Study on Bridge Industrialized Construction Simulation

Hongyan Tang 1, Xiuyan Wang 2, Jianchao Wang 3
1 Tianjin Urban Construction Design Institute Co., Ltd, Tianjin 300122
2 China Construction Sixth Engineering Bureau Corp., Ltd, Tianjin 300451
3 China Xiong'an Group Infrastructure Co., Ltd, Baoding, 071700

Correspondence: wangxiuyan01@cscec.com, Xiuyang Wang

Abstract. Large urban overpasses are important traffic nodes and control points of project construction. How to realize the rapid construction is always the focus of engineers. The industrialized construction of bridges has the advantages including less on-site work, shorter construction period and less impact on traffic, which has great significance for the construction of large urban overpass bridges. In this paper, Tianjin Outer Ring Road Jinlai interchange project is taken as an example to study the simulation of construction using the whole bridge prefabrication and field assembly. Compared with the traditional cast-in-place construction method, the on-site construction time of prefabrication in factory and field assembly of the whole bridge is shortened by 83%.

1. Introduction

The use of large urban overpass bridges is an important scheme to solve the problem of urban vehicle congestion and ensure smooth traffic, and an overpass is often a control node project. In recent years, a variety of new ideas and methods in civil engineering have been continuously developed, and bridge industrialized construction is one of them. This construction method has the advantages of faster speed, more environmental protection, less interference, more safety, and higher quality [1][2]. The industrialized construction method was adopted for the sea crossing bridges such as Donghai Bridge and Hong Kong-Zhuhai-Macao Bridge [3][4]. The prefabricated components need to be manufactured in factory and transported to the specified location for stitching, which greatly reduces the offshore operation time and the construction risk. However, the application of the method in large-scale urban interchange engineering is rare. Taking Tianjin Outer Ring Road Jinlai interchange project as an example, this paper studies the industrialized construction method applied in the large urban interchange project.

2. Engineering background

Tianjin Outer Ring Road Jinlai interchange bridge project includes outer ring road main line bridge, Jinlai road main line bridge and related ramp bridges (Figure 1a), with a total area of 67942m². The main line of the outer ring road is located on the third floor of the interchange, with a design width of 16.5m (Figure 1b); the main line of Jinlai road is located on the second floor of the interchange, with a design width of 12.75m; the design width of relevant ramps is 8m. The original design and construction scheme is cast-in-place prestressed concrete box girder structure, and the on-site construction steps mainly include: erection of support, support preloaded, formwork installation,
concrete pouring, prestressed tensioning and formwork removal\textsuperscript{[5]}. The total construction period is planned to take 18 months.

![Design sketch](image1) ![Typical cross section of original design (cm)](image2)

Figure 1. Jinlai Interchange Project

3. Disassembly and prefabrication of prefabricated members
Jinlai overpass bridge project adopts full prefabricated construction in factory, and the main construction difficulties include variable widths of the special-shaped bridges, the ramp curve bridges and the node connections between the structure members. The standard prefabricated members of the project include pile foundation, foundation, pier column, cap beam, abutment, precast small box girder, composite girder (precast bridge deck and steel girders), as shown in Figure 2. The types and amount of prefabricated members are summarized in Table 1.

![Double pipe vibrio-driven cast-in-place pile](image3) ![PHC pipe pile](image4) ![Precast foundation (main line bridges)](image5) ![Precast foundation (ramp bridges)](image6)

Figure 2. Prefabricated members

4. Transportation and construction simulation of substructure
The pile foundation adopts two types, including: conventional PHC precast pipe pile\textsuperscript{[6]} and cast-in-place double pipe vibro-sinking pile\textsuperscript{[7][8]} to adapt to the actual geological conditions. Considering the special shape and maximum weight of precast foundation (with a part of pier) and pier column, the 200t carrier is used for the transportation of foundation components. During the process of transportation, the support position and method of members should be set according to the designed lifting (cushion) point position to avoid damage. At the same time, the dirt should be prevented from entering the reserved holes of the member or polluting the reinforcement protruding from the end of the members, to prevent the reinforcements from being damaged or bent.
The solid pier columns of the substructure of the main line bridges (including the bridge with variable width and special-shaped section) are connected with fully grouted steel bar connecting sleeve (see Figure 3) [9][10]. The construction does not need to occupy the existing road space and has no effect on the road traffic.

