Project Report

Design and Construction of a High-Angle Swivel for a Small-Radius Curve Ramp Bridge Over Railway on the Pingcheng Street West Extension Line in Datong City

Hongbin Hu

The Fourth Engineering Co., Ltd., China Railway 17th Bureau Group Co., Ltd., Chongqing 401120, China;
Correspondence: 252260021@qq.com

Abstract: This paper presents the design and construction process of a 148° swivel for a curved bridge with a radius of 60 meters. Due to the small radius of the curved bridge, there is a significant imbalance moment during swivel. Therefore, in the structural design, measures such as pier-beam connection, installation of high-strength prestressed anchor rods, pre-eccentricity setting for the swivel structure, and filling of iron sand concrete inside the box beam at the top of the pier are adopted to balance the moment. Both the curve radius and the swivel angle of the bridge set world records for bridge swivel construction.

Keywords: curved bridge; swivel construction; railway bridge; real-time monitoring

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1 Project Overview

This project is located at the cross-railway node of the West Extension Line of Pingcheng street in Datong city, Shanxi Province. It serves as a crucial transportation pathway connecting both sides of the railway in the western part of Datong city. The Pingcheng Street West Extension Project is planned as a main urban road, with a planned red line width of 50 meters. The design speed of the main road is 50 km/h, while the ramp design speed is 30 km/h.

The main bridge and approach bridges span 15 railway lines. The main bridge is designed as a (163+91) meters single-tower single-cable plane cable-stayed bridge, while the approach bridges are designed as continuous steel box girders with spans of (65+59+62) meters. Ramps A and B serve as the lower and upper ramps of the main road, respectively. Ramp A is a curved bridge with a total length of approximately 648.0 meters. The standard width of the ramp bridge is 9.0 m, and the main beam type is a continuous steel box girder. Both the main bridge and the ramp A bridge are constructed by swivel, and this report only involves the ramp A bridge. The diagram of the existing railway and swivel construction scheme for ramp A are shown in Figure 1.

2 Bridge Technical Standards

Design Service Life: 100 years;

Structural Design Safety Level: Level One;

Environmental Category: Class II (Severely cold region);

Vehicle Load Level: The urban Class-A load increased by 30%.

Lane Arrangement: The main road is designed for bidirectional 6 lanes, while the ramps are designed for unidirectional 2 lanes.

Seismic Design Standard: The seismic fortification intensity at the project site is 8 degrees. This project is classified as a key fortification building, so the seismic fortification intensity is increased by 1 degree, corresponding to a fortification level of 9 degrees. The seismic acceleration is 0.20 g, and the design seismic grouping is the second group.

