# Research on Integrated Bridge Builder Based on Mobile Factory

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**Abstract.** The construction of cast-in-place beam with mobile formwork support has been widely used because of its strong environmental adaptability and good economy. But it also has the disadvantages of poor construction condition and low automation degree. To solve this problem, based on a city viaduct project, the research about an integrated bridge-building based on mobile factory is carried out. It clears the integrated closed workshop, steel parts manufacturing and transportation installation, concrete automatic distribution and maintenance and automatic walking and other functions in one assembly line process. An integrated bridge-building structure suitable for the construction of ultra-wide cast-in-place beams is studied. It integrates many functional modules and can ensure the integrity and stability of the structure when crossing the span. The finite element analysis software is used to analyze the whole process of the bridge construction machine, and the structural safety under unfavourable working conditions is determined.

**Keywords:** mobile factory; cast-in-place beam; integrated construction; bridge builder; finite element analysis.

## 1 Introduction

After years of development and exploration of bridge construction technology at home and abroad, new construction methods have been produced. In recent years, relevant researchers continue to deepen the research and exploration of mobile factory cast-in-place beam construction technology, and enrich and improve the integrated in-situ manufacturing process of cast-in-place beam. The mobile factory support system is suitable for continuous beam bridge with span of 25-65m or simply supported beam bridge. It is a large-scale construction equipment for in-situ placement of main beam of PC continuous box beam bridge with equal section. The method of constructing continuous box beam bridge with moving factory technique is called mobile factory method. The method has the characteristics of fast construction speed, strong crossing


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ability, strong environmental adaptability, etc., and it is more economical for the bridge construction with more spans.

At present, there are many kinds of mobile factory structures for bridge construction in China (above and below), and the uses and functions are also different (such as for pouring continuous beams and simply supported beams). The current research direction tends to be towards the industrialization, prefabrication, and standardization of mobile factory construction. Mobile factory construction is a method to transport the standard production line of the factory to the site by mobile vehicles for product manufacturing. Pipelining and efficient production is the most significant feature of mobile factory technology. Mobile factory equipment is also used more and more in cast-in-place concrete structures. In terms of cast-in-place bridge technology, in view of the difficulties in the maintenance of the internal formwork of the cast-in-place simply supported box girder constructed by the mobile formwork method and the difficulty in the integral hoisting of the reinforcement into the formwork, it is proposed to change the beam reinforcement binding construction from sequential operation to parallel operation, and use the gantry crane[1] to hoist into the formwork as a whole, which improves the beam making efficiency. Based on the concept of factory construction, a mobile formwork factory[2] was built to construct the continuous beam structure. Using new ideas and new technology, two I-beams with a height of 400mm are superimposed on the box girder corresponding to the position of the web, and bolt connection is adopted to ensure the stiffness of the main beam, which effectively reduces the weight of the beam body and the blocked air area. Through the manual operation and hydraulic cylinder, the truss is turned inside and outside during mold opening, and the bottom mold is turned up and down, which optimizes the mold opening mode. At the same time, the factory is optimized so that the side form can translate on the bottom formwork, so as to adapt to the curve of cast-in-place beam. In this paper, the innovation of bridge factory construction and standardized operation has been realized, which has promoted the development of mechanization, automation and standardization of large bridge construction, and effectively accelerated the construction progress.

It can be seen from the investigation that the current construction research of mobile factory engineering method mainly focuses on the standardization of reinforcement binding, the automation of factory opening and closing, and the adaptability of mobile factory[3,4]. There are still few researches on the industrial construction of cast-in-place beams based on steel parts. Based on the construction of ultra-wide cast-in-place box beam of a city viaduct, this paper will carry out the research on mobile factory technology based on movable formwork.

## 2 Project overview and overall process

The route of the third phase of an urban outer ring highway starts from K77+350, the design end point of the second phase of the outer ring highway, and is collinear with the plane of Julong Road in the form of viaduct, from the starting point to the southeast direction to the planned Linhui Road. Viaduct upper structure cross section forms for single box 3 rooms, bridge deck width 32.5 m, bottom width 22.3 m, 2 m high beam, after the completion of the bidirectional 6 lane. The section layout of the viaduct is shown in Figure 1.

