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Design and Engineering of Urban Interchange Ramp Bridge Structure

Yuxiao Zhang*, Maode Yang

China Merchants Chongqing Communications Technology Research & Design Institute Co., Ltd., Chongqing 400067, China

Corresponding author: Yuxiao Zhang, carolpcy@163.com

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Abstract: This paper analyzes the structural design of an urban interchange ramp bridge from four aspects, which are the superstructure, pier structure, foundation structure, and deck structure design to summarize the structural design ideas of this urban interchange ramp bridge, which can be used as a reference for future construction of the same bridge.

Keywords: Interchange ramp; Bridge structure design; Pier structure; Foundation structure; Bridge deck structure

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1. Introduction

In the continuous development of modern urban transportation, an increasing number of overpasses are constructed, with interchange ramp bridge structures being the most common. Scientific and reasonable structural design is crucial to the proper construction of such a bridge structure [1]. Based on this, designers and relevant individuals need to cooperate when designing various engineering components of such structures to meet their actual construction and application needs to ensure the proper utilization of such bridges and promote the development of good urban traffic engineering.

2. Project overview

An overpass project on a main road in a city is the research subject of this paper. The overpass is an important traffic hub project in the city where it is located, which includes 10 ramps, with a total length of about 2.69 km, a width of 8.0–13.5 m, and a total bridge area of about 2400 square meter. The number of bridge holes in the whole line is 117 holes, and the total number of piers and abutments is 129, in addition, there are also two frame-type tunnel bridges and one street bridge. The designated speed of the main road of the city where the overpass is located is 80 km/h, the designated speed of the secondary road is 60km/h, the designated speed of the left-turn ramp is 30–40 km/h, and the designated speed of the right-turn ramp is 40 km/h. The radius of the main line-level curve is more than 600 m, the radius of the left-turn ramp level curve is more than 45 m, and

the radius of the right-turn ramp level curve is more than 65 m. The maximum longitudinal slope of the whole line is 4.5%. The line adopts a two-lane design standard, and the standard width of the straight section and ramp section is 9.5 m and 9.0 m respectively. After field investigation, it is found that the overall topography of the bridge area is relatively flat, and it crosses a river with a width of 35 m and a depth of 4 m. The holding layer of the piling foundation within 45 m below the ground level of the bridge area is a powdery clay layer and a mild sandy powdery soil layer. In the surface layer and within 15 m below the ground, the plasticity index of the soil layer is between 12.7–27.7, and the overall geological condition is good. This paper mainly analyzes the structural design of the bridge by combining the above engineering design standards and construction conditions.

3. Structural design of urban interchange ramp bridges

3.1. Superstructure design

In this interchange ramp bridge project, its superstructure mainly includes prestressed box girders, reinforced concrete box girders, prestressed channel girders and hollow slab girders, street bridges, and tunnel bridges. The following is its design analysis:

The first is the design of the prestressed box girder. According to the actual construction and application requirements of this bridge project, the designer used the curved girder with a small radius as a continuous box girder. Because of the existence of curvature and the influence of bending and torsion coupling, the stress situation of curved bridges is particularly complicated. Therefore, in this design, the designer uses finite element analysis software to calculate and design. After finite element analysis, the designer set the structure as two ramps across the main road in an 85cm plane curve radius value design form with two span forms. The first one is a single box and single chamber type with a span of 17.2 m + 43.0 m + 30 m. The second one is a single box and double chamber type with a span of 37.0 m + 37.0 m + 37.0 m. At the same time, since one of the ramps is a double lane, the designer widened the curve design appropriately to a girder height of 1.8 m. The prestressed strand adopts a standard value of 1860 MPa for its tensile strength, which is the same as the standard value of 1.8 MPa. The tensile strength of the prestressing strand is adopted as a high strength and low relaxation strand with the standard value of 1860 MPa, and the tension control stress under anchor is 75% of the standard strength. The construction was carried out by the cast-in-place method with brackets. In the design, to prevent transverse cracks in concrete caused by an overly small radius, it is necessary to encrypt the deployment of U-shaped chipping reinforcement in the curved section, and the chipping reinforcement is welded with the box girder hoop bars to form a whole structure.

