdiction of the Xuchang section from Beijing Railway Station Stake for K796 +803, as shown in **Fig. 2.3.4**. Due to the required 250km/h speed target, the old bridge was replaced with a 24 m span prestressed concrete girder bridge with precast T beams tied through the field diaphragms. This bridge underwent two retrofitting constructions in order to match the requirements of two speed upgrades.

(a) Overview (b) Detailed View

Figure 2.3.4 Girders of Jiangguang Line Bridge “K796+803”

In the first retrofitting, the train speed is increased from 160km/h to 200km/h. According to the speed requirements, field personnel reinforced several members of the original steel bridge. Bridge piers were strengthened by 150 mm thicker after reconstruction. Reinforcement meshes with 300mm spacing was implanted. After reinforcement of the steel girder bridge, it meets the requirements of the new train speed.

When the speed was increased from 200 km/h to 250 km/h in the next speed upgrade, the lateral stiffness and vertical deflection of original steel beam did not meet the requirements of new speed. Thus, the original steel girders were replaced with 24m prestressed concrete girders. At the top and bottom of both sides of the beam line, the lateral vibration of the girders was prevented with a block device, which was connected to the girder with wood blocks. The device was a reinforced concrete member. It was on the piers, connected by the steel mesh of the bridge piers, as shown in **Fig. 2.3.5.**

 

Figure 2.3.5 Lateral Block Device

The bridge is located on a curve. The radius of curvature of the two connection lines is too small to meet the 250 km/h speed requirement. To increase the radius of curvature of the line, the bridge line was moved to the downstream side of bridge, which requires widening the bridge piers. After this change, the line does not coincide with the center line of the center bridge pier. Therefore the downstream side of the bridge pier was thickened by 300 mm, and implanted with steel mesh. The steel mesh is 150 mm deep and the rebar spacing is 300 mm, as shown in **Fig. 2.3.6**. Also, 16 more piles were added around the base, and grouting was added for the footing.

Figure 2.3.6 Pier Reinforcement of Jingguang Line Bridge K796+803

After the retrofitting, the bridge should accommodate a train speed up to 250km/h. However, due to performance limitations of freight trains, the bridge can only accommodate a speed up to 120km/h. For light freight trains (containers), it is a speed up to 160km/h.

(2) Bridge “K751+758” in Jingguang Line

The bridge was originally a steel bridge. Due to serious corrosion, it was replaced with a 12 m span reinforced concrete bridge strengthened by transverse prestress, as shown in **Fig. 2.3.7**. The short span and closely-spaced diaphragms contribute to a high lateral and vertical stiffness. Thus, the bridge is in a good condition and can meet the speed requirement of 200 - 250 km/h.

Figure 2.3.7 Jingguang Line Bridge K751+758

At the beginning of the replacement design, in order to understand the effect of transverse prestressing on the bridge performance, transverse prestress forces were introduced to the diaphragm for one line while no transverse prestress forces were added for the other line, as shown in **Figure 2.3.8**. By comparison, after long-term use of the two bridges, the difference of the bridge performance is moderate.

Figure 2.3.8 Transverse Prestress Arrangement of Jingguang Line K751+758

(3) Steel Girder Bridge in Jingguang Line

The Research team visited a steel plate girder bridge located in Zhengzhou City, Henan Province, 30 kilometers north of the railway bridge across the Yellow River, as shown in **Fig. 2.3.9**. It is an important bridge in the Beijing-Guangzhou railway line. This bridge was completed in April 1960. During the train speed acceleration, the Zhengzhou Railway Bureau bridge inspection team detected the vibration of steel girders. In 1996, a bridge inspection team of the Zhengzhou Railway Bureau conducted a vibration test for one of the bridge girders and found that the measured amplitude at the mid-span was markedly greater than the allowed limit.

Figure 2.3.9 Zhengzhou Yellow River Bridge in Jingguang Line

According to on-site technical personnel, the main problem is due to the large lateral vibration amplitude of the girder, which caused an unloaded train to be derailed twice. To decrease the vibration amplitude, a plan was proposed to connect the top flange of steel girders to enhance lateral rigidity and to reduce the large transverse amplitude due to the high-speed train, as shown in **Figure 2.3.10 and 2.3.11**. This strengthening method has its weakness because girders on two different directions are tied together, one-way traffic will affect the bridge on the opposite direction.

Figure 2.3.10 Upper connection of Old Zhengzhou Yellow River Bridge in Jingguang Line

Figure 2.3.11 Lower connection of Old Zhengzhou Yellow River Bridge in Jingguang Line

As a result, this long-span steel girder bridge was posted with a speed limit for passenger trains of 110 km/h and for cargo trains of 55 km/h.

2.4 Zhengzhou Design Institute of China Railway Engineering Consulting Group Co., Ltd

2.4.1 Background

Zhengzhou Design Institute of China Railway Engineering Consulting Group Co., Ltd is engaged in railway engineering, urban rail transit, highway and municipal engineering, industrial and civil construction projects. The institute has undertaken many important railway projects including: the Beijing-Guangzhou line's speed upgrade, Zhanjiang East Island Railway, Duolun-Fengning Railway, Fengning-Hushiha Railway, Shanxi southern railway corridor, Xinxiang-Yuexiang 2nd railway line, Ceke Station of Lince Railway, Western Station of Swan Lake to Ceke Line, Cahasu mine well, Henan Shenhuo Group, and Hebi Coal Chemical Rail Line. In recent years, the institute won the provincial research award four times, national excellent engineering silver award twice and excellent provincial surveying and design award more than 20 times.

2.4.2 Findings from Zhengzhou Design Institute of China Railway Engineering Consulting Group Co.,Ltd

(1) Meeting on Nov. 8, 2012

The research team has a meeting with three engineers from the institute, as shown in **Fig. 2.4.1**, to discuss bridge strengthening methods during the sixth speed upgrade conducted by the institute. The following conclusions were made.

Figure 2.4.1 Meeting at Zhengzhou Railway Institute

- The main technical parameters are summarized as follows when the speed was increased to 200 km/h
  - (a) Vertical stiffness: when the bridge span (L) is less than or equal to 40m, the largest single-span vertical deflection should be less than L/900, and the multi-span maximum vertical deflection should be less than L/1100.
  - (b) Girder lateral stiffness: when considering the effect of the train rocking force, centrifugal force, wind and temperature, horizontal deflection of the girder should be less than 1/4000 of its span.
  - (c) When the bridge span is longer than 40m and the pier is higher than 20m, the dynamic test of the bridge should be conducted.
  - (d) When using ballast deck to rebuild the bridge and culverts, the ballast thickness should not be less than 30 cm.
  - (e) For existing bridges with flat rubber bearings measures should be taken to limit the lateral movement.
  - (f) When strengthening the structures of bridges, the influence of each system in the whole railway transportation system needs to be considered. This includes line (route, radius of curvature, super elevation, turnout, track, etc.), locomotive vehicle, traction power supply system, and signal equipment.
- According to the original design data, collect bridge parameters in the existing railway section including the number of bridge structures, bridge structure types, bridge site condition, construction time, and design standards.
- Inspect bridges to be upgraded by monitoring existing bridges for understanding general bridge conditions.

(2) Encountered problems and the corresponding measures are discussed below:

(a) In the process of China's existing railway speed increasing, steel girder bridges have more problems. A large number of theoretical studies and field tests were conducted for this kind of bridge reinforcement and reconstruction. Although the steel plate girder bridge can be strengthened for the speed upgrading principally, the actual bridge structure after strengthening still shows problems such as larger transverse vibration amplitude in the field tests. As a result, on the Beijing-Guangzhou route most steel plate girders were replaced with concrete bridges. Attention should be paid to the bridge pier.

(b) Existing concrete girder bridges were found to be weak in transverse stiffness which can derail the train. To solve the problem, the following measures were taken:
   - Horizontal bracing devices should be added at the end of the beam for bridges with rubber bearings or without bearings. This device can effectively limit the lateral deformation of the beam.
   - On the T-beam bridges, one transverse diaphragm should be added every 3-5 m.

(c) In the process of existing railway speed upgrading, bridges should not be the major limitation to the speed upgrade. The bridges which cannot meet the requirements should be replaced.

   In order to meet the requirement of high speed, sometimes, changing the super elevation and increasing line curvature radius are necessary.

(d) For the existing bridge foundations, measures should be considered to increase and widen bearing capacity or pile foundation.

   When strengthening the bridge pier foundation, the train speed should be limited to 45 km/h or less to reduce the impact on construction quality.

2.5 <u>China Zhongtie Major Bridge Engineering Group Co., Ltd</u>

2.5.1 Background

China Major Bridge Engineering Co., Ltd (hereinafter referred to as CMBE) is a wholly-owned subsidiary of China Railway Group Limited which is listed on the stock market by Stock A601390 and Stock H0390. The history of the Company can be traced back to Major Bridge Engineering Bureau, Ministry of Railway of P.R.C, which was established for the construction of the first bridge in China--Wuhan Yangtze River Bridge. CMBE is a large integrated construction enterprise that combines bridge scientific research, reconnaissance and design, construction and equipment manufacturing business, specialized in bridge construction over rivers, lakes and seas under various geological and environmental conditions.

There are more than 16,000 staff and workers in the Company, among them 3 academicians of the China Academy of Engineering, 3 Chinese Engineering Design Masters, 2 National Experts for Outstanding Contributions, 35 experts awarded “Special Subsidiary” for their contributions to the state, 20 Provincial Experts for Outstanding Contributions, 180 professor-level senior engineers, 959 senior engineers and 8,103 engineers and technicians.

