Project Report

Anyang-Luoshan Expressway | Yellow River Bridge

Hua Pan and Shuwei Yuan*

Henan Yellow River Expressway Co., Ltd., Zhengzhou 45000, Henan Province, China;
* Correspondence: 734845791@qq.com

Abstract: The Yuanyang-Zhengzhou section project (the Lanyuan Expressway to Lianhuo Expressway) of the Anyang-Luoshan Expressway project is an important part of the Jingwu Expressway in the national expressway network. The project straddles the Yellow River Wetland Reserve and plays an important role in the construction of the Yellow River economic axis. It is of great significance to promote the integrated development of cultural tourism, to promote the core demonstration of ecological protection in the Yellow River Basin and to help the high-quality development of the Yellow River.

1 Overall Design

The project (Yellow River Bridge) is 21.655 kilometers in length, with an approved budget of 10.69 billion yuan, a design speed of 120 km/h, and two-way eight-lane traffic. The width of the main bridge is 51.5 meters, and the design load is highway-I. The main bridge is a cable-stayed bridge with twin towers and double cable planes, and the span arrangement is 110 m+135 m+520 m+135 m+ 110 m=1010 m. The main girder is a bilateral box steel–concrete composite girder with an overall width of 45.5 m. The cable tower is a bronze zun-shaped (The 'zun' is a bronze vessel containing wine in the Shang Dynasty.) structure. The tower is a steel shell concrete composite cable tower with a total height of 182 m; the tower column is a hollow circular-end single-box single-chamber section, and the outward profile dimensions of the horizontal bridge and the vertical bridge are both 10 m. The cable pylon foundation is 2 separate pile caps with concrete pile group foundation. The grouting process at the pile bottom and pile side was used to improve the bearing capacity of a single pile. A total of 4 × 23 pairs of cable-stayed cables are installed across the bridge. Both the auxiliary pier and the transition pier were in the form of capping beam + concrete column pier + steel tube composite pile.

In response to the characteristics of the large bridge, the poor geological conditions of the Yellow River and the high environmental protection requirements, the Anluo (Anyang-Luoshan expressway) Yellow River Bridge adopted a steel–concrete composite girder structure. This is the first time in China that steel–concrete composite girders have been used on a large scale in bridges in inland areas, and it is also the first time to put forward the design concept of inland bridges, which is "light-weight, factory, standardized and assembled".

The project features 5 domestic first-time technological innovations: the first-ever use of steel shell concrete structures without longitudinal reinforcement, the inaugural adoption of the distributed pile foundation grouting process, the pioneering construction of a 1700-meter steel-concrete composite beam using the incremental launching method, the first-ever utilization of a steel pipe composite structure without a bearing platform pile column, and the introduction of longitudinal and transverse bi-directional energy dissipation devices for the first time. Additionally, there are 3 first-time technological innovations in Henan Province, including the initial long-distance application of an intelligent bridge deck runoff collection and treatment system, the first-ever use of an intelligent production line construction process for the prefabricated bottom mold of a bridge deck, and the first proposal of a formwork-free rapid construction structural design plan.

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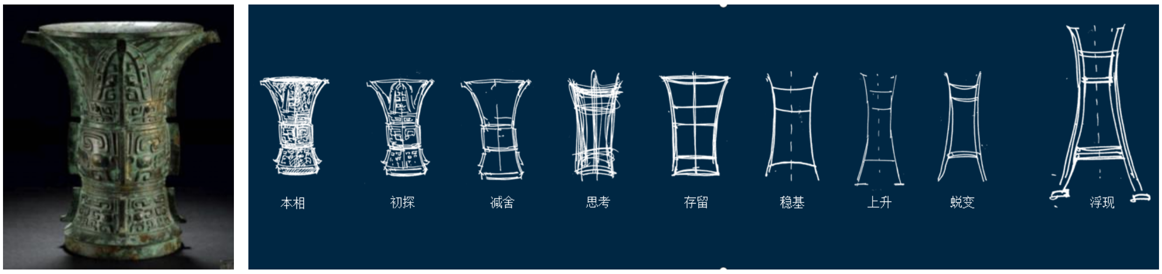

Figure 1 Source of innovative design inspiration for the bridge

Figure 2 Rendering of the Anluo Yellow River Bridge

2 Main Bridge

2.1 Overall Layout and Constraint System

The main bridge of the Anluo Yellow River Bridge is a cable-stayed bridge with twin towers and double cable planes. The arrangement of the bridge span is 110 m+135 m+520 m+135 m+110 m, with a total of 1010 m. The ratio of the side to mid-span is 0.471. The semi-floating structure system is adopted. A vertical spherical steel bearing, a longitudinal E-type dynamic energy dissipation device and a transversal limiting energy dissipation device are arranged at the lower cross beam of the cable tower, and the transitional pier and auxiliary pier are both equipped with seismic isolation bearings.