(a) Diagram of main bridge

(b) Diagram of ramp detail

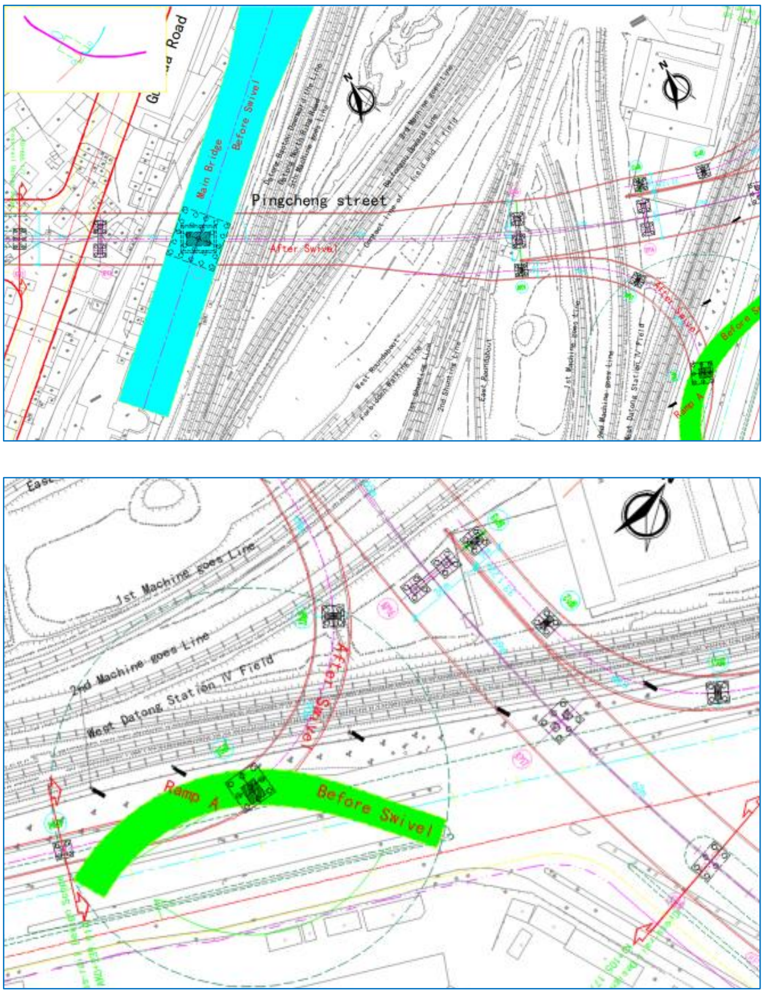

Figure 1 Diagram of the existing railway and swivel construction scheme for ramp A

3 Bridge Structural Design and Construction

The ramp bridge of this project spans the West Datong Station, which has many tracks and is busy with operations. The bridge design and construction must meet railway planning and the safety requirements of railway operations. In addition to meeting the railway clearance requirements, the clearance under the bridge is considered to be not less than the height of the contact wire pole top plus 0.5 meters for safety.

The plan, longitudinal section, and cross-sectional design of the bridge conform to the overall design of the road project. The cross slope of the main bridge and approach bridge decks on the railway is 2.0% in both directions, while the cross slope of the ramp bridge deck is 2.0% in one direction.

3.1 Bridge Plan Design

Pingcheng Street starts from the current West Wuzhou Road and ends at the current Weidu Avenue. There are a total of 4 intersections within the project scope, see Figure 2. The main road section over the railway consists of a straight section and a circular curved section with a radius of 700.0 meters. Ramp A spans over 5 railway lines. In order to minimize the oblique intersection between the ramp and the railway, reduce the span of the ramp over the railway, and lower the design and construction difficulty, Ramp A adopts a circular curve section with a radius of 60.0 meters, with a transition curve length of 35.0 meters.