CMBE is a top enterprise which has designed and constructed the most bridges in China and has always played the lead role in bridge construction in China. So far, CMBE has designed and constructed more than 1500 bridges at home and abroad with a total mileage of more than 1400km. CMBE has also participated in construction of railway line works and high grade road works. Among these works, some have been accredited as excellent works and received a lot of prizes.

2.5.2 Existing Railway Bridge Construction Example by CMBE

In cooperation with the China Railway Bridge Bureau, more than 100 workers spent a month working on the implementation of bridge replacement construction for the railway bridge which connects Hankou and Hanyang on the Beijing-Guangzhou Railway Line, as shown in **Fig. 2.5.1 and 2.5.2**.

Figure 2.5.1 Beijing-Guangzhou Railway Han River Bridge

Figure 2.5.2 Beijing-Guangzhou Railway Han River Bridge Reconstruction

2.5.2.1 Bridges Overview

Han River Railway Bridge is part of the Beijing-Guangzhou railway line. Bridge spans consist of 2 × 16.1 m (concrete T beams) +2 × 20.7 m (steel plate girders) +3 × 55.1 m (steel trusses) +2 × 20.7 m (steel plate girders) +16.1 m (concrete T beams). The whole bridge length is 296.4 m, as shown in **Fig. 2.5.3**. As the bridge has become aged, it is difficult to adapt the bridge for high-speed trains. The implementation for replacing the aged girders will help improve the safety of the railway. Bridge spans to be replaced are shown in **Fig. 2.5.3 and Fig. 2.5.4**.

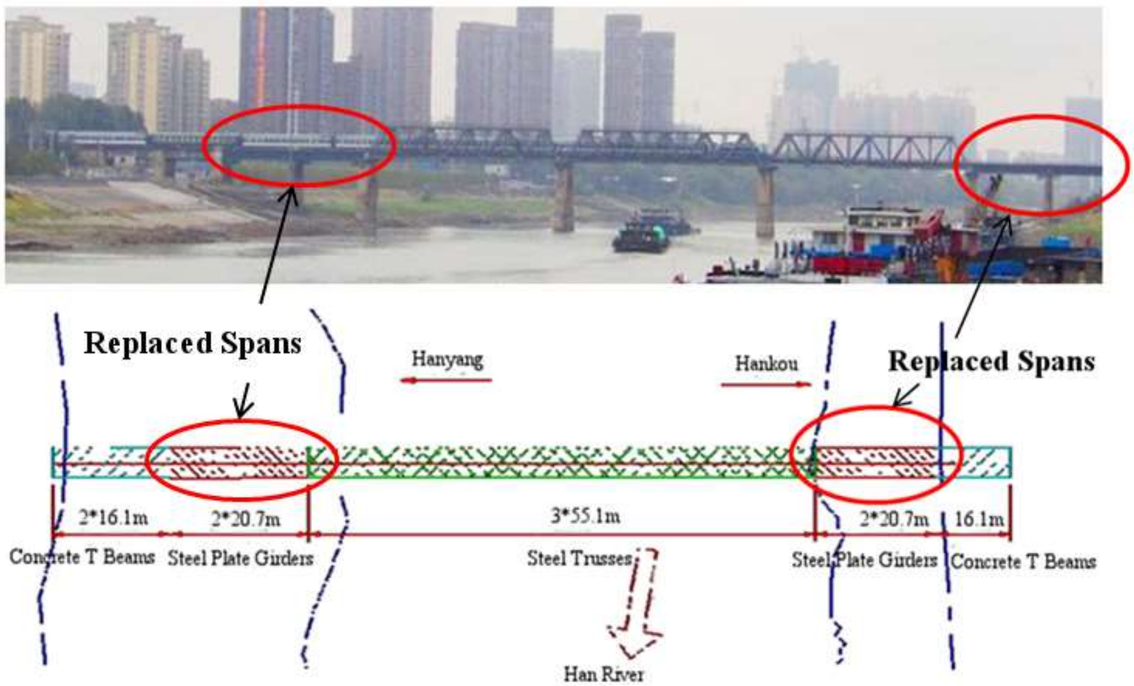

Figure 2.5.3 Han River Bridge Layout and Replaced Spans

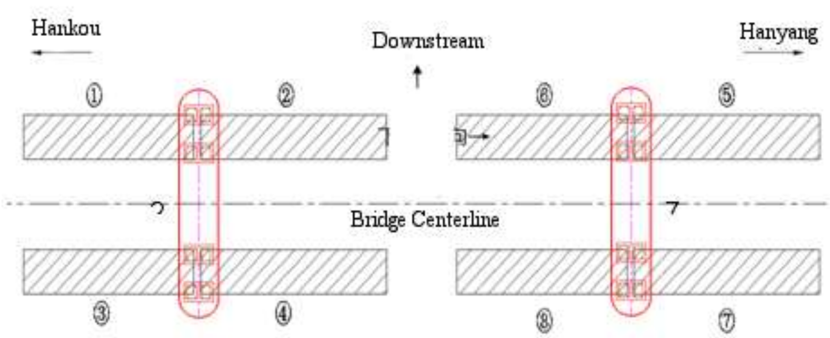

Figure 2.5.4 Numbering of the Replaced Girders

The replaced girders are a simple supported structure with a standard span of 20.7 m. Cross-section is comprised of two I-shaped main beam components. Main beams have 2.0 m spacing, 1958 mm height at midspan, and a 1944 mm height at bearing. The upper flange plates of the main beams have 400 mm width and 20 mm thickness. Their webs have 1908 mm height and12 mm thickness. The lower flanges are overlapped by two steel plates. The inside plate has 600 mm width, 16 mm thickness; outside plate has 560 mm width, 14 mm thickness, and is terminated at a distance 2440 mm from the bearing. The horizontal beams are set between the two main beams and set a cross beam every 4 m. Cross beams and main steel beams are connected by bolts. The rest parts of the bridge are connected by welding. One new single span steel plate girder weighs 22.6 tons.

To satisfy bearing conversion and to prevent top beam girders from falling in the progress of plate girder replacement, end cross beam are made by a solid-web structure. Set the temporary support bracket at the outside of the steel girder and at the temporary lifting points at the inside of the steel girder. The temporary support bracket is 750 mm from the center of the steel girder. Spherical steel bearings QZ are used for the new girders.

2.5.2.2 Overall construction program for girder replacement

(1) General consideration

Since rail operation cannot be interrupted, girder replacement can only be completed in a short closure time. For the Beijing-Guangzhou line, closure time for replacement construction is only 2 hours. In order to ensure the traffic safety during girder replacement, a construction plan that the new and old girders simultaneously traverse was eventually adopted. First, lift the new steel plate girder up to the bracket; then move longitudinally to the position next to the old girder and wait for replacement. After new and old girders are simultaneously traversing, the new girder moves to the position where the old girder is located, and the old girder moves to the bridge centerline. Finally, use the decomposition approach to demolish the old girder. After the new girder in place, the rails drop and fix to the cross-ties. After making sure satisfying the traffic requirements, the bridge reopens.

(2) Brief construction procedure

Construction procedure for this replacement project was introduced briefly below. More details of several steps are discussed in the following sections.

Step 1:

- Reroute the municipal high voltage power lines on the bridge;
- Build the cofferdam for Pier #3;
- Construct sidewalk, level and harden the site ground, build temporary dock;

- Construct the foundation of the temporary bracket, construct the working platform for the erection crane;
- Install steel-tube column and Bailey bracket, install the girder for longitudinal sliding way, build construction platform and ladder;
- Set up the protective shed, height-limit overhead sign and traffic dispersion sign at the entry of the crossing with highway.

Step 2 (as shown in **Figure 2.5.5**):

- Fabricate and assemble steel plate girders in factory;
- Transport the girders to the site;
- Crane the girders to the sliding way by crane trucks.

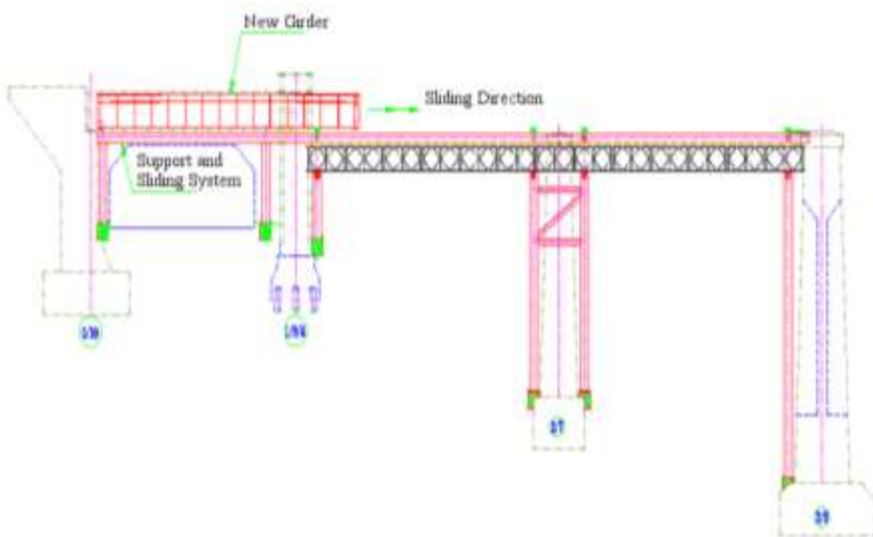

Figure 2.5.5 Schematic of Step #2

Step 3:

- Remove the auxiliaries, e.g. maintenance sidewalk, of the old girder;
- Remove the protect structure of Pier #1 and Pier #8;
- Clear the path of sliding way.