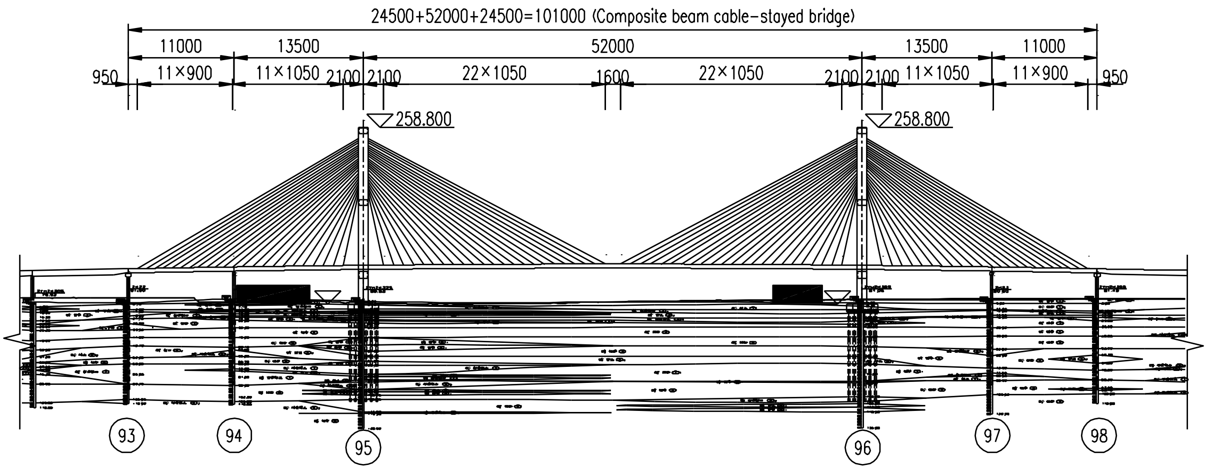

Figure 3 Arrangement of cable-stayed bridge with double towers (Unit: mm)

2.2 Bridge Pylons and Foundation

The main bridge pylons are a combination structure of steel shell concrete without longitudinal reinforcement. The appearance is shaped after the Shang Dynasty bronze "Chinese wine vessel" ('Zun'), symbolizing its form and expressing its significance, paying tribute to the Yellow River and presenting a gift to the Central Plains. The total height of the pylons is 182 meters, with a height above the bridge deck of approximately 142 meters and a height-to-span ratio of 0.273. The concrete of the pylons adopts C55 compensated shrinkage self-consolidating concrete. The steel shell of the pylons and steel anchor beams are made of Q355D, while the end sections of the steel beams use Q420D. The internal steel of the pylon's steel shell is composed of Q235B.