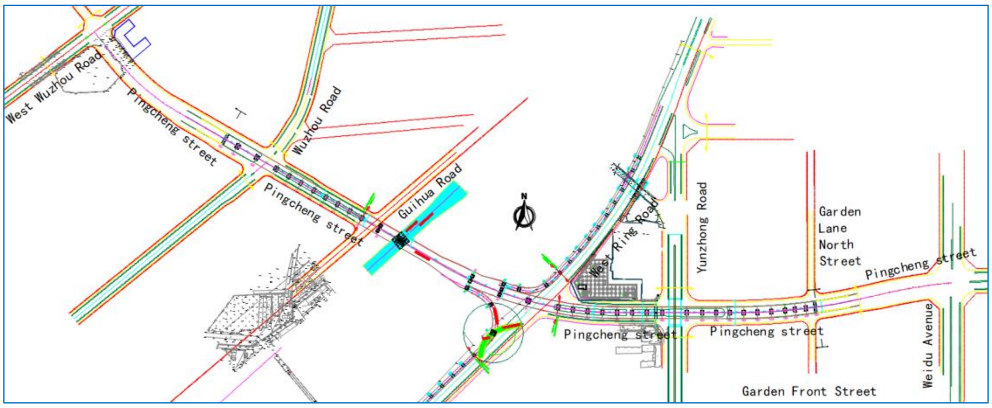

Figure 2 Road plane design

3.2 Bridge Longitudinal Section Design

The longitudinal section design of Pingcheng Street's main road needs to be combined with the current intersection road elevation and consider the clearance elevation over the planned Wuzhou Road, Guihua Road, current railways, planned West Ring Elevated Road, and current Yunzhong Road. Within the design range, the maximum longitudinal slope of Pingcheng Street's main road is 3.8%, and the minimum longitudinal slope is 0.94%. The minimum length of the convex curve is 388.639 m, the minimum convex curve radius is 2000.0 m, the minimum concave curve radius is 1149.0 m, and the minimum vertical curve length is 40.214 m, meeting the specification requirements.

Ramp A has a maximum longitudinal slope of 4.0%, and a minimum longitudinal slope of 0.2%, see Figure 3. The minimum convex curve radius is 3000.0 m, the minimum concave curve radius is 900.0 m, and the minimum vertical curve length is 37.8 m, meeting the specification requirements.

Ramp B has a maximum longitudinal slope of 4.0%, and a minimum longitudinal slope of 0.3%. The minimum convex curve radius is 2000.0 m, the minimum concave curve radius is 1200.0 m, and the minimum vertical curve length is 44.4 m, meeting the specification requirements.

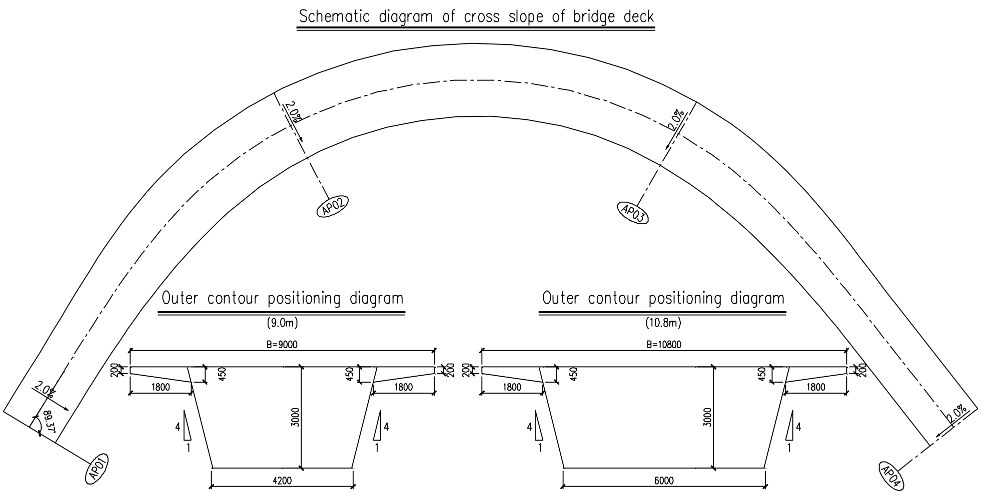

Figure 3 Plane and section design of ramp A (Unit: mm)

3.3 Swivel System Structural Design

Ramp A has a small curve radius and a large eccentric moment during swivel construction. In order to ensure the safety and stability of the structure during swivel construction and subsequent use, the design includes measures such as connection structure design and adding counterweight loads, see Figure 4 to Figure 6. The specific design is as follows:

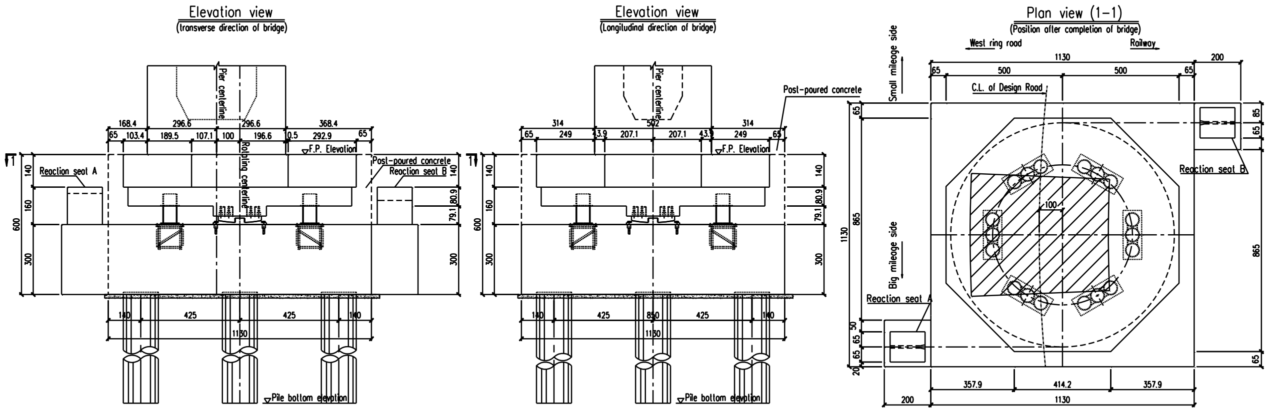

Figure 4 Relative position diagram of the pier and swivel structure (Unit: cm)

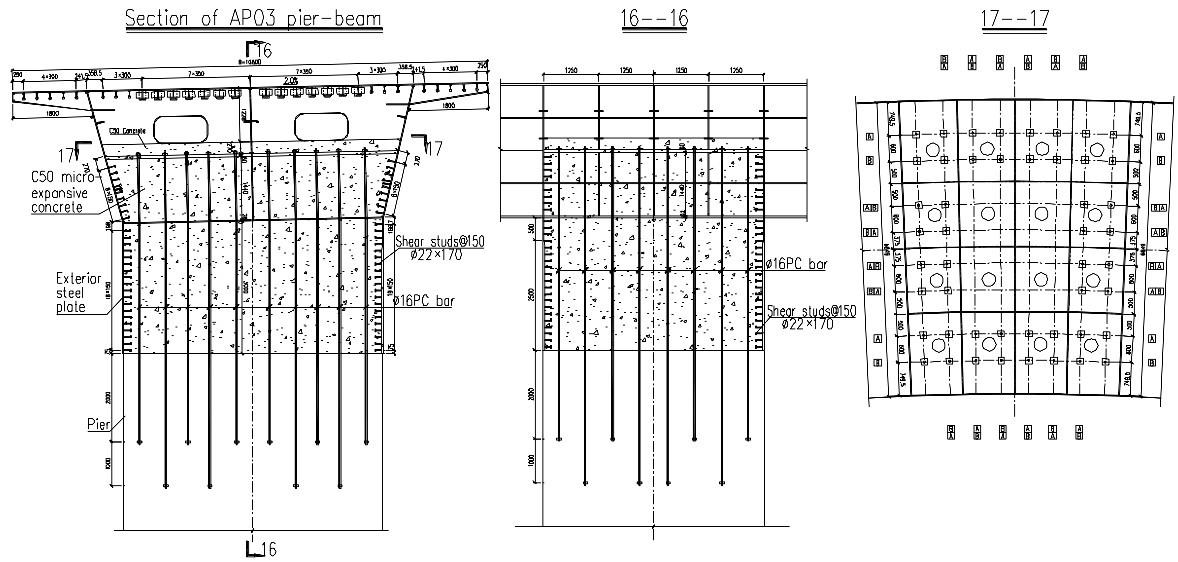

Figure 5 Prestressed anchor arrangement diagram of beam-pier consolidation (Unit: mm)