Step 4 (as shown in **Figure 2.5.6**):

- Slide the new girders to the design position;
- Reposition the slide stopper.

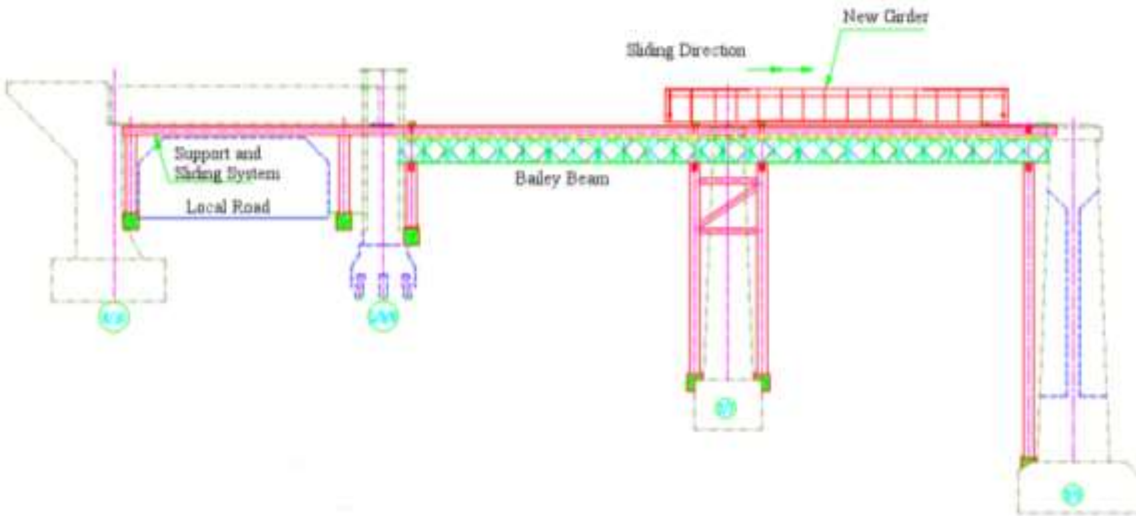

Figure 2.5.6 Schematic of Step #4

Step 5:

- Install and calibrate the horizontal sliding device; install temporary bearings;
- Jack up the new girder by 50mm, move it laterally toward the centerline of the bridge by 1.5 m to provide enough space for new maintenance sidewalk construction.

Step 6:

- Mount new maintenance sidewalk for the new girder;
- Drill holes and notch grooves for sleepers on the new girder;
- Loosen one fastener every two fasteners, limit the train speed to 25 km/h, and wait for the bridge closure time.

Step 7:

- Close the bridge, loosen all fasteners of old girder, jack up the rails by 25cm;
- Remove the bearing bolts of old girder;
- Jack up the old girder by 30~50 mm, and lock the stroke position;
- Move new and old girders simultaneously in a lateral direction to the design position;
- Locate new girder on the temporary bearings;
- Fasten the fasteners on the new girder, maintain the route, open the bridge while limiting the train speed;
- Remove old bearing pad stone, cast new pad stone and install permanent bearings, , remove the temporary bearing and transfer girders to new bearings;
- Increase the train speed gradually to the design operation condition.

Step 8:

- Transport the old girders out of the site, install all new auxiliaries of the new girder;
- Repeat these procedures for all other spans;

- Recover the power-line; remove the temporary support platform, temporary sidewalk and hardened site.

(3) Support platform for girder replacement

Girder replacement construction platform for this project uses expanded concrete foundation and steel pipe column bracket. Steel columns use ø630*10 spiral welded pipe and flange connection. Bailey beams were used as the superstructure of the platform. Construction platform and steel plate girder longitudinal and lateral sliding system were placed on the Bailey beams.

Construction platform layout is shown in **Fig. 2.5.7**. Site construction pictures are shown in **Fig. 2.5.8 and 2.5.9**:

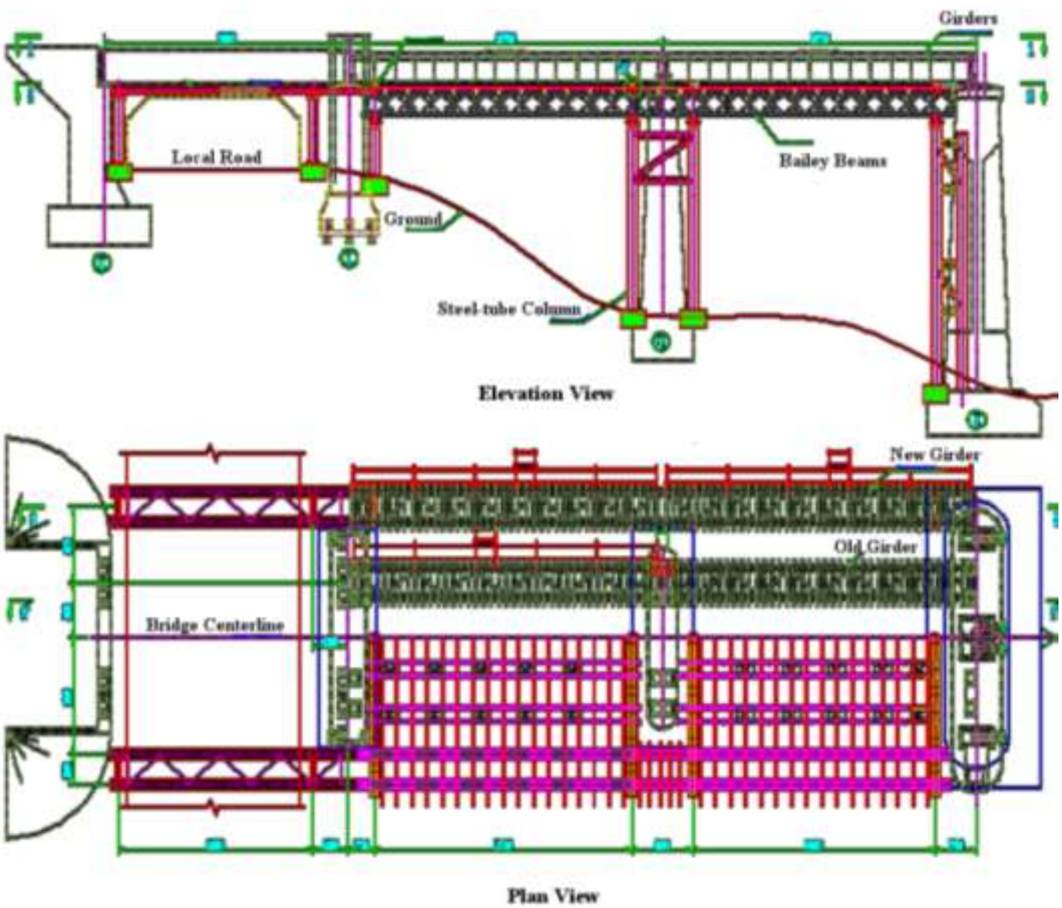

Figure 2.5.7 Elevation and Plan View of Support System Layout (Hankou Side)

Figure 2.5.8 Bailey Beams and Supporting Brackets for Construction Platform

Figure 2.5.9 Construction Platform and Shift Sliding System

(4) Replacement of catenary column

Move 2# pier catenary pillar to middle of 1# pier away from the side of the Han River. Move 7# pier catenary pillar to middle of 8# pier away from the side of the Han River. Move 9# pier catenary pillar to middle of the pier. Replace catenary return line for the cable and move to beam change bracket. 2# and 7# pier catenary pillar movement program shown in **Fig. 2.5.10**.

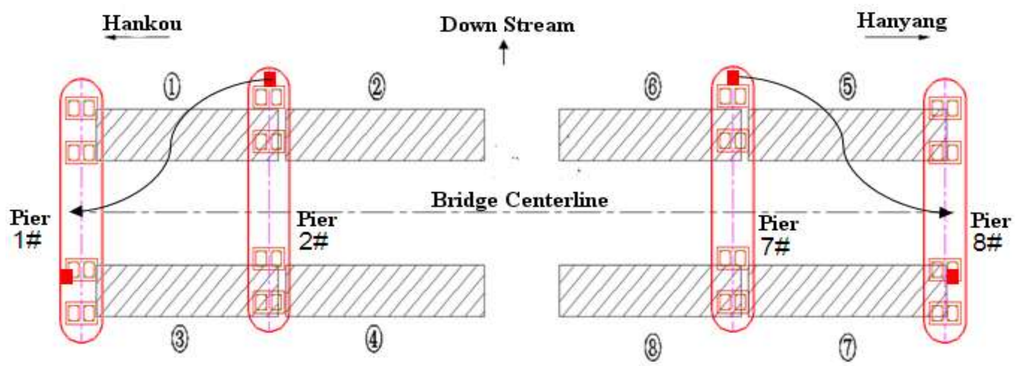

Figure 2.5.10 Catenary Colum Movement Schematic

After catenary pillars moved to middle of the pier, replace them with "T" type columns where the two lines share the same column (as shown in **Fig. 2.5.11**).