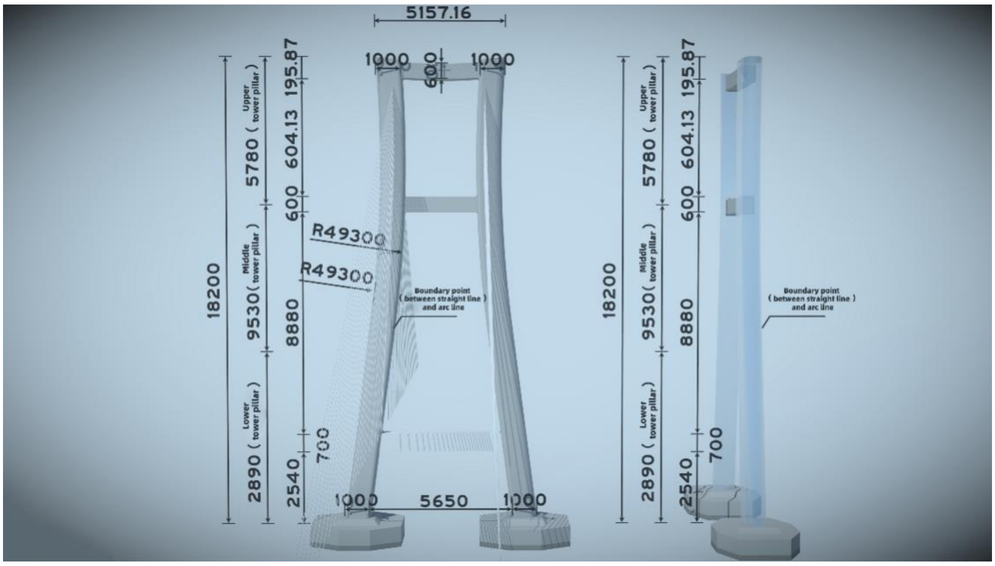

Figure 4 General layout of the pylon (Unit: cm)

The tower column adopts a hollow round-ended, a single-box, and a single-chamber configuration. The transverse and longitudinal outer dimensions of the tower column are both 10m. The wall thickness of the upper tower column is 0.8m, with 23 steel anchor beams in a tower column. The wall thickness of the middle tower column is 0.8m-1.1m, and the wall thickness of the lower tower column is 1.1m-1.4m. The steel structure of the tower segment consists of inner and outer steel wall plates, vertical stiffening ribs, horizontal stiffening ribs, horizontal angle steel, vertical angle steel, and welded studs.

The standard segment height is divided into 4m to 6m, with a maximum segment lifting weight controlled within 100t. Stiffening ribs (slab used as stiffening rib) with openings and shear studs are set in the inner and outer steel wall plates of the tower segment. Steel wall plates and concrete are interconnected through PBL (Perfobond Leiste) shear keys and shear studs, allowing the steel plates and concrete to working together. Stiffening rib slab holes are reinforced with tendons to enhance shear resistance between steel and concrete. The connection between the steel shell and the pier is formed by high-strength threaded steel bars embedded in the pier and the anchoring structure at the bottom of the inner and outer wall plates of the first tower segment. The connection between the steel shell and the concrete tower seat is formed by shear studs on the outer wall plates of the first tower segment. The first outer wall panel uses a diameter of 40mm high-strength threaded steel bars to connect with the concrete of the pier.

The foundation of the tower is 2 separated pile caps + concrete group pile foundation. 36 borehole cast-in-place quincuncial piles with diameters ranging from 2.2m to 2.7m are installed under a single pile cap, with a pile length of 95m. The borehole

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cast-in-place piles are designed as friction piles, and the distributed pile bottom and pile side grouting process are used to increase the bearing capacity of a single pile.

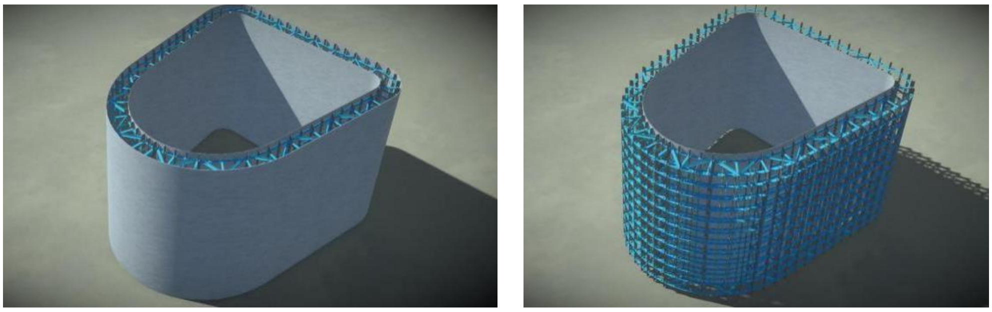


Figure 5 Tower segment 3-D model

2.3 Main Girder and Stay Cables

The main girder adopts a full-width double-box steel-concrete composite beam, with a total width of 45.5m (excluding wind fairing), and a beam height of 4.168m at the center of the composite beam. In the mid-span section, the steel beam has a height of 3.5m, and the bridge deck thickness is 0.26m. In the side-span section, the steel beam has a height of 3.28m, and the bridge deck thickness is 0.48m. Q355D steel is used for the side main beam, transverse beam, small longitudinal beam, splice plate, and support stiffening beam, while Q420D steel is used for the steel anchor box inside the beam. The steel beam forms a longitudinal and transverse grid structure composed of side box beams, small longitudinal beams, and transverse beams. Considering on-site transportation conditions, the dimensions of the steel beam structure are controlled within the width suitable for land transport.

