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Original Paper

Research on the Design Scheme of the Mainline-to-Ramp Widened Bridge Node for the Expressway Upgrade Project of Beichen Avenue (North Second Ring Road - Qinhan Avenue)

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Abstract

The width of the prestressed concrete beam is integrated with the width-split width. The existing prestressed concrete beam and the width-split beam are connected by cantilevers. The horizontal steel bars are implanted in the existing bridge cantilevers and the horizontal steel bars are connected with the cantilevers of the wide beam cantilevers. The longitudinal steel bars are arranged. The cast-in-place wet joints are UHPC (ultra-high performance concrete). In the study of the design plan for the main line connection ramp wide-split bridge of Beichen Avenue (North Second Ring Road - Qinhan Avenue) rapid transformation project, the wide-split bridge was mainly studied and analyzed from two plans. Plan 1, the bridge deck was not widened, and the superstructure was hinged. The plan focused on the impact on the current bridge traffic during the construction period. The bridge deck was widened. The bridge deck was built on the outside of the current bridge. The new and old bridge deck was connected with wet joints; Plan 2, the bridge deck was widened, and the superstructure was semi-rigid. The plan focused on the impact on the current bridge traffic during the construction period. The bridge deck was widened, and the new and old bridge decks were connected with wet joints.

Keywords

prestressed concrete, width combination, articulation, widening

1. Project Overview

The proposed rapid transformation project of Beichen Avenue (North Second Ring Road-Qinhan

Avenue) is located in the section of Beichen Avenue North Second Ring Road to Qinhan Avenue in the northern part of Xi'an city. Beichen Avenue is an important part of the "three horizontal and three vertical" expressway network in the northern area of Xi'an City ("Approval of the Xi'an Municipal Development and Reform Commission on the Feasibility Study Report on Zhuhong Road Rapid Renovation Project/North Third Ring Road and Taihua Road Interchange Project" - Municipal Development and Reform Review and Issuance [2017]); it is a north-south expressway connecting the Economic and Technological Development Zone and Gaoling District; an important channel for the mutual conversion of traffic with the Northeast Second Ring Road and the Ring Expressway; it is connected through the East Second Ring Road and Xin'an East Street-Yan Yin Road, and jointly form a vertical expressway connecting all areas in the east of the city; it is an important transportation channel for the Second "Belt and Road" International Cooperation Summit Forum and the 14th National Games ("Feasibility Study Report on the Rapid Renovation Project of Beichen Avenue (North Second Ring Road ~ Qinhan Avenue)" China Municipal Engineering Zhongnan Design Research Institute Co., Ltd., September 2017).

The rapid transformation project of Beichen Avenue (North Second Ring - Qinhan Avenue) starts from the North Second Ring Road in the south and ends at Qinhan Avenue in the north. The total length of the road is about 9.5km (station number K0+000~K9+525.07). The project is divided into short-term and long-term construction. The near-term construction scope is the section of the North Second Ring Road to Building Materials North Road (station number K0+000~K1+570, K2+605~K7+260, among which K1+570~K2+605 is the implementation scope of the intersection between Fengcheng 5th Road and Beichen Avenue). The long-term construction scope is the section from Building Materials North Road to Qinhan Avenue (station number K7+260~K9+525.07). This project is undergoing rapid transformation based on the current roads. The red line width of the planned road from the North Second Ring Road to the Ring Expressway is 100m, and the red line width of the planned road from the Ring Expressway to Qinhan Avenue is 60m.

Overall layout: The construction form of "main line elevated + ground auxiliary road" is adopted. The north side of Xinjiamiao Interchange maintains the status of the landing section. The main line elevated starts before Fengcheng 2nd Road, and then connects the main line elevated bridge through the guide bridge. There are 4 interchange interchange along the line, namely Xinjiamiao Interchange, Fengcheng 5th Road Full Interchange, Fengcheng 8th Road Partial Interchange, and Ring Expressway Full Interchange. Among them, Xinjiamiao Interchange was established to revise the interchange, which means a new NE ramp was added; Fengcheng 5th Road Interchange was a separate project, which was not within the design scope of this project. In addition, a total of 5 new parallel ramps and 1 pedestrian overpass (Xianba Avenue pedestrian overpass) have been built on the entire line. Lane size: 6 lanes in both directions of the elevated standard section, including 6 lanes in both directions, and some sections of the road include auxiliary lanes; 6 lanes in both directions of the ground auxiliary lanes.