The second is the reinforced concrete box girder design. The designer divides this kind of structure into two kinds based on the requirement. The first one is a curved girder structure, which has three types of girder forms, namely, single box with single chamber, single box with double chamber, and single box with three chambers; the span of the box girder is between 10–30 m, the height is between 1.2–1.6 m, three to four holes are generally set in each link, and the radius of the plane curve is usually more than 45 m. The φ25 mm rebar is arranged in the top plate while φ35 mm rebar is arranged in the bottom plate, and the in-situ casting construction is mainly constructed by full scaffolding. The second type is the shaped beam structure, in which its cross section is treated according to the single-box multi-compartment structure to create a neat appearance. When designing the separated foundation, the designer should set the structural joints on the top slab, to reduce the lateral stiffness and prevent the lateral displacement cracks on the structural surface caused by the uneven settlement of the foundation.

The third is the design of the prestressed channel girders and hollow core slab girders. According to the

construction standard of this project, its span needs to be maintained between 16–27 m. At the same time, because the structure needed to cross the river, the designer designed the structure as a simply supported girder, and used the class IV thick steel bar as the main girder, with a strength of no less than 750 MPa. To ensure the convenience of the subsequent construction and to save land area for stacking the materials on the construction site, this kind of structure needs to be prefabricated and processed in the factory, and then transported to the construction site for the construction [2].

The fourth is the design of the street crossing bridge. In the design, to ensure the convenience of pedestrian travel, the designer has set up a cross-street bridge in the bridge structure, in which the main structure is in the form of reinforced beams, and the cross-section is designed as a single box single-compartment structure. Specifically, the steel plate is 16Mn steel plate, the beam height is designed to be 0.9 m, the length of the wing edge cantilever is designed to be 0.8 m, and the main span of the beam body spanning diameter is 30 m. To ensure the convenience of the overall construction and to save the on-site material storage space, this kind of structure needs to be prefabricated and processed in the factory, and then transported to the construction site for assembling construction [3].

The fifth is the design of the tunnel bridge. Based on the construction standard of this bridge project, the clearance height of the tunnel bridge should be designed as 10m, the thickness of the side plate should be designed as 0.60 m, and the thickness of the top plate should be designed as 0.55 m. The whole tunnel bridge plate is a frame structure, and reinforced concrete is used for the casting construction.

3.2. Pier structure design

The design of the pier is particularly crucial in the design of the interchange ramp bridge structure. Based on this, the designer emphasized the design of the structure by combining it with the bridge construction standards and its application requirements to ensure the pier structure is reasonably designed [4]. Usually, the cross-section of the pier columns of such bridge structures should be designed as rectangular, which not only makes the pier structure more beautiful but also achieves good adaptability with the box girder, so that the overall bridge structure is beautiful enough [5]. At present, in this bridge project, there are four main section types of single-column pier column structures, comprising rectangular or square structures with different sizes. Designers need to reasonably determine the pier column structure form and size according to the conditions to meet the actual design and application requirements of bridge engineering. **Table 1** shows the main section types and basic design standards of the single-pillar pier structure of the current interchange ramp bridge.

Table 1. The main section types of single-column pier structure of the interchange ramp bridge and their basic design criteria

Type of pier	Shape of pier	Size of pier	Type of chamfer
The first type	Square section	1.35 m × 1.35 m	Circular arc
The second type	Square section	1.70 m × 1.70 m	Circular arc
The third type	Rectangular section	1.50 m × 1.00 m	Circular arc
The fourth type	Rectangular section	1.20 m × 1.00 m	Circular arc

In this project, the designer designed the pier abutment of the bridge as a lightweight abutment structure in the form of a straight breast wall, and its pier columns were designed according to the second cross-sectional form. In the specific design based on engineering standards and construction requirements, the designer only needs to set longitudinal trays on each joint end column and does not need to set cover beam structures on other

pier columns [6]. In this way, the overall appearance of the bridge pier structure can be made simple enough to further enhance its overall aesthetic effect while meeting the actual application requirements of the bridge abutment piers and columns [7].