The transverse beams between the box beams have a I-shaped section, with a longitudinal spacing of 3.0m in the cable-stayed region and 3.5m elsewhere. Beam segment connection method: Except for fusion welding used between the top plates of the side box beams and the box-shaped transverse beams in the cable-stayed pier area, all other longitudinal and transverse beams are connected using high-strength bolts. The bridge deck is made of C60 concrete and is constructed using a combination of factory prefabrication and on-site casting. Wet joints in the bridge deck are located on the upper edge of the steel transverse beams.

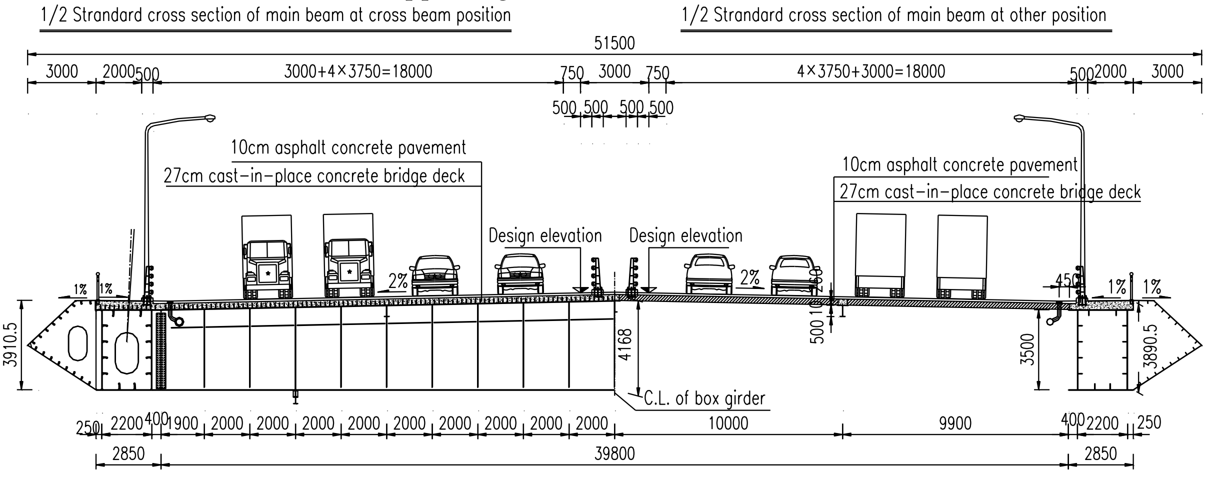


Figure 6 Standard section of main girder (Unit: mm)

To ensure the safety, durability, and convenient transportation and installation of the inclined cables, 1960MPa epoxy-coated prestressed steel strands are used for the cable stays, with a stress range of 250MPa. The anchoring method at the beam end of the cable stays is steel anchor box anchoring, while at the tower end, it employs steel anchor beam anchoring.

The entire bridge is equipped with 4×23 pairs of inclined cables. The standard cable spacing at the beam is 10.5m, and in the side-span cable-stayed region, the cable spacing is 9.0m. Different specifications of cables are used based on the varying cable forces across the entire bridge. The smallest cable specification consists of 43 steel strands, located at the mid-span on cable Z1#, the largest cable model consists of 109 strands of steel strands, located at the mid-span on cable Z23#.