The construction scope of this project is about 6225m in the near future, with a pile number range of

K0+000~K1+570, K2+605~K7+260. The line crosses 15 current roads including North Second Ring Road, Xiangba Avenue, Fengcheng 2nd Road, Fengcheng 3rd Road, Euya 2nd Road, Euya 3rd Road, Fengcheng 8th Road, Yuchang Road, Hongqi East Road, Hongguang Road, North Third Ring South Auxiliary Road, Ring Expressway, North Third Ring North Auxiliary Road, Zhaoyuanmen Road, Bapu 2nd Road (Branch Material North Road), and crosses 2 current pedestrian overpasses (Fengcheng 3rd Road pedestrian overpass and Yuchang Road pedestrian overpass). The current Fengcheng 2nd Road pedestrian overpass is demolished. The standard red line width of this section of the road is 100m south of the Ring Expressway, and the standard red line width of the north of the Ring Expressway is 60m north of the Ring Expressway.

Current situation: NW ramp, North Second Ring Main Line, WN ramp, East Second Ring Main Line, and SE ramp will be connected to Guang'an Road. The main line of Fengcheng Eighth Road adopts a two-way four-lane underpass passage, which is arranged on the first floor. The ground road of Beichen Avenue and the ground auxiliary road of Fengcheng Eighth Road are on the first floor, the main line of Beichen Avenue elevated road is on the second floor, and the SW (south → west) and ES (east → south) steering ramps are arranged on the third floor. The remaining steering traffic is solved by parallel ramps on both sides and ground plane light control intersections.

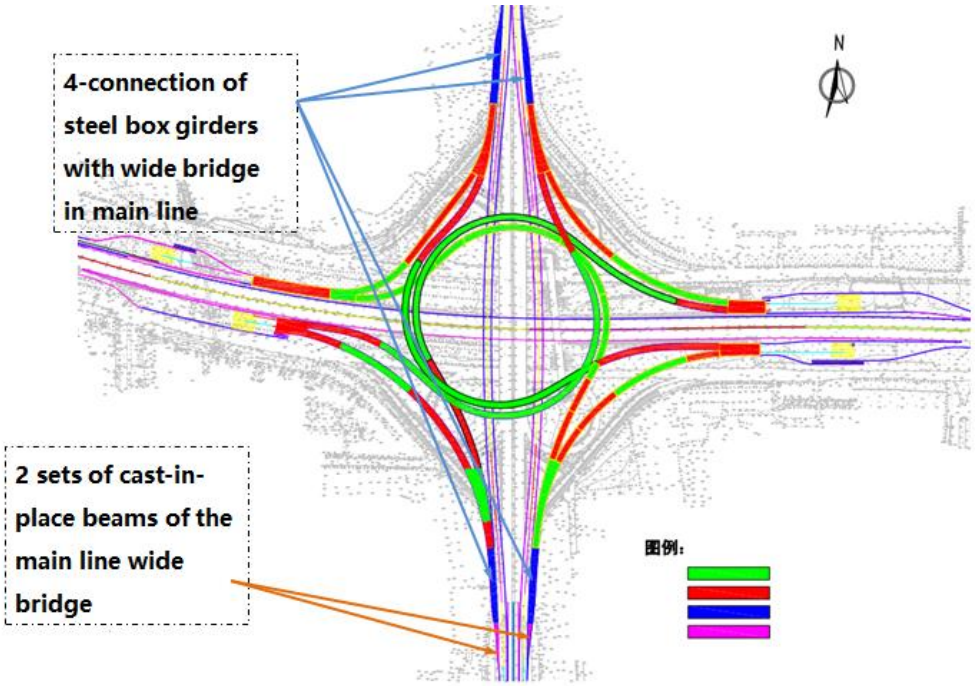
According to the design plan agreed by the Provincial Department of Transportation, the project is located at the intersection of Beichen Avenue Expressway and the Ring Expressway, and a "turbo" fully interchange is arranged. The ramp toll station is arranged in four quadrants, with two entering toll stations and two out toll stations (both 5 lanes are used). The overpass ramp is 10m wide according to the double-lane standard on the highway. The east side of the overpass adopts a plan to add an auxiliary lane to the main line of the ring expressway (including the Pinkuan Bahe Bridge). Simultaneously implement ancillary projects such as greening relocation and restoration, road traffic, pipeline relocation, lighting, and highway-related housing construction mechanical and electrical toll systems.