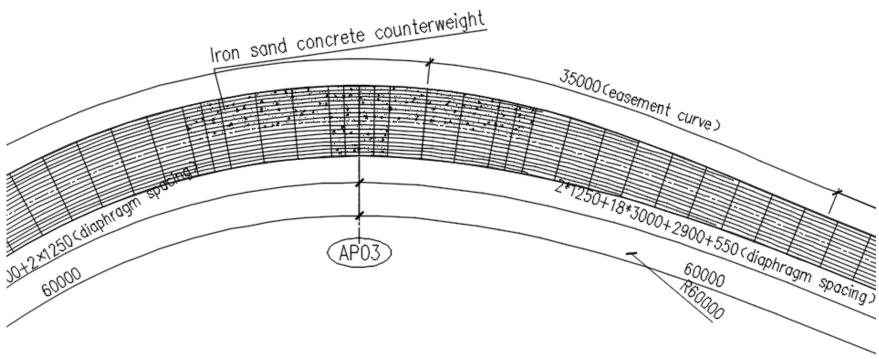

Figure 6 Diagram of the iron sand concrete counterweight zone in the beam (Unit: mm)

The pier for swivel construction is a hollow pier, and the pier-girder is consolidated. The pier has a solid section of 7.0 m at the top and a solid section of 1.5 m at the bottom. The pier body has a wall thickness of 1.25 m. The cross-sectional dimensions of the pier body along the bridge direction are 5.932 m × 5.02 m. The dimensions of the foundation cap are 10.9 m × 10.9 m × 6.0 m, with 9 φ1.5 m bored piles under the foundation cap, each with a length of 58.0 m. The pier body adopts C40 concrete, the foundation cap adopts C50 concrete, and the pile body adopts C30 underwater concrete.

To ensure stability during swivel operation, the center of the pier is offset by 1 meter in the transverse direction from the swivel center, while there is no offset in the longitudinal direction. Additionally, counterweight concrete is added inside the box girder to adjust the unbalanced moment. By weighing the structure before the swivel, the offset load of the bridge is determined, and counterweights are strategically placed above the turntable to achieve precise balance, thereby reducing the risk during swivel construction.

3.4 *Swivel System Construction Scheme*

The swivel system consists of an upper turntable, a lower foundation cap, a swivel bearing, support legs, slide rails, traction cables, traction reaction seats, a swivel traction system, an assist system, and a fine-tuning system. The swivel system is primarily supported by the swivel bearing, with support legs controlling the stability of the swivel. Two sets of intelligent continuous swivel jacks apply equal and continuous swivel torque smoothly, see Figure 7. The bridge's position during construction is monitored in real-time and fed back to the swivel command personnel, who precisely command the swivel of the bridge to achieve alignment.