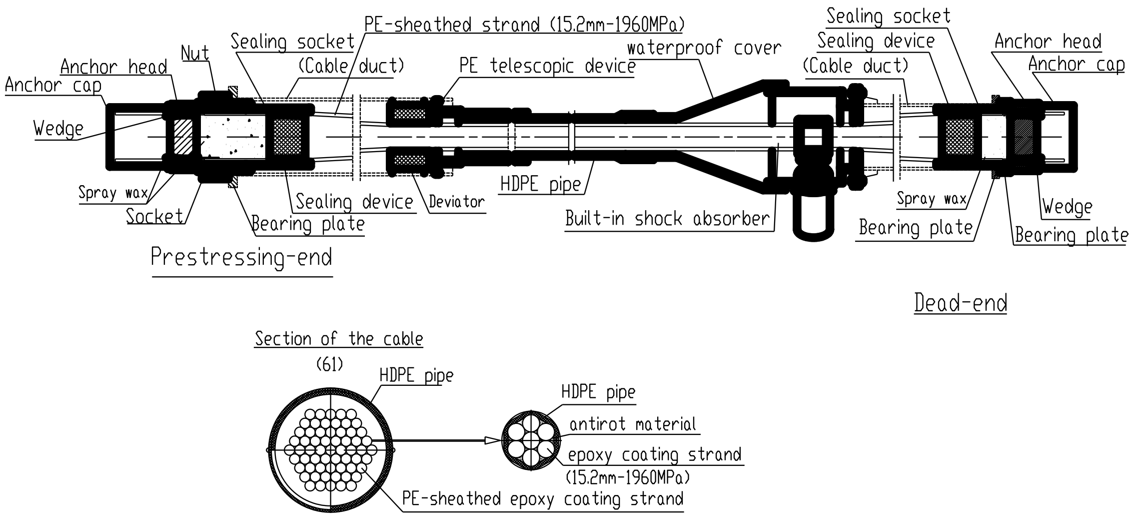
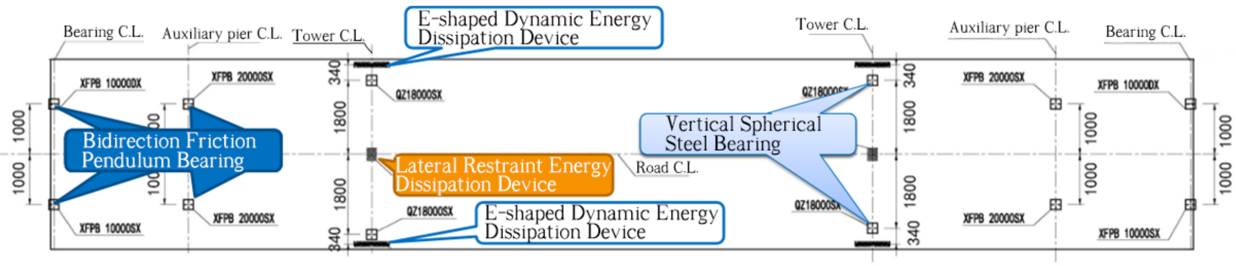


Figure 7 Schematic diagram of epoxy-coated prestressed steel strand inclined cables

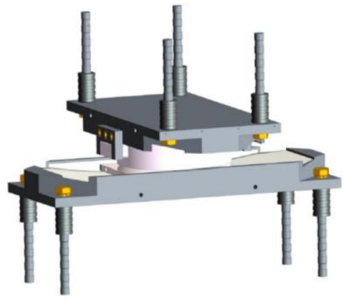
2.4 Bearings, Energy Dissipation, and Expansion Joint Devices

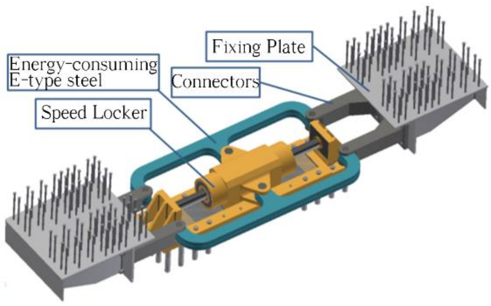
Bearings: There are a total of 4 vertical spherical steel bearings at the tower locations and 8 friction pendulum bearings with lateral restraint functions at the auxiliary piers and transition piers, as shown in Figure 8.

Energy Dissipation Devices: There are a total of 4 longitudinal and transverse E-type dynamic energy dissipation devices at the tower locations, and 2 lateral restraint energy dissipation devices at the tower locations.



(a) Schematic diagram of the main bridge restraint system





(b) Vertical spherical bearing (c) E-shaped dynamic energy dissipation device

Figure 8 Restraint system of Anluo Yellow Bridge

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Expansion Joint Devices: The main bridge's north and south beam ends are equipped with an expansion joint connected to the auxiliary bridge (horizontally segmented). A multi-directional displacement comb-toothed plate expansion device is employed. The long groove is placed on the side of the auxiliary bridge, with an expansion allowance of 1280mm. The gap between the beam ends is 950mm (800mm on the main bridge side + 150mm on the auxiliary bridge side).