One new interchange is built at the ring highway node. The interchange is generally arranged as a four-story and a half-turbo-type fully interchange interchange. Each left-turn ramp uses a roundabout semi-directional ramp. In order to reasonably utilize the red line space, a compact and symmetrical arrangement is adopted to form a "turbo" style. Use the current situation to arrange toll stations at the green belt space on both sides of the ring road expressway. The first floor is the main line of the ring expressway; the second floor is the main line of Beichen Avenue; each steering ramp is arranged in the space from the third to the fourth floor.

The interconnection and wide-width bridge project between Beichen Avenue and the ring highway, the bridge design includes the BCZ main line connecting the ramp bridge with the left BCZ main line connecting the ramp bridge with the right BCY main line connecting the ramp bridge with the right BCY main line connecting the ramp bridge with the right BCY. The main line of the ring expressway interchange is connected to the EN ramp Pinbroad Bridge with a total length of 159.509m, and the pile number range is YK1+384.453~YK1+543.962. The total length of the NW ramp Pinbridge Bridge

connecting the main line of the ring expressway interchange is 159.293m, and the pile number range is ZK1+384.453~ZK1+543.746. The main line of the ring expressway interchange is connected to the SE ramp Pinbian Bridge with a total length of 227m, and the pile number range is ZK0+452.453~ZK0+679.453. The main line of the ring expressway interchange is connected to the WS ramp Pinbroad Bridge with a total length of 227m, and the pile number range is YK0+452.453~YK0+679.453. The superstructure adopts steel box girder structure and cast-in-place box girder structure. The lower structure piers adopt vase piers, and the piers adopt bored and cast-in-pile foundation.

Real scene of the current interchange



Ramp steel box girders are 27 connections, with an area of 32678.18m2;

31 joints of cast-in-place beams on the ramp, with an area of 26282.6m2;

The main line is equipped with wide bridge steel box girders 4, 4877.80m2;

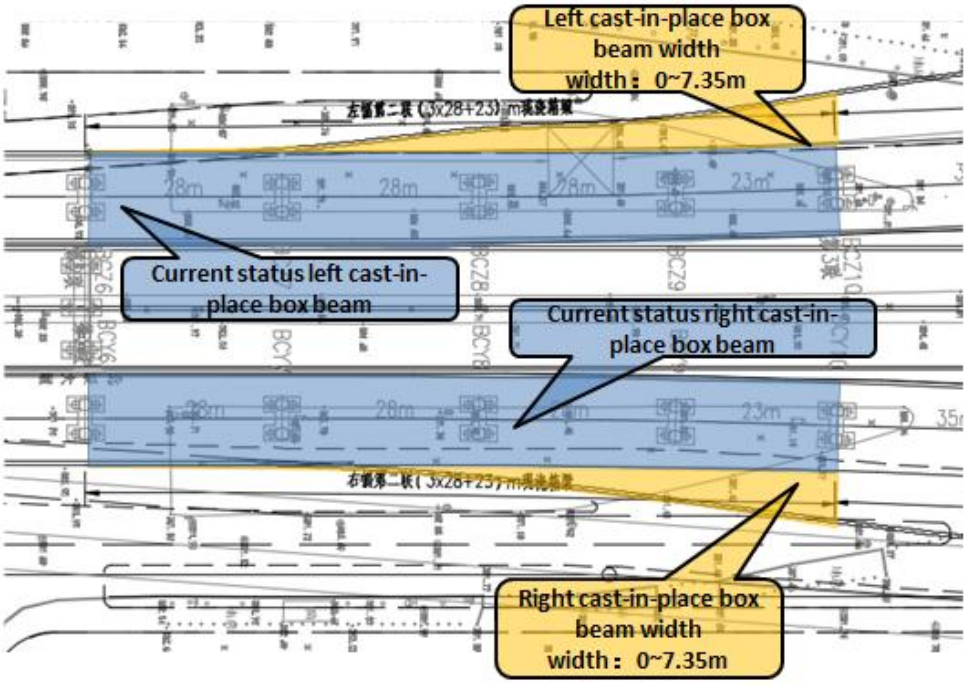
2 sets of cast-in-place beams of the main line wide bridge, 572.30m2;

Overpass wide-width diagram

2. Overview of the Width-Splitting Node Scheme for Concrete Bridges

2.1 Wide-size Plan

The span combination of the current concrete cast-in-place box girder is: (3x28+23)m. The total length of the bridge is 107m and the width of the bridge is 13m. According to the overall width requirements of the plan, the width of the cast-in-place concrete box beams is 0~7.35m in width.