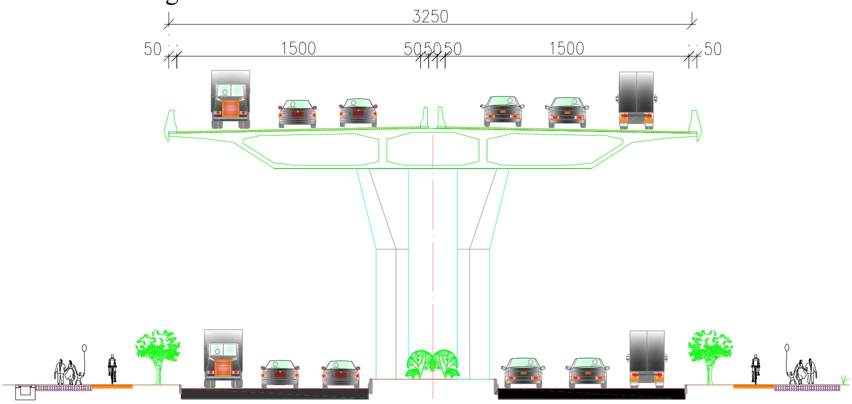



**Fig. 1.** Section layout of a city viaduct

Since the bridge under the project is the main road of the city, with large traffic flow and busy traffic, the road cannot be closed during the construction period, and there is no prerequisite for large-area erection of supports, so the integrated bridge building technology based on mobile factory is one of the main construction methods considered in this project. When the bridge builder crosses, the formwork beam needs to be moved out to avoid the bridge pier. Due to the large width of the beam, the stability of the overall structure is easy to cause in the opening and closing process of the beam, which is more difficult[5,6].

In the traditional cast-in-place process, the binding of reinforcement requires a lot of manpower and the construction period is long. It is an effective way to adopt the construction method of reinforced part quality, which can realize the synchronous operation of reinforcement production and concrete pouring. When this technology is applied to this project, there are some problems such as lifting and transportation difficulties caused by the excessively wide and overweight steel frame. The project location has a long rainy season, high temperature weather in summer, and heavy rain, thunderstorms and typhoons. The adverse climatic conditions pose a severe challenge to the in-situ operation of the project.

According to the characteristics of this project, an integrated construction method of cast-in-place box girder based on mobile factory is proposed. The core idea is to introduce the concept of modern mobile factory in the construction of cast-in-place box beams, and develop a production line integrating the functions of enclosed workshop, reinforcement parts manufacturing and transportation installation, automatic concrete distribution and maintenance, and automatic walking. The overall layout of the mobile factory is shown in Figure 2.

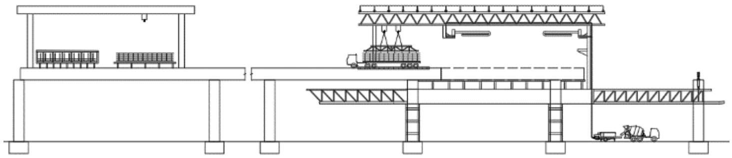


**Fig. 2.** Mobile factory general layout

The overall construction technology is: When the mobile factory walks to the N span, the reinforcement parts that have been made in advance in the starting span are lifted in whole or in pieces, and the reinforcement parts of the N span and the prestressed pipeline are quickly connected. While making the N+1 span reinforcement parts, the N span concrete is poured and cured. After the strength of the concrete reaches the design requirements, the prestress is tensioned, and then the mobile factory demits itself to the N+1 span. Repeat the above steps to complete the construction of all cast-in-place box beams span by span. When pouring the box girder, the concrete conveying equipment is located directly under the front end of the bridge builder, which will not affect the traffic under the bridge[7].

The overall process flow diagram of the cast-in-place box girder mobile factory is shown in Figure 3.

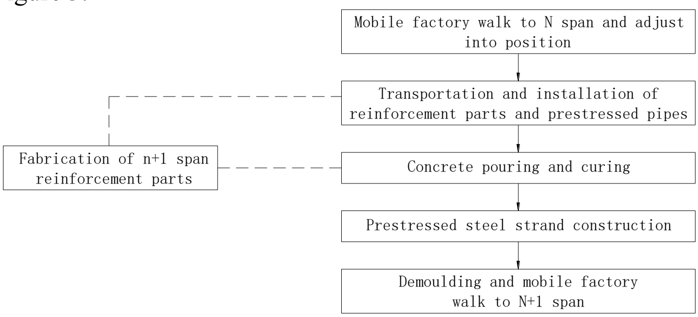



**Fig. 3.** Mobile factory overall construction process

The integrated construction method of cast-in-place box girder based on mobile factory has the following advantages:

1) The construction method of cast-in-place box girder reinforcement parts can realize the simultaneous construction of concrete pouring and reinforcement binding, thus forming multiple working surfaces and realizing flow operation; In addition, using the site on the beam as a rebar processing workshop eliminates the need to establish a separate rebar processing plant, which improves the utilization rate of the site.