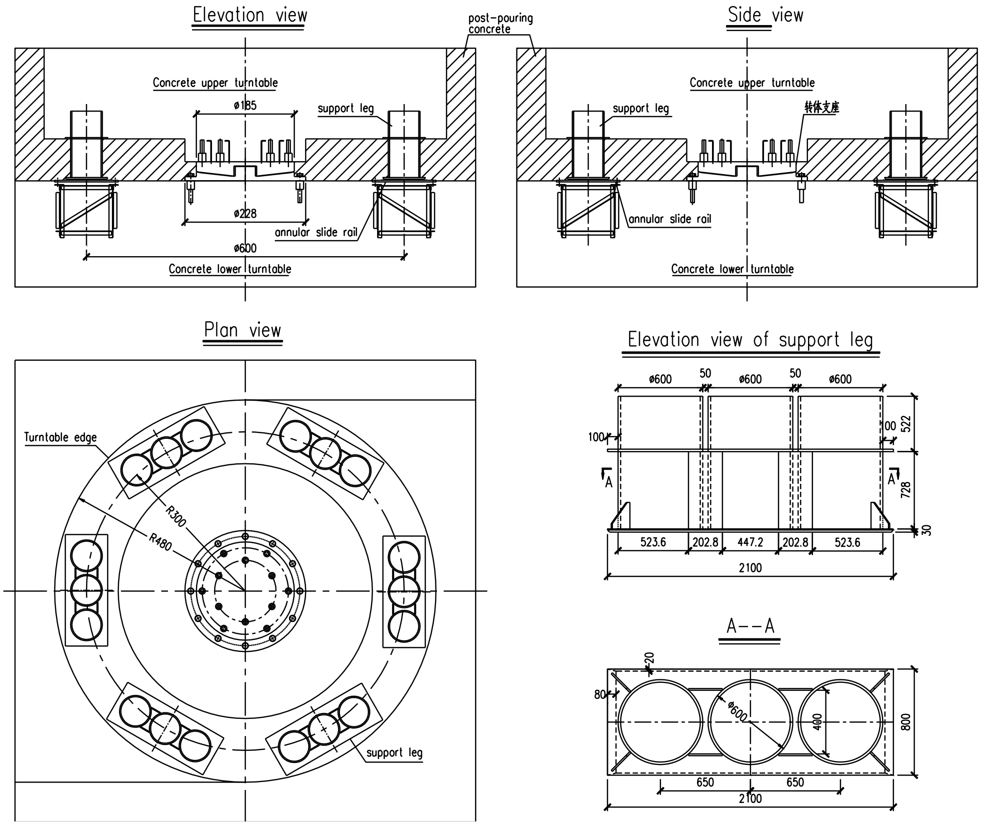

Figure 7 Swivel structure and support leg structure diagram (Unit: mm)

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The swivel bearing adopts the ZTQZ-Z-25MN-type bearing, which consists of an upper ball pendulum, lower ball pendulum, wear-resistant plate, sleeve and anchor rod assembly, anchor bars, bolts, and sealing device. The main body of the ball pendulum is made of ZG270-500 steel, and its chemical composition and mechanical properties after heat treatment should meet the "Carbon steel castings for general engineering purposes" (GB11352-2009) specification. The welding quality should meet the requirements of the "Recommended joint preparation for gas welding, manual metal arc welding, gas-shield arc welding and beam welding" (GB/T 985.1-2008) and the "Construction machinery – General specifications for welding parts" (JB/T 5943-2018) specifications. The wear-resistant plate adopted a modified polytetrafluoroethylene slide board with a sliding friction coefficient not greater than 0.03 (lubricated with silicone grease). The radius of the horizontal plane of the ball pendulum is 0.925 m, and the radius of the ball is 4.95 meters.

The upper turntable is made of C50 concrete and is an important structure for swivel construction, bearing loads in multiple directions during the entire swivel process. The lower turntable serves as the foundation supporting the entire weight of the rotating structure. It is made of concrete not less than C50 grade. After swivel completion, the upper and lower turntables are poured together to form a whole foundation. The upper turntable is equipped with a swivel bearing, annular slide rails for steel pipe concrete support legs, and a swivel jack reaction seat. During concrete pouring, strengthening curing should be applied to control temperature deformation and cracks.

The support legs serve as safe structures to support the smooth swivel of the rotating structure during swivel. Considering the force during swiveling, the six sets of supporting legs should be symmetrically distributed around the upper turntable. Underneath the support legs (i.e., the top surface of the lower turntable), there is a 1.35-meter-wide circular slide rail with a center radius of 3.0 meters, see Figure 7. The circular slide rail should be horizontally arranged, with a relative height difference of no more than 1 mm on its horizontal surface. During the swivel of the bridge, the support legs can slide within the circular slide rail to ensure a uniform and smooth swivel process.

The support legs are made of triple steel pipe concrete structure with a Q235 steel pipe thickness of 24.0 mm and an outer diameter of 600.0 mm and are filled with C50 expansive concrete. Below the steel pipe, there is a 30.0 mm thick steel plate, and under the steel plate, there is a 4.0 mm thick polytetrafluoroethylene (PTFE) board. The bottom surface of the plate is machined to a precision level of Grade 3. A 30.0 mm thick circular steel plate is connected to the frame via bolts and finely adjusted for height. A 2.0 mm thick stainless steel plate is welded onto the steel plate, forming a sliding surface between the PTFE board and the stainless steel plate. The gap between the bottom surface of the stainless steel plate and the top surface of the PTFE board on the slide rail is maintained at 15.0 mm, see Figure 8. During installation, consideration should be given to the influence of the settlement of the upper structure and related adjustment measures.