Table 1. Statistics of prefabricated components.

| Position             | Members                      | Amount | Size (length) or weight |
|----------------------|------------------------------|--------|-------------------------|
| **Pile**             |                              |        |                         |
| PHC pipe pile (1.0m) | 440                          | 40m~50m|                         |
| double pipe vibro-driven pile (1.2m) | 290 | 30m~52m |                      |
| **Foundation**       |                              |        |                         |
| Pile cap with pier column | 94 | 50t~118t |                     |
| Segment of top pier | 48                            | 85t~116t|                       |
| **Substructure**     |                              |        |                         |
| main line bridges    |                              |        |                         |
| Pier column with foundation | 176 | 40t~62t |                      |
| Solid pier column | 80                             | 46t~57t |                      |
| **Ramp**             |                              |        |                         |
| Cap beam             | 69                            | 82t~111t|                      |
| **Abutment**         |                              |        |                         |
| Foundation           | 46                            | 70t~105t|                      |
| Column               | 16                            | 74t~115t|                      |
| **Superstructure**   |                              |        |                         |
| 30m-precast box girder |                            |        |                         |
| Interior girders     | 197                           | 72.6t  |                         |
| Outer girders        | 138                           | 96.9t  |                         |
| **Ramp**             |                              |        |                         |
| Precast bridge deck  | 3640                          | 0.8t~1.8t|                     |
| I-girder             | 525                           | 11.5t~16.4t |                   |
| Steel cross beams    | 7000                          | 0.3t   |                         |
| **Special shaped bridge with variable width** | | |            |
| Precast bridge deck  | 2820                          | 0.8t~1.8t|                     |
| I-girder             | 372                           | 9.2t~20.7t|                    |
| Steel cross beams    | 5245                          | 0.3t   |                         |
| **Retaining wall (height × length)** | | |            |
| 2m×5m                | 60                            | 28t    |                         |
| 4m×5m                | 90                            | 67t    |                         |
| 6m×5m                | 37                            | 83t    |                         |

Figure 3. Fully grouted steel bar connecting sleeve.
The hollow pier column (pier top section) of the substructure of ramp bridges are connected by self-locking vertical prestressed anchorage system [11][12]. The anchorage system is mainly composed of fixed end anchorage, tension end anchorage, cable body and embedded pipe. Compared with the vertical prestressed anchorage system used in cast-in-place bridge piers, this construction method using self-locking prestressed anchorage system is simple and quick, and the quality is easy to guarantee.

According to the external dimension and weight of the precast bent caps, 200t flat carrier is selected as the transport vehicle. The precast caps and the pier column are connected by full grouted steel bar connecting sleeve [9][10].

The maximum weight of foundation and abutment of the precast abutment is 114t, and 200t flat carrier is selected as transport vehicle. Between the abutment foundation and the abutment column, the form of reserved notch in the foundation and on-site pouring is adopted. The inner side of the notch is concave and convex shape, which can increase the connection strength between the cast-in-place section and the foundation, to realize the rapid construction of the connection between the abutment and the foundation.

5. Simulation of transportation and construction of superstructure

In order to realize the rapid construction, the connection of precast concrete girders is specially designed. The precast concrete girder consists of precast girders (C55) and cast-in-place concrete joints (T150), in which diamond-shape joint [13] is adopted. Diamond joint is an improvement to solve the smooth flat interface joint problem. The change of interface shape improves greatly the shear resistance of the interface, which can improve the response of the structures under shear. This type of joint has been widely used in engineering.

During the prefabrication process of precast deck, the protruded reinforcements are reserved at the joint position, and the reserved protruded reinforcements between two precast slabs is staggered and overlapped with UHPC poured to realize rapid construction.