2）The mobile factory of cast-in-place box girder integrates the functions of formwork crossing, formwork adjustment, integral lifting and installation of reinforcement, automatic concrete pouring and maintenance, closed construction, etc. It has a high degree of automation, mechanization and strong function expansion, and can realize the factory construction of cast-in-place box girder.

3）The integrated construction method of cast-in-place box girder based on mobile factory has clear process and small labor demand, which is conducive to further shortening the construction period, improving the construction quality of cast-in-place box girder, reducing labor operation intensity and ensuring operation safety, and has significant social and economic effects.

## 3 Composition of integrated bridge builder

The integrated bridge builder is a new type of cast-in-place box girder construction equipment based on the concept of mobile factory, which integrates the functions of reinforcement component hoisting, automatic concrete pouring, maintenance and automatic shifting. It is mainly composed of bearing system, formwork system, hanger system, support bracket, propulsion system and mobile plant. The composition of integrated bridge builder is shown in Figure 4.

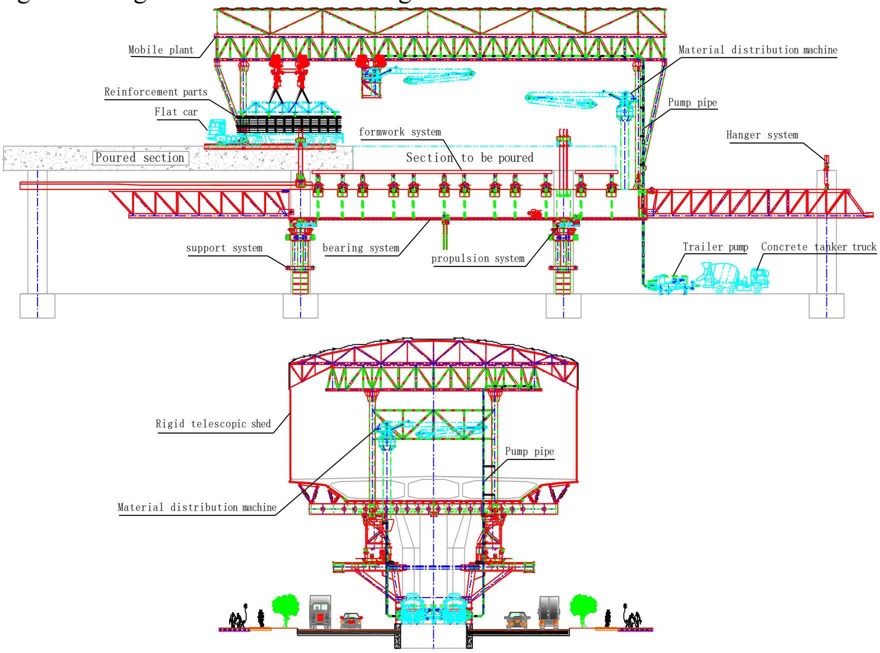



**Fig. 4.** Composition of integrated bridge builder

### 3.1 Bearing system

The bearing system is composed of two groups of main beams and nose beams. The box girder is arranged on both sides of the pier, which is the main bearing structure. The truss nose beam is installed at the front and rear ends of the main beam[8].

The main beam is a box-type structure made of welded steel plates. Considering the high local torsion resistance requirement in the process of opening and closing mold, K-type support is installed inside. The segments are connected by 10.9S friction type high-strength bolts. A guide rail is provided at the bottom of the main beam web, and the guide rail slides on the trolley slide when the bridge builder pushes through the span. At the bottom of the main beam is set near the center guide for longitudinal launching. At the corresponding front and rear brackets, a reinforced bracket is welded on the inner web of the main beam, and the bracket is lifted by a vertical jack to achieve the lifting of the mobile formwork. In order to adjust the horizontal angle of the main beam and the nose beam, the front and rear ends of the main beam are welded with hinged joints for connecting the nose beam. The top of the rear nose beam is connected with a walking track, which is the walking track of the rear walking trolley and is used for the propulsion of the bridge builder. The rear nose beam shall be reset after considering that the rear traveling trolley crosses the span, and the length shall extend to the position of the previous pier body. The bearing system structure is shown in Figure 5.