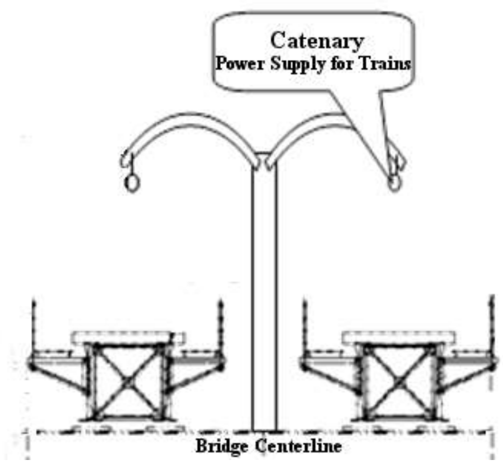

Figure 2.5.11 Share Catenary Column Schematic

After all steel girder replacement was complete, the power supply of catenary was recovered.

In order to ensure traffic safety and time point during the construction period, consider changing eight steel plate girders for 8 times, and change one steel plate girder every time. According to catenary pillar movement program, girder replacement order is shown as below:

Girder Replacement Order:
②→⑥→①→⑤→④→⑧→③→⑦

(5) Movement of municipal power lines and communication lines

a. Before the bracket construction, move the high-voltage lines through this bridge and catenary lines. The railroad administration and the power supply administration signed security and coordinate agreements. A specific moving program was formulated after the power supply administration sent a technician for on-site visiting. The power supply administration organized the construction. Movement of high voltage and catenary must be completed before the installation of Bailey beams. Details of the movement of the high-voltage lines and catenary in this project are shown below:

◆ Lines that are required to be moved on the Hankou side upstream (upstream direction) included 2# pier catenary column, catenary lines, power lines and poles, and 3# pier electric tower. On-site figure is shown in **Fig. 2.5.12**.

Figure 2.5.12 Electricity Lines in Hankou Upstream Side

Figure 2.5.13 Electricity Lines in Hankou Downstream Side

◆ Lines that are required to be moved on the Hankou side downstream (downstream direction) included 2 # pier catenary column, catenary lines, power lines and poles, and 3# pier electric tower. On-site figure is shown in **Fig. 2.5.13**.

◆ Lines that are required to be moved on the Hanyang side upstream (upstream direction) included 7 # and 9# pier catenary column, catenary lines, power lines, poles and cable tray line. On-site figure is shown in **Fig. 2.5.14**.

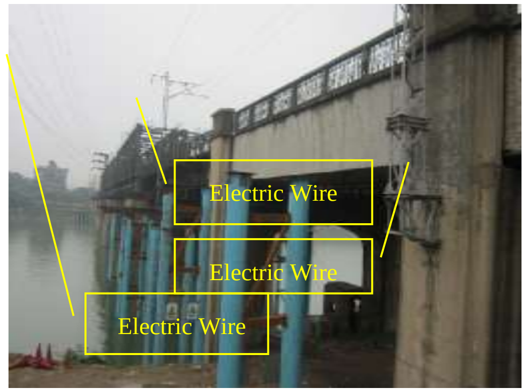

Figure 2.5.14 Electricity Lines in Hanyang Upstream Side

Figure 2.5.15 Electricity Lines in Hanyang Downstream Side

◆ Lines that are required to be moved on the Hanyang side downstream (downstream direction) included 7# and 9# pier catenary column, catenary lines, power lines and poles, and 6# pier electric tower. On-site figure is shown in **Fig. 2.5.15**.

b. The protection and movement of communications and signal cables, optical cables.

The railroad administration, the communication administration and the electricity administration signed security and coordinate agreements. The moving program was formulated after the power supply administration sent a technician on-site visiting. The device management departments prepared for the moving construction. The movement of the cable tray in practice is shown in **Fig. 2.5.16**.

Figure 2.5.16 Movement of Cable Tray in Practice

2.5.2.3 Special considerations for girder replacement

(1) Preparation before beam replacement

a. Permanent seat bolt holes

The bolt holes for the permanent seat should be drilled in the previous week before the procedure by using a concrete coring machine with a diameter of 100 mm, the drilling depth of which is 19 cm. The drilling position is shown in **Fig. 2.5.17**.

After the positions of anchor bolt holes of permanent support were located, the bracket of the old steel girder and the restrain block that impact the drilling of the bolt holes were removed. A concrete coring machine was used to drill the bolt holes. The relationship of the drilling position with the existing girder position is as shown in **Fig. 2.5.18**.

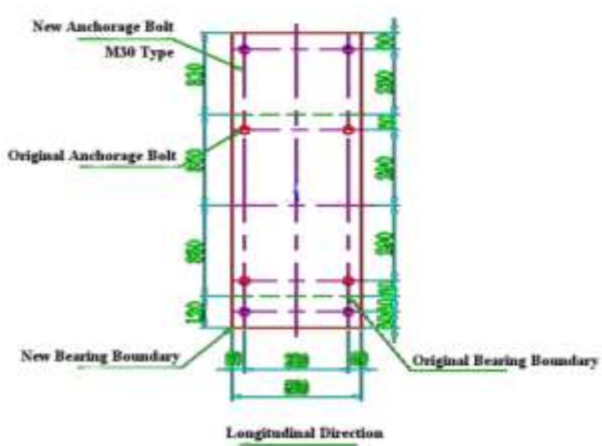

Figure 2.5.17 Bearing Bolt Hole Layout

Figure 2.5.18 Drilling Position

b. Installation of temporary bearing

The steel plate and embedded rebar of the temporary bearing for the new girder were designed carefully, as shown in **Fig. 2.5.19**:

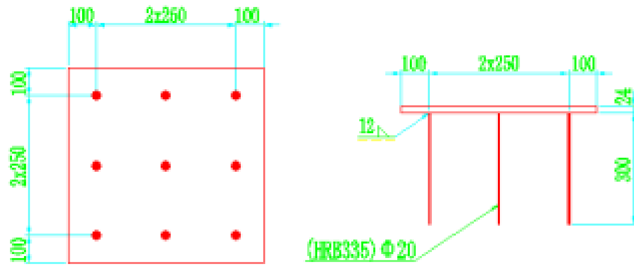

Figure 2.5.19 Layout of Embedded Steel in Temporary Bearing

The elevation and levelness of the temporary bearing should be controlled strictly. The elevation of the bearing is designed according to design elevation of the top of the rail structure. That is, the elevation of embedded parts of temporary bearing = design elevation of beam top - height of the new steel girder – height of bearing pad - height of temporary support + compression of support - 5 mm. The elevation of embedded steel top in the temporary support is scheduled by negative error control.

c. Removal of the affiliated facilities

The removal work of affiliated facilities in the existing bridge deck, which will affect the transferring girder, can be accomplished after the completion of the construction platform for girder erection. This work included the removal of the fence of abutment top, street lamp columns, pier 1# and 8# protective wall, wagon under beam and its wagon tracks, dust cover of the bridge bearing, etc. All deck operations must be carried out within the period of temporary traffic closure and the construction plan should be reported on the previous day. The construction security protection was carried out by Wuhan bridge section.

d. The stop block device should be installed in embedded steel of the temporary bearing in order to prevent the steel girders from exceeding the design position during the process of vertical and horizontal movement.

(2) Transportation of Steel plate girder

a. Requirements of Steel plate girder transportation

The steel girders were assembled by high-strength bolts at the factory, and then transported to the construction site (Yanhe Avenue and Concert Avenue) by road transportation. Considering the width of the temporary supports on both sides, the total width of the girder is 4 m, the length is 20 m, which exceeded the permission of highway transport specifications, so the local transportation department arranged a special transport route and approaches for the steel girder. The girders were transported during the night. The transportation of the new girders and surrounding road condition are shown in **Fig. 2.5.20**.

Figure 2.5.20 Transportation of the Steel Plate Girder

b. Steel girder transport route

Steel girders were transported by the fabricator to the construction site. In order to ensure continuity of transportation and construction, it was necessary to closely cooperate with the fabricator, and to plan routes in advance and make sure arrival time of the steel girders. The specific transport route was inspected by the fabricator and the transporter. After transportation to the site, the steel girders were parked in a way to not affect traffic.

(3) Steel girder hoisting

After the crane was in place, transportation trucks entered the designated parking position from the temporary site, and lifted the steel girder to the slide-way which was assembled on the framework. Slide bearing and jacks should be emplaced in the slide corresponding position before hoisting of the girder. The position of slide bearing must be matched with the transverse spacing of the slide beam, and the distance between slide and ends should also be consistent. The direction of the girders on the slide-way must be consistent with the direction of the bearing arrangement. The procedure is shown briefly in **Fig. 2.5.21**.

Figure 2.5.21 Steel Girder Hoisting

a. Selection and location of crane

Because both sides of the road are relatively narrow, the crane and the transportation trucks cannot be parked next to each other, but can only park one after another. 240 tons of crane was selected for lifting according to the radius of hoists and hoist weight. The position of the crane and the steel transportation truck is shown in **Fig. 2.5.22**.