The steel-concrete composite structure [14][15] is adopted in the ramps and bridges with varied width and special-shaped section in Jinlai interchange project. The steel-concrete composite girder bridge structure is divided into standard members which are easy to be fabricated in factory, including I-girder, concrete deck, steel cross beams. After prefabrication, the standard members are transported to the site and assembled. Two construction schemes are used for ramps and bridges with varied widths and special-shaped section, including on-site assembly standard members, and integral prefabrication and installation of single-span bridge.

On-site assembly of standard members is mainly based on the fabrication of standard members. I-girders, concrete deck and cross beams can be fabricated in factory, and be assembled on-site to realize the rapid construction. On-site assembly construction is simple and mature, which can improve the highway construction quality, increase the service life of structures, reduce the construction cost and maintenance cost, to effectively improve the economic benefits of enterprises and to speed up the development of highway construction.

Integral prefabrication and installation of single-span [16] is mainly suitable for concrete bridges. The dead weight of the concrete girder is large, and the traditional road transportation is not convenient, but professional equipment is required. The Self-Propelled Modular Transporter (SPMT) is usually used.

6. Comparison of construction cost and time

6.1. Construction cost

When cast-in-place construction scheme is adopted, the project cost is about 351 million RMB. If full prefabrication construction scheme is adopted, the project cost is about 386 million RMB after deducting the construction or reconstruction costs of the factory, the purchase cost of large-scale new
equipment (such as SPMT) and other amortization costs, which is 10% higher than that using the cast-in-place scheme.

Table 2. Comparison of construction cost

| Construction scheme | Serial number | Project name         | Quantity | Total price subtotal (Million RMB) | Total price (Billion RMB) |
|---------------------|---------------|----------------------|----------|-----------------------------------|--------------------------|
| **Cast in place**   | 1             | Bridge area          | 67942m²  | 344.55                            | 0.351                    |
|                     | 2             | Reinforced concrete retaining wall | 935m | 6.98 | 0.00 |
| **Prefabrication**  | 1             | Substructure         | 1.0m and 1.2m piles | 92.12 | 0.386 |
|                     |               |                      | Foundation and pier column | 460 pieces | 92.12 |
|                     |               |                      | Cap beam | 81 pieces | 92.12 |
|                     | 2             | Superstructure       | 30m precast small box girder | 253.44 | 0.386 |
|                     |               |                      | Steel-concrete composite beam | 34698m² | 253.44 |
|                     | 3             | Retaining wall       | 187 pieces | 12.36 | 0.00 |
|                     | 4             | Ancillary structure  | Waterproofing and asphalt concrete | 67942m² | 28.93 |

6.2. Construction time

The original construction scheme of Jinlai interchange project is cast-in-place box girder structure, and the construction time is planned to take 18 months. After the full prefabrication construction method is adopted, the planned on-site construction time is 3 months, and the construction time is shortened by 83%.

Different from ordinary roads, municipal roads are mostly located in the centre of cities with large vehicle flow and high frequency of use. Road construction will have a large negative impact on the normal traffic environment, causing road congestion and threatening traffic safety. Urban overpasses are important traffic nodes and control points of project duration. Construction time is often the top priority of current political engineering construction. The completion of the project ahead of schedule not only reduces the urban traffic congestion, but also saves the energy consumption and time cost for social vehicles and construction equipment, which brings immeasurable social and economic benefits.

7. Conclusions

The paper studies the simulation of construction with whole bridge prefabrication and on-site assembly. The main conclusions are summarized as follows.

1) Bridge industrialization construction using full prefabrication and on-site assembly can reduce the amount of on-site concrete pouring, reduce the construction occupation and construction time, and make the bridge construction more environmentally friendly, safer, higher quality and lower consumption.

2) Bridge industrialization construction greatly reduces the construction time, improves the engineering quality, and promotes the progress of road and bridge industry, which responds to the strategic requirements of national energy-saving, environmental protection, and green building.

3) Bridge industrialization construction can speed up the construction progress and minimize the impact of construction on urban traffic and residents' lives, which is one of the important development directions of large-scale urban interchange construction.
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