**Fig. 5.** Bearing system structure

### 3.2 Formwork system

The formwork system consists of formwork beam, external formwork and opening and closing cylinder. The external formwork is fixed on the formwork beam, and the line shape of the formwork is adjusted by an adjustable screw on the beam. During pier crossing, the two groups of formwork beams drive the external formwork to separate from the main beam to both sides. Considering that the main beam is an ultra-wide structural box beam, in order to maintain the overall structural stability of the bridge builder, the rear formwork beams shall be closed immediately after the completion of the crossing, and the front two groups of formwork beams shall be opened again, and the crossing shall be carried out in turn until the bridge builder moves to the next construction area as a whole. Because only part of the formwork is opened and closed during the crossing, the two main beams are always connected as a whole, which ensures the structural stability during the crossing, and greatly improves the safety compared with the conventional main beam separation type crossing. The status of integrated bridge builder during crossing is shown in Figure 6.

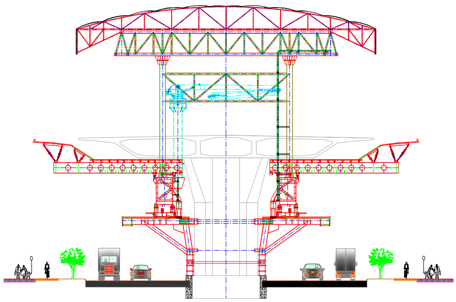


**Fig. 6.** Mold opening status of integrated bridge builder during crossing

### 3.3 Hanger system

The hanger system is composed of front hanger, middle hanger and rear hanger, which is used to realize the inversion of the brackets in the suspension load system and the displacement of the bridge builder. The front hanger is in front of the nose truss and connected to the front nose bridge. When transporting the bracket, the front hanger is supported in front of the nose bridge. The middle hanger is an anchor box structure. Its main functions are as follows: first, it is installed in front of the rear pier and connected with the main beam with finish rolled threaded reinforcement during pouring to reduce the lower deflection of the main beam; Second, when transporting the bracket, it is installed behind the front pier to suspend the whole bridge builder together with the rear hanger to provide support for the transportation bracket. The function of the rear hanger is similar to that of the middle hanger. When transporting the bracket, the bridge builder is suspended together with the middle hanger through the rear traveling trolley. When walking, the rear walking trolley hung under the rear hanger and the front pier bracket together support the bridge builder to glide into place. The middle hanger and rear hanger are transported by traveling crane in the mobile plant.

### 3.4 Support and propulsion systems

The role of the bracket is to transfer the load from the main beam to the pier. The support brackets are installed on both sides of the pier body and are composed of triangular brackets and steel columns supported on the pile cap. It is supported and fixed by prestressed reinforcement and pier shaft. The propelling trolley is the driving system of the bridge builder. It is installed on the bracket system and can move across the bridge by relying on the transverse cylinder. At the same time, it can move on the main beam by relying on its own roller. And it can use the propulsion cylinder to push the bearing system forward step by step. The support and propulsion systems are shown in Figure 7.

**Fig. 7.** Support and propulsion systems

### 3.5 Mobile plant

The mobile plant is composed of main truss, crane, rigid telescopic shed, distribution system and maintenance system. The front legs of the main truss are supported on the four-fluorine slide at the front end of the main beam and fixed with a limiting device to ensure that the legs have a certain space to adapt to the movement during the walking process and the construction state of the circular curve section. The rear legs are supported on the bridge floor under construction, supported by jacks with mechanical self-locking function during beam making. When walking, it falls on the track of the bridge deck propulsion system and moves forward synchronously with the propulsion cylinder on the propulsion trolley. The crane is installed on the truss longitudinal beam and is used for the hoisting of reinforcement components and other structures. It can move vertically and horizontally to achieve full coverage of the segments to be poured. The distribution system is composed of a distribution machine and a fixed pump pipe[9]. The two distribution machines are located at the front end of the mobile crane and the main beam to cover the whole pouring area. The pump pipes are arranged along the longitudinal beam of the mobile plant from the lower end of the main beam. The construction can be started when the pump pipe is connected with the trailer pump during pouring. The rigid telescopic shed covers all the top and sides of the mobile plant to form a workshop like working space and effectively improve the box girder construction environment. In case of strong wind, the ceiling can be retracted to reduce the windward area and protect the plant structure from damage by strong wind.

When the bridge builder is in place, complete the accurate adjustment of the formwork, use the crane of the mobile plant to hoist the reinforcement parts, and install the prestressed pipes and reinforcement joints.