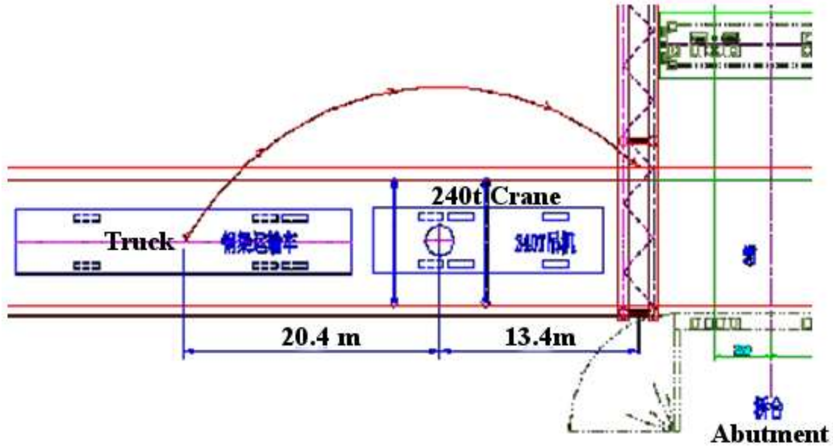

Figure 2.5.22 Positions of Crane and Steel Transportation Truck

b. Note of steel girder hoisting

◆ The hoisting site is very close to the existing line, so the lifting operations must be strictly abided by the relevant provisions of "Railway Construction Safety Code". The hoisting of the steel plate girder met the above requirements according to the hoisting and catenary moving plan, which is as shown in **Fig. 2.5.23**.

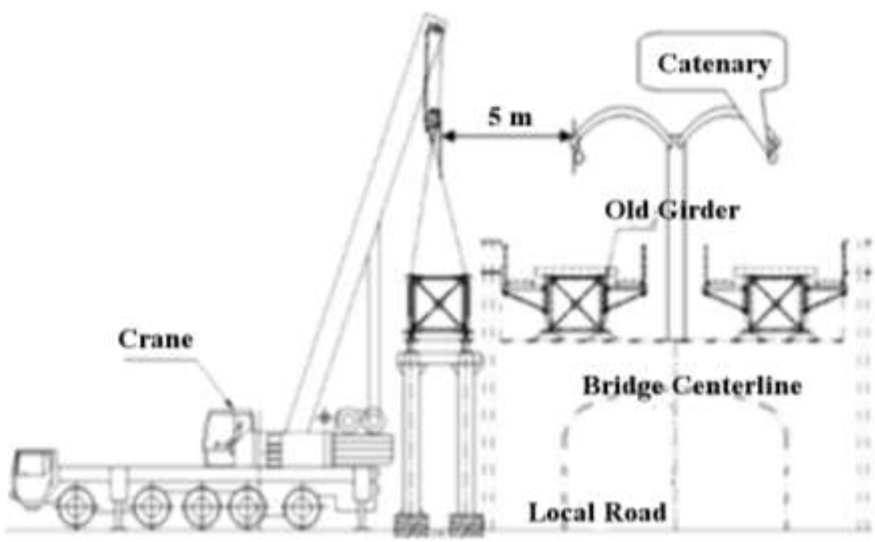

Figure 2.5.23 Relationship of Hoisting Steel Girders with the Existing Line

◆ The erection construction belongs to class B according to railway transportation [2010] No. 51 "Railway Construction Safety Management of Business Line Complementary

Approach". Upon request, the construction should be included in the railway bureau construction plans.

- The following checklist should be accomplished before lifting:

i. Before the lifting, the lateral dimensions of the slide beam to the existing line and the new relationship between the old girder and the end of new girder has to be checked;
ii. Check whether the longitudinal sliding path is parallel to the existing centerline;
iii. During lifting operations, the lifting objects must be firmly secured. The hook suspension points and the gravity center of lifting objects should be in the same vertical line, the steel rope of hook should remain vertical. Lifting objects should not be partially landed to prevent the ropes from deviating. The lifting hook is not too loose before the hoisting object is fixed or stable.

When lifting the steel girders, they should be firmly lashed with wind cable wire, the positional relationship between the steel girders and the surrounding structures should be guarded by the specified personnel, and the wind cable wire should be tightened appropriately to adjust the position of steel beams, preventing the steel girders and various structures from collision.

The lifting operators must have taken professional safety training and are approved for the job and is only allowed to operate independently after getting the certificate of qualification. Unqualified persons are strictly prohibited from using the lifting equipment.

Operators must coordinate with the workers, both constrained by the command signal of the commanding officer. They must honk at first before operating. The driver has the right of refusing to perform work if the command gesture is unclear or wrong, the driver must stop immediately for an emergency stop signal issued by any person, eliminating any insecurity factor before continue to work.

(4) Longitudinal movement of the steel plate girder

After the installation of sliding system, the slide and jack were installed on the slide beam. Then the steel plate girder was hoisted to the slide beam (as shown in **Fig. 2.5.24**), a 54 kN hand tractor was used to drag the steel plate girder to the position close to the replaced steel girder (as shown in **Fig. 2.5.25**). A bottom view of the slide beam is shown in **Fig. 2.5.26.** The schematic of this system is shown in **Fig. 2.5.27.**

Figure 2.5.24 Locating Steel Plate Girder on the Slide Beam

Figure 2.5.25 Dragging the New Girder Longitudinally by Using 54 kN Hand Tractor

Figure 2.5.26 Bottom View of the Steel Plate Girder Sliding System

The notes of the longitudinal movement:

The steel plate girder must be in control of the location during the longitudinal shift to ensure that there is no need to adjust the longitudinal position when the transversal shift is finished, so a set limit device is required in the slide beam end in advance. The plumb bob was employed to check whether the longitudinal displacement was in place and the error should be controlled within 2 mm.

Avoid making the girder inclined during the transverse shift process. The lateral slide beams were installed perpendicularly to the center line after longitudinal movement was finished. The new and old girders should be kept in parallel condition by measuring the distance between the ends of the two girders. Slight adjustments should be carried out by jack.

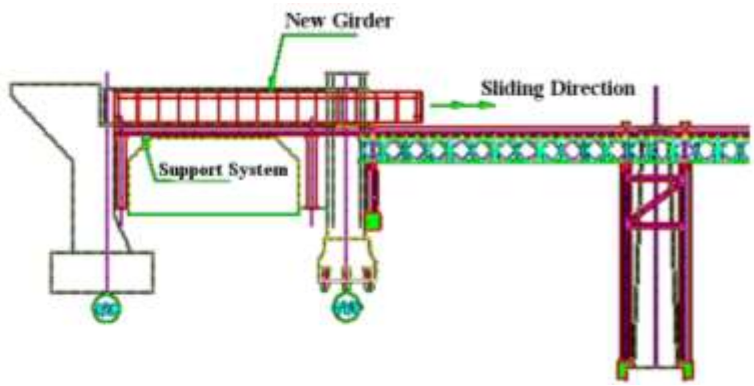

Figure 2.5.27 Longitudinal Movement of the Steel Plate Girder

(5) Pilot shift of new girder

The new girder was moved transversely by 1.5 m toward the centerline after the disposal of the old girder and its pedestrian sideway bracket. New sidewalk bracket was installed outside the new girder, and the bridge cross-ties construction platform was installed as well. The bridge cross-ties should be punched and grooved in the workshop in advance according to the design requirements. After shipped to the site, ties were fixed to the new steel girder according to the design requirements. Such construction as bridge cross-ties and slide was contributed by the Wuhan Railroad Bridge Section who also made the corresponding security protection.

All equipment should be arranged in place the day before installation of the bridge ties. The new girder was moved transversely by 1.5 meters toward the old girder to test the system so as to get the lateral movement parameters, as shown in **Fig. 2.5.28**.

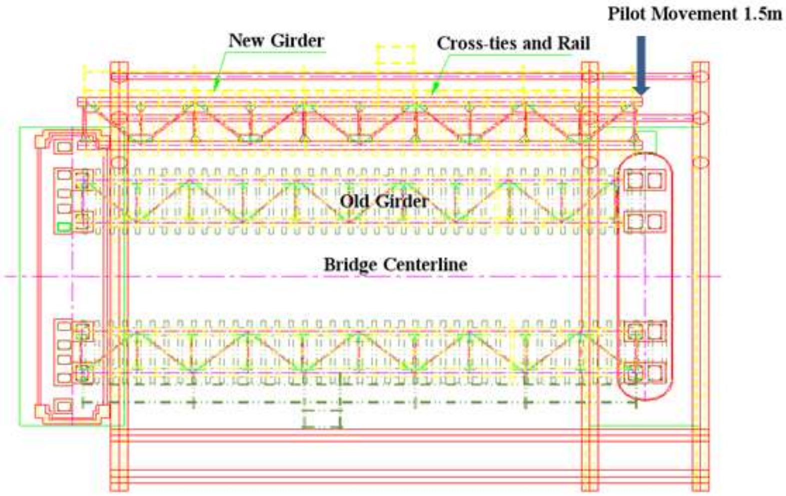

Figure 2.5.28 Pilot Transverse Shift

After moving the transverse by 1.5 m, temporary bearings for the new steel girder were installed under the supporting bracket of the steel girder, and the elevation of the new steel girder is lifted 40 mm higher than the design elevation to ensure the smooth transverse shift.

Before the new and old girders are sliding transversely and simultaneously, new and old girders are connected together by a connecting rod, as is shown in **Fig. 2.5.29**.