The upper turntable has a diameter of 10.0 meters, and the center diameter of the slide rail is 6 meters. The weight of the rotating structure is calculated as 25000 kN for the traction system. Through force analysis, when no counterweight is added, i.e., during eccentric swivel, the support legs are engaged, and the traction force required for initiation is 176.7 kN (without considering the assistance system). After adding the counterweight, i.e., during balanced swivel, the support legs are not engaged, and the calculated traction force required for initiation is 110.0 kN (without considering the assistance system).

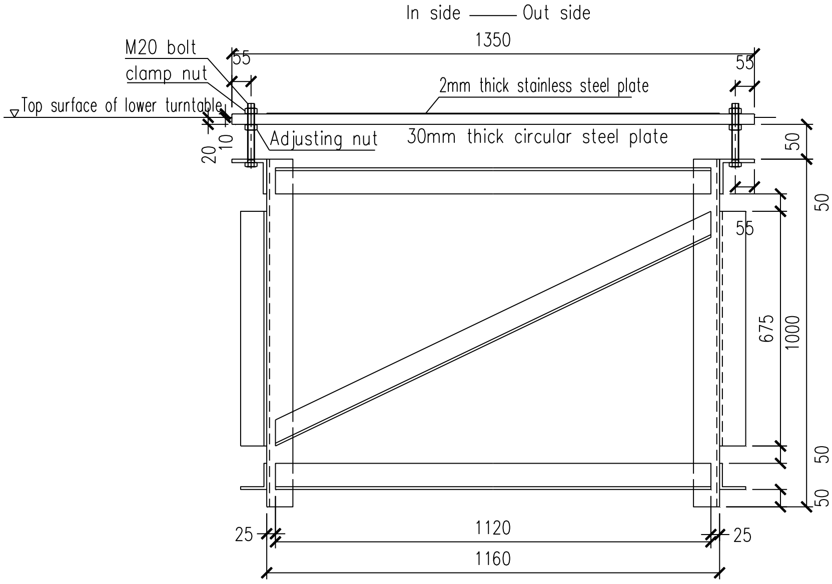

Figure 8 Turntable steel plate slideway and support frame elevation diagram (Unit: mm)

4 Summary

Current information on the swivel construction of bridges with minimum radii and rotation angles is presented in Table 1.

Table 1 Information on the swivel construction of bridges

Location	Construction date	Bridge Type	Curve radius (m)	Rotate angle (°)	Consumption time (min)	Weight (t)	Construction unit
Linyi, Shandong	2023.03.20	Concrete T-Type 2×70 m	850	46.0	50	12750	CREC
Dongguan, Guangdong	2023.01.04	Concrete T-Type 2×68 m	400	70.5	70	16000	CRCC
Guangzhou, Guangdong	2022.11.16	T-Type 104 m	300	44.0	50	3800	CREC
Chongqing	2021.08.28	T- Type 44.5+51.5 m 42.5+37.5 m	350	98.0	150	/	CSCEC
Hechi, Guangxi	2021.08.05	Concrete T-Type 48 m	300	/	45	2000	CREC
Jinan, Shandong	2019.05.30	Low Tower Cable-Stayed 2× 120 m	800	43.5	60	25000	CREC
Nanning, Guangxi	2018.11.07	T- Type	260	120.0 /110.0	180 /180	18000 /18000	CREC
Panlong, Shaanxi	2014.08.25	V-Leg Rigid Frame 2×75 m	250	30.0	30	9600	CREC
Beijing	2012.11.01	Concrete T-Type 2×71 m	470	33.46	30	7130	CREC

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Location	Construction date	Bridge Type	Curve radius (m)	Rotate angle (°)	Consumption time (min)	Weight (t)	Construction unit
Zoucheng, Shandong	2015.01.19	Single Tower Double Pillar Parallel Double Cable-Stayed	/	97.3	109	22400	MBEC
Baoding, Hebei	2019.07.30	Double Tower Single Cable-Stayed Precast Concrete	/	67.4 /52.4	70	34600 /45600	CSCEC

Based on the aforementioned curve radius and rotation angle of swivel construction of bridges, this project has set records for the smallest curve radius (60 m) and the largest swivel angle (148°) during construction. The diagram of bird's-eye view after swivel construction sees Figure 9.