Overall layout of the piezo

2.2 The Connection Form of the Bridge Width is Shown in the following Table

Connection Method	No Connection	Hinged Connection	Semi-Rigid Connection	Rigid Connection
Structure	Uses expansion joints or fillers to connect old and new structures	Connects old and new structures via dummy joint reinforcement to form a hinge	Connects via bridge decks	Connects via crossbeams or full-sections
Mechanical Behavior	No internal force transfer; no mutual influence between old	Transfers shear force but not bending moment;	Transfers both shear and partial bending moment	Transfers shear and bending moment

Connection Method	No Connection	Hinged Connection	Semi-Rigid Connection	Rigid Connection
	and new structures	minimal mutual influence		
Characteristics	Clear force transmission but prone to damage, requiring frequent maintenance or high cost	Clear force transmission; ignores interaction between old and new structures; continuous deck with good applicability but poor durability	Controllable uneven settlement impact; complex force transmission but ensures deck smoothness; lower connection difficulty	Significant uneven settlement impact; unclear force transmission but ensures deck smoothness; higher connection difficulty
Remarks	Applicable when widening width >5 m and the widened structure can independently bear loads	Requires control of deflection differences between old and new structures	Wet joints must use special concrete with rapid hardening, early strength, low shrinkage, micro-expansion, and good toughness/anti-cracking properties	Requires substructure connection to reduce uneven settlement between old and new structures

2.3 Factors to Consider when Applying a Concrete Beam width:

(1) The width-splitting plan must fully consider the impact of the width-splitting bridge on the current bridge structure safety.

(2) The width-pairing plan must fully consider the smoothness of the bridge deck and driving comfort.

(3) Landscape effect of wide-split scheme

(4) The impact of wide-width structure construction on current traffic

(5) Construction period of the width plan.

3. Design Ideas for Wide-size Solutions

(1) From the perspective of the impact on the current structure, it is not recommended to use a rigid connection width scheme for superstructure connections.

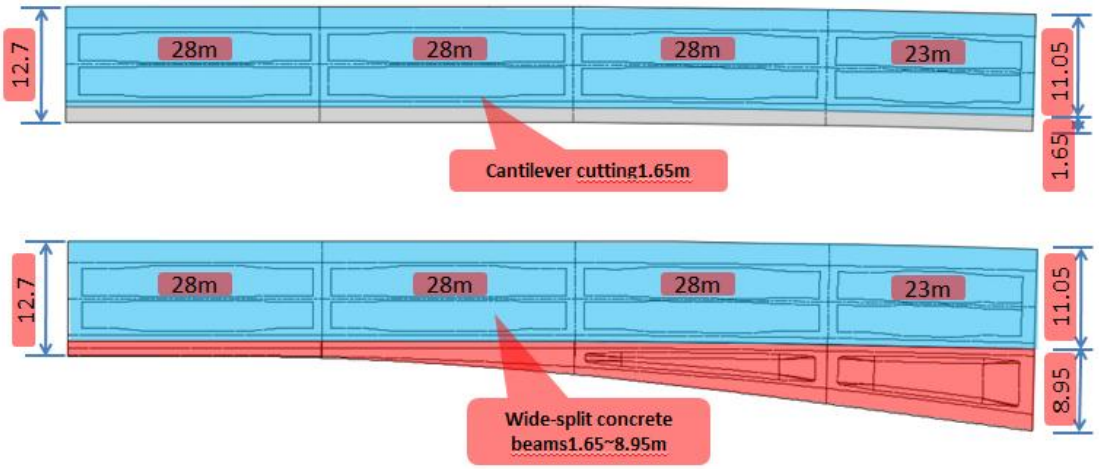
(2) From the perspective of driving comfort, it is not recommended to use a non-connection scheme with longitudinal construction joints in the upper structure connection.