3.3. Foundation structure design

The foundation structure is the most important component in the overall bridge structure of the interchange ramp bridge. Only if the foundation structure of the bridge structure is scientifically and reasonably designed, can the overall quality of the bridge foundation be effectively ensured, and provide strong support for the subsequent construction quality and safety. Thus, the designer must pay full attention to the design of the foundation structure, and take reasonable measures to design the foundation structure according to the actual situation.

The designer of this project specially used the driven pile as the foundation structure of the bridge and reinforced concrete casting was used for construction based on the engineering standard and the actual situation on the site. In the specific design, the designer reasonably designed the thickness of the bearing platform, welded several structures on the steel plate, and set the reinforcing steel mesh on the top and bottom of the structure, so that the bridge has high-stress tolerance [8]. In the design of the simple support beam structure, the designer first determined the preliminary length of the foundation piles according to the initial construction standards and then corrected the length of the foundation piles through the comprehensive consideration of the settlement of the continuous beam structure and other factors.

In this process, to effectively ensure the safety and stability of the underground pipeline, the designer also carried out reasonable control on the length and diameter of the bored piles. During the construction, all the foundation piles are required to enter into the inner holding layer of powdery clay to ensure the solid effect and quality of the bridge foundation. **Table 2** shows the control of basic design parameters of the interchange ramp bridge foundation structure in this project.

Table 2. Control of basic design parameters of interchange ramp bridge foundation structure in this project.

No.	Project	Parameter
1	Section specification of driven pile	40 cm × 40 cm
2	Cap thickness	1.5 m
3	Initial length of simple beam pile	26 m
4	Final length of simple beam pile	30 m
5	Length of bored pile	40 m
6	Diameter of bored pile	0.7–1.5 m

3.4. Bridge deck structure design

The bridge deck structure is one of the most critical components in the interchange ramp bridge [9]. The bridge deck structure should be meticulously and reasonably designed according to the application standards and the actual situation of the construction site. This can effectively ensure the overall construction quality of the bridge project and ensure the stability and safety of vehicle traffic to the maximum extent possible.

The designer used the concrete mat structure as the paving layer on the bridge deck of this interchange ramp bridge. The designer set the concrete grade as C30 and the thickness of the pavement as 8 cm based on the guidelines. In the design of the prestressed continuous girder structure, the designer set the reinforcing steel mesh and waterproofing bedding layer reasonably on the bridge deck structure to improve the loading capacity

and waterproofing performance of the bridge deck. In the construction process of this part of the bridge deck structure, the construction personnel are required to evenly apply a layer of waterproof coating to the negative bending moment above the bridge floor cushion and then lay a layer of asphalt concrete on the waterproof coating with the thickness controlled at 5 cm. The designer utilizes rubber bearing and rubber plate expansion joints to ensure reasonable control of the quality of construction joints of the bridge deck structure [10]. For the motorway on the bridge deck, the designer arranges the composite collision wall structure on both sides, and its overall structure is composed of continuous steel pipe and reinforced concrete wall. At the same time, the designer also set up a drainage outlet in its unilateral or bilateral, so that rainwater on the bridge deck is channeled and discharged to the drainage facilities on the ground through the drainage pipe. In this way, the drainage effect of the whole bridge deck is achieved to avoid water accumulation problems which could have adverse effects on the quality and traffic of the bridge deck.

4. Conclusion

In summary, interchange ramp overpass girders are the most important form of bridge structure in modern urban transportation engineering. Through the reasonable design and construction of such bridges, it not only can effectively meet the traffic demand of the main roads and secondary roads of the city, and ensure the quality and safety of transportation, but also can significantly improve the overall bridge aesthetics of the cityscape. Hence, the designers and relevant personnel must ensure the bridge structure should be reasonably designed based on the specific construction standards of the site. This study can act as a scientific reference for subsequent structural construction to ensure the quality of such bridges is achieved to the maximum extent possible.

Disclosure statement

The authors declare no conflict of interest.

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