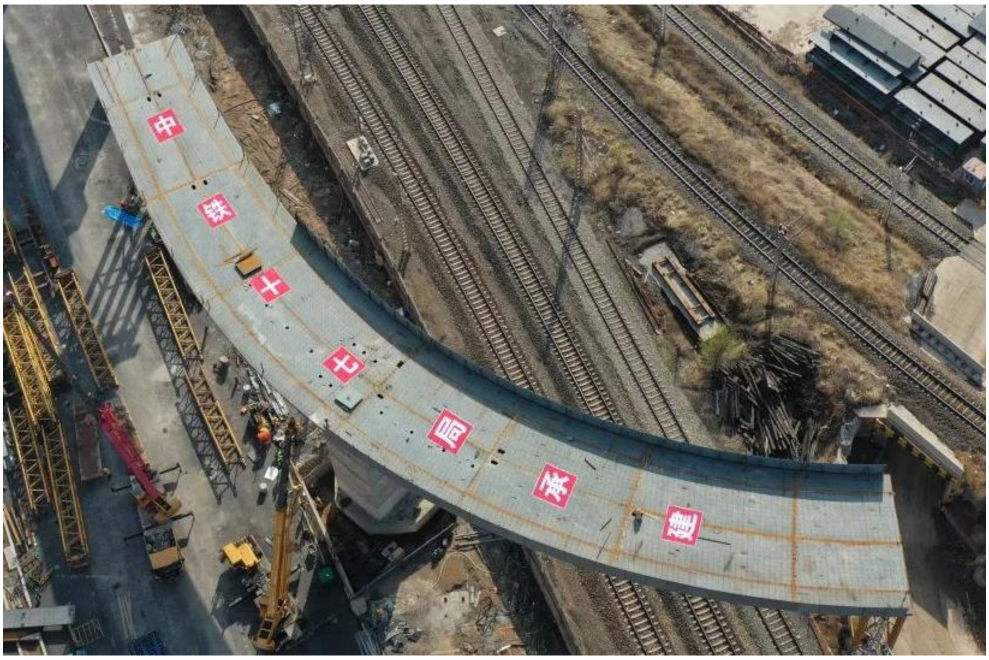

Figure 9 Bird's-eye view after swivel construction

The project utilizes continuous jacks to drive steel cables for bridge swivels, with an average rotation speed of 1°/min. The work team monitors and adjusts the rotation speed of the turntable in real-time using the scale, sensors, and cameras. They also monitor the posture, trajectory, and vertical vibration status of the beam in real-time, ensuring construction precision at the millimeter level for the swivel process. At the same time, they utilize incremental control of the hydraulic jacks, preset limit-type steel, and rubber cushion pads to prevent over-rotation, ensuring the achievement of "zero-error" operational goals.

The ramp bridge completed swivel construction ahead of the main bridge on April 22, 2023, meeting all specifications. The project serves as a reference case for the design of similar small-radius curved ramp bridges, offering valuable insights into high-angle rotational construction methods.

Conflict of Interest: All authors disclosed no relevant relationships.

Date Availability Statement: The data that support the findings of this study are available from the corresponding author, Hu, upon reasonable request.

AUTHOR BIOGRAPHIES

Hongbin Hu
Engineer, Graduated from Xi'an Shiyou University in 2016.
Work Direction: Bridge Engineering Construction and Management.
Email: 252260021@qq.com