(3) The upper structure connection scheme adopts two solutions: articulation and semi-rigid connection schemes

(4) From the perspective of landscape effect, the bridge deck adopts two solutions: structural widening and non-widening.

3.1 The Bridge Deck Is not Widened, the Superstructure Articulation Scheme

This plan focuses on landscape effects. Since the bridge deck is not widened, the cantilever of the current bridge must be cut to a sufficient width to arrange the wide-split bridge structure.



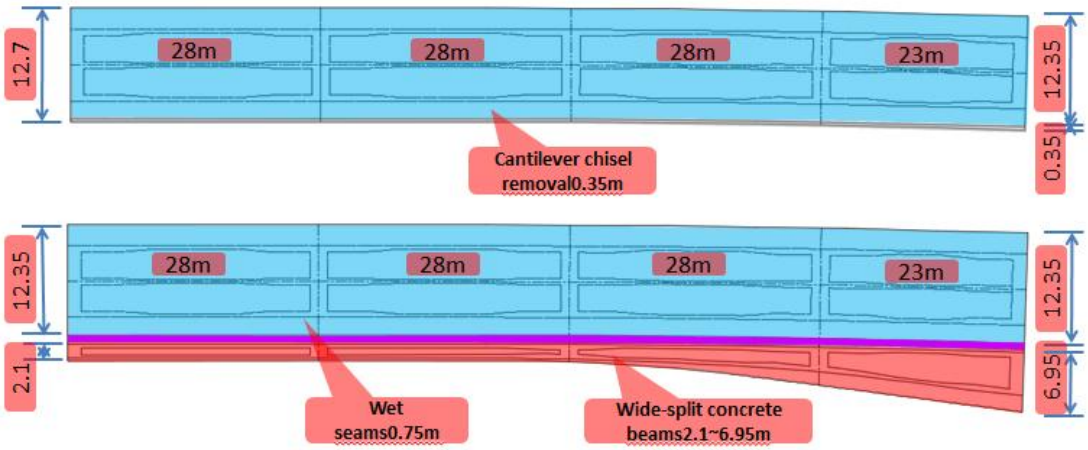
Plan one Floor Plan

If this plan uses semi-rigid connection, the current bridge cantilever must be cut first and then chiseled off a certain width. The leakage bridge deck steel bars are overlapped with the bridge deck steel bars on the wide-split bridge deck steel bars. The construction process is complicated, the construction period is long, and it has a great impact on traffic. Therefore, this plan adopts a hinged connection plan (Yuan & Gu, 2012).

The problem of deflection difference between new and old structures must be considered when using the articulation scheme. Therefore, the cantilever size of the wide bridge in this scheme must be basically the same as the cantilever size of the original structure.

3.2 Bridge Deck Widening, Semi-rigid Connection Solution for Superstructure

This plan focuses on the impact on the current bridge traffic during construction. The bridge deck is widened, and a new wide bridge is built outside the current bridge. The new and old bridge decks are connected by wet joints (Luo, 2017).



Plan 2 layout

Due to the widening of the bridge deck in this plan, the construction of the wide bridge will not affect the current bridge structure and vehicle traffic. After the construction of the wide-width concrete beam is completed, the current bridge guardrail will be cut to connect the new and old bridges.

Since the old bridge cantilever is basically not removed in this plan, the cantilever of the wide-width concrete beam is limited by the bridge width. Due to the large difference in the stiffness of the cantilever of the new and old bridges, the deflection difference between the new and old structures is large, and the articulated connection method is not suitable. Therefore, this solution adopts a semi-rigid connection scheme.

4. Conclusion

The comprehensive comparison of Plan 1 and Plan 2 is as follows:

Scheme	Scheme 1	Scheme 2
Description	Non-widened deck, hinged upper structure	Widened deck, semi-rigid upper structure
Driving Comfort	Good	Good
Durability	General	Good

Scheme	Scheme 1	Scheme 2
Construction Period	4 months	4 months
Traffic Impact	Significant; requires closing one lane throughout construction	Minor; only short-term closure needed for upper structure connection and auxiliary works
Landscape Effect	Good (non-widened deck)	Relatively poor (widened deck); can be enhanced via later landscape decoration
Comparison Conclusion	Not recommended	Recommended

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