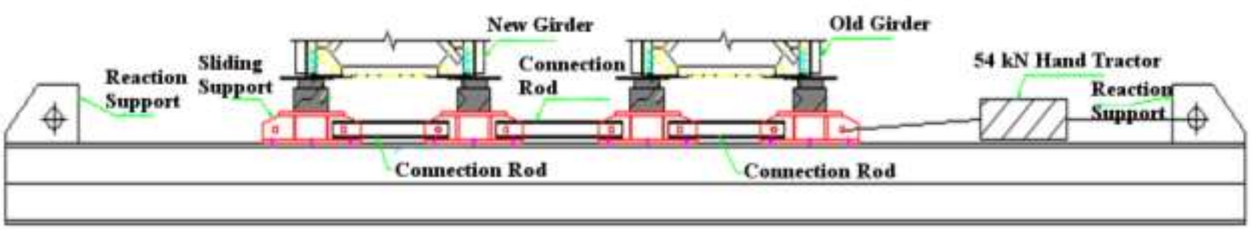

Figure 2.5.29 Installation Sliding Connecting Rod

To ensure the synchronization of lateral movement, a synchronous control continuous jack system was adopted to pull the drag steel girders and two sets of 54 kN hand tractor were additionally arranged to cope with emergencies.

(6) New and old girder simultaneously transverse moving to the design position

a. Preparation

Replacement of the girder should be carried out in the down-line followed by the up-line, every time only one girder was replaced which resulted in 120 minutes of closure time. The following should be prepared before the replacement:

- The disposal of pedestrian deck and framework of old girder, the installation of pedestrian deck outside of new girder, the erection of bridge cross-tie platform.
- The installation of bridge tie groove.
- The disposal of guard rail and the installation of gauge rod.

Two days before the girder replacement, 90 minutes closure to the traffic was applied. The old guard rails were disposed of by the bridge personnel, and the insulated gauge rod is installed, as shown **in Fig. 2.5.30**.

Figure 2.5.30 Installation of Insulated Gauge Rod

b. Jacking the old girder for trial. In order to ensure the smooth jacking within the closure time, 90 minutes should be applied for trial jacking of the old girder before the formal construction.

The trial jack-up procedure is listed as follows:

- The slide and jack are installed under the old girder as required. The old support anchor bolt nuts are disposed (as shown in **Figure 2.5.31**).

Figure 2.5.31 Removal Bearing Connection of the Old Girder

- Old bearings and bottom flange of the old girder were connected by welding with rebars to ensure that the bearings would rise up when the girder was jacked, as is shown in **Fig. 2.5.32**.

Figure 2.5.32 Connection between Old Bearing and Bottom Flange of Old Girder

- All the rail fasteners within the scope of beam across 5 m were loosened by the bridge personnel within the closure.

◆ After all fasteners are loosened, start the pump and jack up the old girder to 5 mm. Then make four bearings released from the pier.

Some preparations are listed before the closure:

◆ The train speed was scheduled to under 25 km/h before two hours of closure; guard rail was disposed of outside the lines; the long rail fasteners were loosened every other one within 30 m of the girder (as shown in **Fig. 2.5.33**).

Figure 2.5.33 Loosening the Long Rail Fasteners Every Other One

◆ When replacing the steel plate girder near the main beam, in order to avoid the collision of the old steel girder and the main girder bracket during moving, the old steel plate girder end-webs should be cut off along the white line in the circle of **Fig. 2.5.34** the day before the closure.

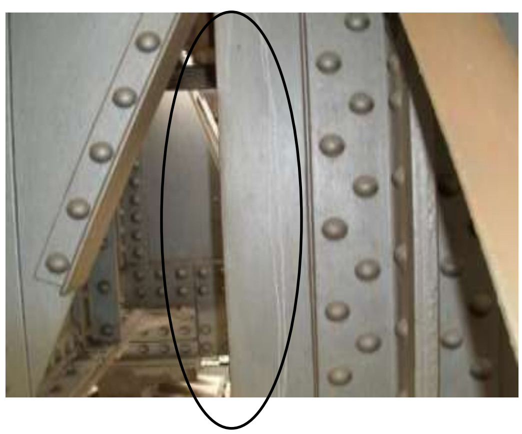

Figure 2.5.34 Cut Off Webs of Beam-end

◆ Synchronization control continuous jack system and other equipment should be inspected two hours before the closure, and all the emergency measures should be in place.

- ◆ Two hours before closure, a layer of 5 mm thick cement mortar on the steel plate in the temporary support was embedded serving as a leveling layer. The ratio of cement and sand for this mortar is 1:2. Coarse sands are used and screened out particles more than 2 mm.
- ◆ The corresponding workers from two stations (Hanyang station, Hanxi station) were on duty three hours before the closure, and the guides arrived to the designated place, preparing to install protective facilities after receiving the station dispatching command.
- ◆ All construction personnel should be in place one hour before closure and make sure the communication signal work well.

c. Working within the closure

- ◆ When the closure starts, all the rail fasteners were loosened completely, the long rail was jacked up gradually by 250 mm (the lowest distance from the bridge tie should be kept more than 100 mm), as shown in **Fig. 2.5.35**. The sleepers were put to make the rails steadily and fixed firmly in the end of the adjacent span. This work was completed by the Wuhan Railroad Bridge Section, and all the preparation work was accomplished in advance.

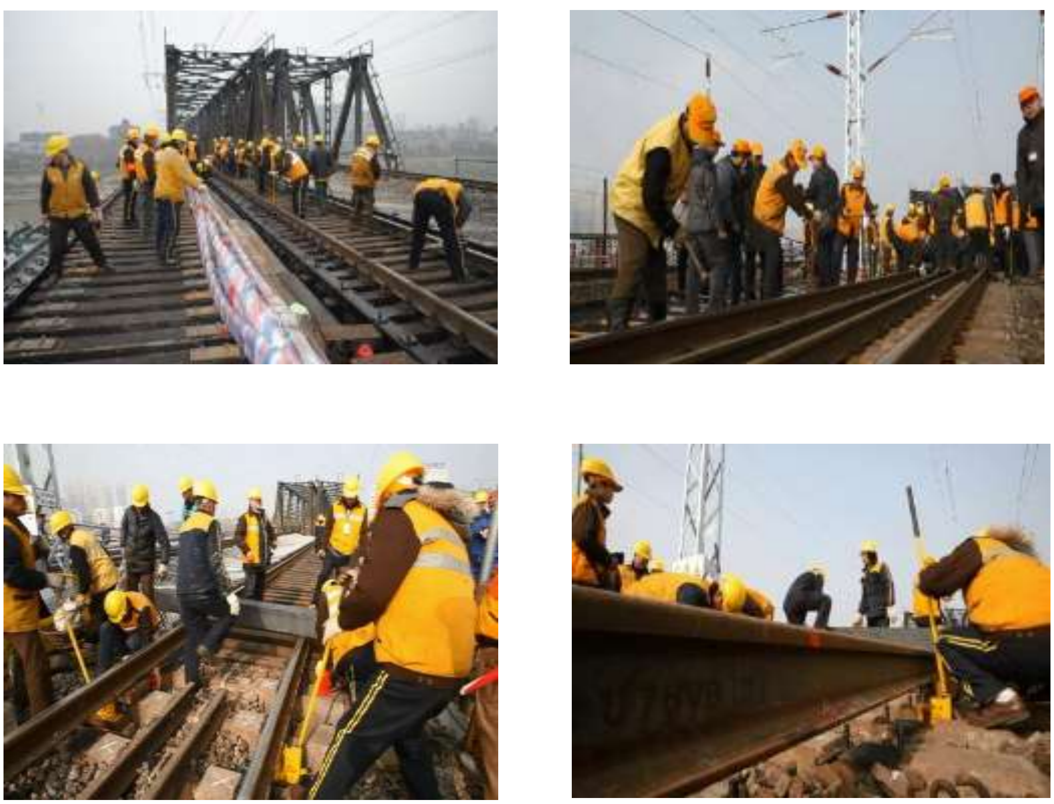

Figure 2.5.35 Jacking Up the Rail of Old Bridge

- After the completion of the first jacking level of the railway, the old girder was jacked up by 20mm to separate four bearings from the pad, using the oxygen-cutting to cut the bearing bolts of the original girder flat with the top surface of the pad. In order to ensure efficiency of this work, the old girder was tested one day before the closure.
- After removing the rails from the road, the old steel girder was jacked up about 40mm to ensure a smooth transverse shift (as shown in **Fig. 2.5.36**).

Figure 2.5.36 Lifting Old Steel Plate Girder

- The workers should have a clear understanding to their responsibilities. Clean up all obstacles on the transverse sliding path. Then, by using the synchronization control system, the new and the old girders which are paralleled to the center line direction were moved transversely about 3.5 meters towards design position simultaneously, as shown in **Fig. 2.5.37**. The speed of synchronous traction can be up to 400 mm/min, under normal circumstances they can be transversely moved in place within 10 min.