3 Main Bridge Construction Technical Challenges and Innovations

3.1 Construction Technical Challenges

The project construction faces four challenges: firstly, poor geological conditions in the bridge area, with the predominant soil types being clay and sand along the Yellow River, resulting in low bearing capacity of the foundation and high seismic intensity. Secondly, construction is constrained by multiple factors, as the Yellow River is not navigable, making transportation by water impossible; and without water transportation, road access is limited. This necessitates the use of a combination of structures to address these challenges. Thirdly, the project involves a large scale, with a total length of 15.223 kilometers, making it the longest road bridge on the Yellow River. The entire bridge requires 500,000 tons of steel, approximately 3 million high-strength bolts, and welding seams totaling around 850,000 linear meters, making it the largest steel structure used in a road bridge in inland China. Lastly, there are high environmental protection requirements, as the construction takes place in a provincial-level natural protection area for the Yellow River wetlands, necessitating strict control and measures.

In response to the above challenges, conducting relevant specialized research and striving to achieve the following four points:

(1) Thorough Top-Level Design: Delving deep into top-level design to achieve light weighting of the bridge.

(2) Building a Smart Construction Site: Creating intelligent construction sites to achieve production standardization.

(3) Emphasizing Collaborative Progress: Prioritizing collaborative advancement to achieve component standardization.

(4) Innovative Technology Application: Applying innovative technology to achieve construction modularization.

3.2 Construction Technical Innovations

3.2.1 Distributed Pile Bottom and Pile Side Grouting Process

The foundation of the tower consists of separated pile caps and concrete group piles foundation. Under each individual pile cap, 36 bored cast-in-place piles are installed. These piles are designed as friction piles, utilizing pile bottom and pile side grouting process. Distributed piling effectively disperses the load on individual piles. After piling, cement slurry is injected laterally into the piles. This not only fills the gaps between the piles and the soil but also solidifies the surrounding soil, thereby improving the pile-soil interface strength and shear area. This process enhances the bearing capacity of each individual pile by approximately 25% and reduces settlement.

3.2.2 Bidirectional Energy Dissipation Device

The Anluo Yellow River Bridge is located on the southern edge of the seismic zone in the North China Plain, adjacent to the active fault zone in front of the Taihang Mountains, with a seismic intensity of 7 degrees. In order to reduce the impact of earthquakes on the structure, a bidirectional energy dissipation device has been developed, and at the same time, base isolation bearing have been employed to effectively enhance the bridge's bidirectional seismic performance.

3.2.3 Lightweight, Modular, Standardized, and Assembled

Based on the current conditions of the bridge site, there are various constraints on construction. Therefore, a combination structure is adopted for the main bridge, breaking it down into modular components. This marks the first large-scale use of a steel-concrete composite beam bridge in the inland regions of China. The project introduces the design concept of "lightweight, standardized, modular, and assembled" for inland bridges, reducing the requirements and investment in large lifting equipment, minimizing transportation and installation difficulties, lowering construction risks, and achieving the industrialized construction of the entire bridge.

3.2.4 Reinforcement-Free Steel Shell Concrete Pier Structure

This project represents the first use of a reinforcement-free steel shell concrete composite pier structure in China. Only some reinforcements are placed between the steel shell rib plates, significantly reducing on-site steel joint connections. This greatly facilitates on-site construction, enabling the rapid construction of bridge piers. The steel shell of the main tower serves both as a permanent structural component and as a formwork for constructing concrete segments during the construction phase, realizing the concept of "formwork-free construction". "Formwork-free construction" uses prefabricated permanent structures from the factory as construction templates, streamlining construction processes, improving construction precision, accelerating construction progress, and meeting the requirements for industrialization and assembly.

3.2.5 Intelligent Bridge Deck Runoff Collection and Treatment System

Due to the project's location in the Yellow River wetland protection area with high environmental protection requirements, an intelligent bridge deck runoff collection and treatment system is proposed. It concentrates and stores sewage within the protection area, meeting environmental protection requirements while reducing the maintenance costs of the bridge.

Conflict of Interest: All authors disclosed no relevant relationships.

Data Availability Statement: Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

AUTHOR BIOGRAPHIES

	**Hua Pan** Senior Engineer. Graduated from Changsha University of Technology in 2003, Majored in Traffic Civil Engineering. Participated in Pakistan's M5 Highway Project, Which Was a National Key Project of the "the Belt and Road". Won the National Quality Engineering Gold Award, Luban Award, and Zhan Tianyou Award. Email: 310936827@qq.com		**Shuwei Yuan** Engineer, Graduated from Chongqing Jiaotong University with a Master's Degree in Materials Engineering in 2014, Specializing in High-performance Road Construction Materials. Email: 734845791@qq.com