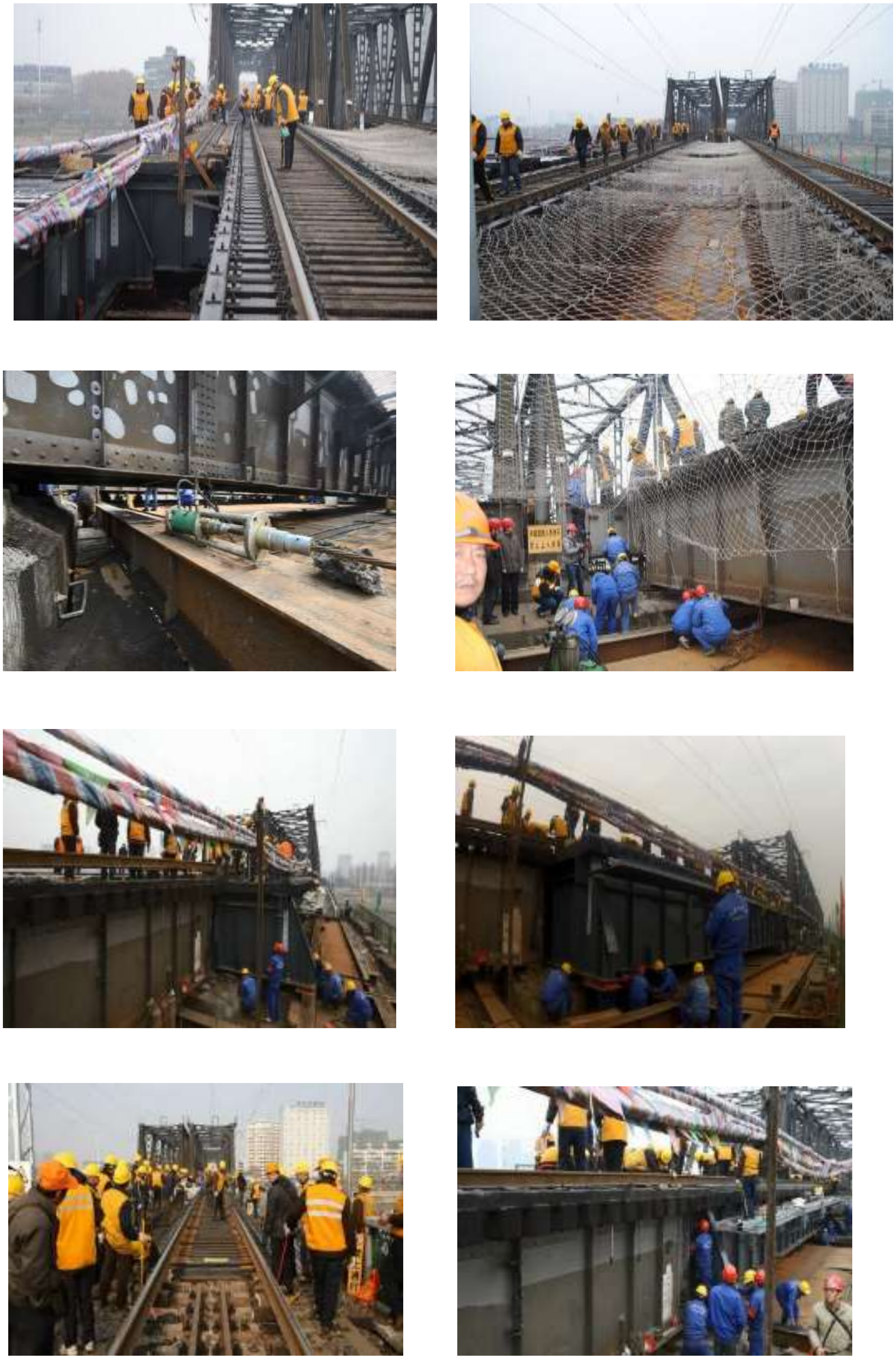

Figure 2.5.37 Lateral Movement of the New and Old Steel Girders

The notes of traverse shift of girders:

- Two hours before the traverse shift, making a scale every 5mm inside the flange of the track beam or fixing steel tape on either side of the slide girder so that when traversal moving, technicians on-site can monitor the synchronization of both ends of the moving girder all the time and report the lateral displacement of the ends loudly. When the deviation of both ends exceeds 5mm, it is necessary to be adjusted.
- The day before the traversal move, the center line was leaded to the piers top and offset 1300 mm on each side of the center line to make a new fringe line of the steel girder bottom. Specialized persons monitored the movement of the girder, when the new girder was nearly in place; the monitor personnel used the plumb for counterpoint and informed the situation to the commanding officer. Once located to accurate position, the moving stopped.
- When the steel girders were nearly in place, they should be dragged slowly to prevent traction overruns. In case the traction overruns, the traction was gauged in the opposite direction outside the new beam.
- Recheck the center line periodically after traction in place, while inspecting the longitudinal position of the beam and adjusting it periodically. Horizontal adjustment can be controlled by the traction system, while longitudinal adjustment can be carried out through a 20-ton hand screw jack.
- After the plane position of the new girder was in place, the girder can be taken down slowly so that the bearings fall on embedded steel, measuring the difference between the new top elevation and design elevation of steel girders. The thickness of the mortar leveling layer can be adjusted promptly according to the measurement conditions to guarantee the efficiency of top elevation of steel girders.
- The girder fell down once the elevation was adjusted in place, welding the limit steel plate all around the temporary supports to restrict vertical and horizontal displacement of the supports.
- When the steel girder is in place, the girder can be made to fall into the rail groove, fasten rails and so on.
- Repair and check the route. Then reopen to traffic. The train speed was limited to 25 km/h. After two hours or the passing of two trains, the train speed can be increased to 45 km/h. When all the replacement work was completed, the speed can be increased to the normal speed progressively.

(7) Installation of permanent bearings

The original supporting pad was removed by the electric pneumatic pick. The permanent bearing was installed at the bottom of the steel girder by connecting bolts. There was a 5 mm gap between the supporting and the plate, leveling the lower hem of the support, and grout cast the bearing pad after temporary fixation. When the grouting material reached the strength standard, the support was transformed on the fourth day after girder replacement, connecting bolts of up hem was taken. The girder was jacked up slightly, a 5 mm thick stainless steel plate (there are drillings as the standard of the up hem on the plate) was loaded at the gap between the up hem and the plate. The connecting bolts were installed and tightened, and the pad plate under the temporary support was taken out. Then the permanent support installation and load transfer were accomplished.

Removing the temporary support and gradually increase the speed limit enforced on the railway until eventually restoring normal operation. The installation of permanent bearings is shown in **Fig. 2.5.38**.

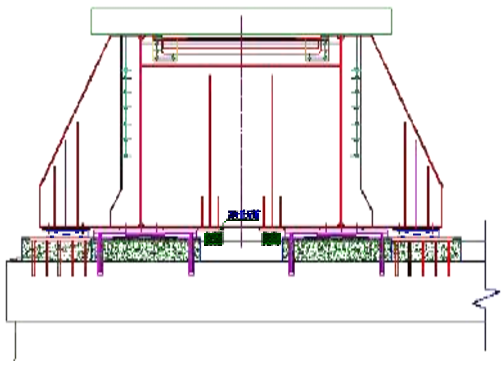

Figure 2.5.38 Installation of Permanent Bearings

(8) Disintegration and demolition of existing girder

After the new steel plate girder was installed, the old one was moved to the place near the centerline of the bridge. Now it is then disintegrated and dismantled so that there is work space for changing the girder on the other side. In order to dismantle the old girder as soon as possible, the girder was dismantled by the way of breaking up the whole into parts. Because the steel plate girder cannot be lifted across the line, on the construction platform, the parts of the old girder were transported to the inside of the track beam, and then they are lifted to the transportation barge by crane and carried away, as shown in **Fig. 2.5.39**.

Figure 2.5.39 Plane View of Old Girder Demolition

Notes for removal of the old girder

- Before dismantling, be familiar with the structure of steel pipe support, bailey beam and platform panel layout drawings. Also understand the details of various structures and the specification and weight of each piece. It is important to know the builder's safety technical disclosure and to strengthen safety awareness.
- Deck must have safety protection during the operation
- All construction personnel must dress in orange work clothes on operation
- Connecting rod of old girder should be a segmented and removed with webs to prevent overturning of web when cutting.
- Hoisting operations of steel plate girder block should be carried out within the closure.
- Demolition operations should heed the train traffic on the bridge, to ensure the safety of train and operation personnel.
- After removing the old steel girder and completing the maintenance of the new girder and other auxiliary structures, construction scaffold were removed.
- Tests were implemented to verify the bridge satisfies the driving requirements after girder replacement (as shown in **Fig. 2.5.40**)

Figure 2.5.40 Bridge Satisfied Driving Requirements after Replacement of Girders

SECTION 3: SUMMARY AND RECOMMENDATIONS

After the completion of the scanning investigation of China's existing railway speed upgrades, overall understanding of China's existing railway-speed-increasing profiles, implementation considerations, and accelerated bridge strengthening design and construction are summarized below.

3.1 Summary of Scanning Tour Investigations

1. Before the railway speed upgrades, CARS conducted a series of investigations to understand the existing railway traffic, the forecast for the future development, and the existing railway conditions, including track, turnout, subgrade, bridge and tunnel structures, rail, locomotive, vehicle, signal equipment, communications equipment and information facilities.

2. During the railway speed upgrades, a few main lines were first selected to accumulate the needed upgrade experience through field tests. After that, the speed upgrade specifications were developed to guide other upgrade projects.

3. In terms of bridge structures, the main line is controlled by stiffness, not controlled by strength when the train speed is increased, especially for the high speed railway. When the speed is increased four times faster than the current speed on existing lines, bridges demonstrate an insufficient lateral stiffness, especially for steel bridges. Most steel girder bridges on existing lines in China were replaced with concrete girder bridges. If the replacement is not feasible, the train speed is limited when crossing steel bridges.

4. In the process of long-term operation of the upgraded rail lines, a monitoring system of bridge structures is implemented in China to observe the vertical and lateral accelerations and deflection.

5. Adding transverse prestress in the diaphragm between the beams of the existing bridges can effectively increase the transverse stiffness of the bridge. When the bridge superstructure needs to be reinforced, investigation should be made at the same time on the possible impact on bridge piers and foundations.

6. When the bridge is located on a curve, the widening of the bridge pier is needed to accommodate the increase of the curvature radius of the line. In one of the bridges in China, it was done by thickening the concrete pier with another layer of concrete wrapped around the existing concrete pier.

7. Small-span reinforced concrete bridges (12 m span with transverse prestress strengthening) were found to perform well during the speed upgrades in China.

8. A typical construction step of replacing the bridge is summarized below: (1) raise power and communication lines by 80 cm higher than the top of the bridge girder; (2) prepare a temporary support platform using steel column bracket, concrete spread foundation, and Bailey truss; (3) ship the new bridge girders to the job site (or assemble them on site); (4) lift the new girders by one-site cranes. When hoisting the steel plate girders, the direction of the beam is placed on the sliding seat and must be consistent with the direction of the bearing; (5) shift the new girder longitudinally and laterally so that the existing and new girders are parallel to each other. If not, fine adjustment should be conducted by jack; (6) jack-up the steel track on existing girders. The existing cross ties will be taken away when cross ties are detached from the steel track, and the new cross ties could be laid on girders; (7) synchronously shift the existing and new girders by connecting slippers of the existing and new girders as a unit. A synchronization control jack system was utilized to ensure that the lateral movement of the existing and new girders is synchronous. The original steel rail and new cross tie will be connected when the new girder is moved in place. Finally, the track gauge would be adjusted to finish the replacement of girders; and (8) remove the existing support pads. The permanent bearing is fixed at the bottom of girders with connecting bolts.

3.2 Recommendations

1. In terms of the feasibility study of speed upgrade in U.S., investigation on the current and future demands of passenger and freight transportation of the existing railways in the U. S. is necessary. We must identify the railway corridors that need speed upgrade and the degrees of speed upgrade for these railway corridors. Then a survey is needed of several existing railways in the U.S. based on the requirement for several degrees of speed upgrade. Determine if the speed of existing railways should be upgraded to the desired degrees at one time or over several times. The bridges must be classified on the existing railways according to their materials and structural types, since different kinds of bridges may encounter unique problems. Once the information is gathered about the quantity of bridges on the existing railways choose the bridges representative of each material and structural type for further study. A field survey of the bridges should be conducted. Investigate how bridge components influence one another if the operating speed on a railway bridge is upgraded. Identify if bridge strengthening and retrofitting should be applied to both bridge superstructures and substructures.

2. In terms of bridge strengthening and retrofitting for speed upgrades in the U. S., relevant Chinese experience may be considered when speed upgrades of existing railways are conducted in the U. S. When the railway line on a bridge needs to be altered, and the original piers and

foundation are in good conditions, it is not necessary to change the piers and foundation. It is suitable to widen and strengthen their sides to accomplish the modification of the railway line. For short-span bridges with good structural integrity, it is not necessary to retrofit them when on-site testing and evaluation indicates that they can satisfy the requirements for speed upgrades. The experience of bridge speed upgrades in China shows that it is expensive and not very effective to retrofit steel girders. When speed upgrades are carried out in the U. S., it is important to evaluate the cost and actual effects of strengthening and retrofitting of steel bridges. The fast construction method used in China may be helpful to reduce the impacts of construction on the normal operations of existing railways during speed upgrades in U.S. When bridge speed upgrades are conducted, the responsible technicians should have construction experience and understand the corresponding technology and construction equipment. It is important to reduce the effects of train operation on the construction quality of bridge strengthening and retrofitting. This report suggests that train speeds should be decreased when they travel on the bridges under construction. When bridge strengthening and retrofitting are completed, the train speeds should be gradually increased over a certain period of time.

3. In terms of on-site construction of the U.S. existing railway bridges for speed upgrades, it is important to understand the time tables of train operation on U.S. existing railways to make reasonable railway reconstruction plans and decide the corresponding construction technology. This suggestion can lower the effect of on-site construction on the normal operation of a railway line. When on-site construction is performed on the bridges of an existing railway, structural types of the bridges, the methods of reconstruction, the actual conditions of other infrastructures on this railway, of the constructors' experience level, and their familiarity with construction technology and equipment, should be considered to make the detailed on-site construction plan. The on-site construction of a bridge requires the cooperation of other components in a railway transportation system, including: electric power line, communication devices, route, rail, transportation equipment and so on. It is necessary to coordinate different departments to ensure the punctual completion of the on-site bridge construction and normal operation of the railway. Before a portion of railway is closed, make all the necessary preparations and take full advantage of the closed time period to accomplish the planned construction.

4. Field investigation should be conducted to get the knowledge about the current situation of railroads in the United States considering Chinese practices experience in speed upgrades of existing railroads, to compare the US railroad bridge system with the Chinese railroad bridge system and identify the most significant technologies for implementation in the United States, and propose strategies to accommodate a higher speed for the nation's shared rail corridors. The on-site survey of the speed improvements between Memphis and Harrisburg in the Crescent Corridor route is recommended. The report developed a series of amplifying questions to help focus the discussion with engineers and to show them the topics of interest.

5. When evaluating bridge structures for a possible speed upgrade, it is recommended that the following information be collected based on the Chinese experience: the type of bridge (span size, materials and structure); the number of the different types of bridges; operational life; design criteria; speed rating (design speed, operational speed); substructure; previous inspection on the record of the bridge to include crack, corrosion of steel bar, fatigue crack, joint bolt falling off, unleveled surface, leakage tendons, peeling, empty hole; and field testing results of horizontal and vertical deflection under static and dynamic loads, the angles of rotation at bridge ends, horizontal and vertical acceleration and amplitude of girder and piers, and impact factor.

APPENDIX A: CONTACTS IN AGENCIES AND ORGANIZATIONS VISITED

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A.2 Zhengzhou Railway Bureau

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Sunquan Qin is a member of the Chinese Academy of Engineering. He graduated from Bridge and Structural Engineering of Southwest Jiaotong University. He is the chief engineer of China Major Bridge Engineering Co., Ltd, chairman of China Railway Major Bridge Reconnaissance, Southwest Jiaotong University and Southeast University part-time Professor. He serves as a Vice Chairman of Bridge Committee in Mao Yisheng Science and Education Foundation, Steel Bridge Branch Vice President of China Steel Association, China Civil Engineering Society Bridge and Structural Engineering branch vice president and other part-time. He has long been committed to the design, theoretical research, engineering, structural analysis and construction technology management of long-span bridges, to solve a number of national key projects of the key technical problems. He presided over the completion of the national, provincial and ministerial level more than 30 major research projects, created a phased construction of the bridge unstressed state control method. Presided over the development of the railway passenger line 900t bridge erecting machine, transporting girders, vehicles, and other key bridge construction equipment, fill a number of gaps in bridge construction equipment. He was awarded one national scientific and technological progress special awards, one first prize, two second prize, and award three provincial and ministerial level scientific and technological progress first prize, one second Technology Invention , won four of the national patent for invention. In 1996, he was awarded the Ministry of Railways, "young scientific talent" title, in 2000 won the Hubei Province, "model worker" title. In 2002, he won the China Railway Engineering Corporation "outstanding contributions of experts" title. In 2003 was elected the Tenth National People's Congress. In 2004, he won the eighth China Youth Science and Technology Award, the same year the first batch of candidates for the New World million Talents Project national candidates. In 2005, he won the national title of model worker.

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APPENDIX C: AMPLIFYING QUESTIONS

The following questions apply to the plan for the Experience Survey of the Speed Upgrading for Existing Bridges in China. The scanning team developed a series of amplifying questions to help focus the discussion with the Chinese experts and to show them the topics of interest. The amplifying questions addressed several topics related to speed upgrade of existing railway bridges: the working procedure of bridge strengthening and retrofitting according to the upgraded speed, the requirements for railway bridges based on the grades of speed upgrading (such as dynamical responses and other structural behavior indices), the methods of railway bridge performance evaluation, experimental study of construction technology, the design methods and practically effective approaches of bridge strengthening and retrofitting, the influences of different locomotives on speed upgrade, typical problems during operations after speed upgrade, the diagnosis of these problems, the reasons for these problems, the corresponding technical measures to solve these problems, and so on.

1. Can you briefly summarize the experience of speed upgrades of existing railroad bridges in view of the experience from six speed upgrades in China?

2. How did you develop the needed technical documents and specifications which were used to guide the speed upgrade of existing railroad bridges in China? Have you published them?

3. Are there any distinct influences due to the different type of operational locomotive on railroad bridges during speed upgrades?

4. What are the typical bridge strengthening methods to accommodate the speed upgrade? Are these methods bridge-type dependent?

5. During the speed upgrade, how did you identify the problems and the corresponding solutions to these problems?

6. How do you evaluate the performance of upgraded existing railroad bridges?

7. During the six different speed upgrades in China, what was the most effective bridge strengthening method for the following potential issues: (1) lateral stiffness; (2) resonance; and (3) lateral amplitudes of railroad bridge piers; (4) bearing distress and fatigue crack in steel girders?

8. What progresses were made in the construction technology for the railroad bridges reconstruction project during the speed upgrade?

APPENDIX D: BIBLIOGRAPHY

This appendix contains a list of the resource material that was made available to the team before, during, and after the scanning study. For further information, contact a member of the scanning team.

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