After the reinforcement construction is completed, connect the drag pump pipe in front of the pier body and start the concrete pouring of the section to be poured. Then, remove the pump pipe connected to the ground for concrete curing. During concrete curing, the top and sides of the telescopic ceiling are all closed, providing a closed curing space for the main beam. At the same time, the spray system is used for aerosol spraying. When the concrete strength meets the design requirements, use the front and rear brackets and the jack on the rear leg of the mobile plant to lower the bridge builder by 200mm, complete the demoulding, and move to the next span. The mobile factory is shown in Figure 8.

**(a).** Opening status of rigid telescopic shed **(b).** Closing status of rigid telescopic shed

**Fig. 8.** Mobile factory

# 4 Simulation analysis

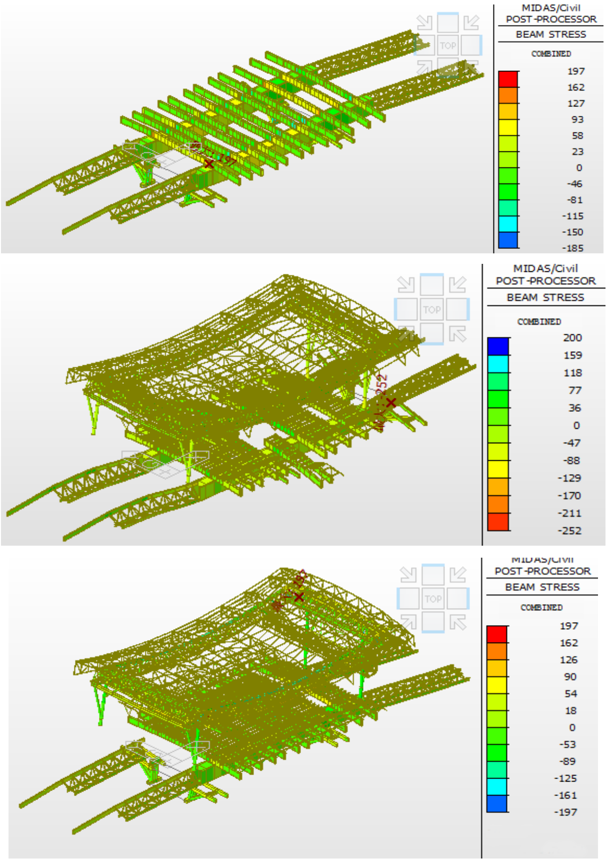
The structural stress state of the integrated bridge builder varies greatly under different construction conditions[10]. It is necessary to analyze the whole construction process, determine the most unfavourable stress condition, and verify the structural strength and stability under the corresponding conditions, so as to ensure the safety of the bridge builder. Midas Civil finite element software is used to simulate the structure of the bridge builder. The material property is an ideal elastic-plastic constitutive model. During the modeling process, the structure is simplified accordingly. The guardrail, formwork, stiffener and other ancillary structures are loaded on each node and element with distributed mass, and the connection and fulcrum of each component are simplified as common node or elastic connection. According to the characteristics of the box girder structure, the concrete load, formwork load, crowd construction load and wind load are respectively loaded on each part of the bridge builder, among which the concrete load is 15000kN, the formwork load is 1200kN, the crowd construction load is 1.0kN/m$^2$, and the wind load is 0.26kN/m$^2$. The most unfavourable stress conditions at each stage of construction are as follows:

(1) Standard segment pouring condition. The standard 31.5m segment is poured, and the concrete pouring is completed (the concrete weight is 1500t), but the initial setting is not completed.

(2) Walking condition of bridge builder. Supported by the rear traveling trolley and bracket, open two groups of cross beam formworks to pass the pier.

(3) Hoisting condition of reinforcement parts. After the bridge builder moves in place, it is fixed, and the 40t reinforcement parts are hoisted by the crane in the mobile plant to move to the middle of the span.

Stress nephograms of bridge builder under different working conditions are shown in Figure 9.




**(a).** Stress nephogram of bridge builder under standard segment pouring condition

**(b).** Stress nephogram of bridge builder under walking condition

**(c).** Stress nephogram of bridge builder under hoisting condition of reinforcement parts condition

**Fig. 9.** Stress nephograms of bridge builder under different working conditions

The calculation results of each working condition of bridge builder obtained through finite element analysis are summarized in Table 1:

**Table 1.** Summary of calculation results under various working conditions

| Working condition | Stress (MPa) |
|---|---|
| 1 | 197 |
| 2 | 252 |
| 3 | 197 |

The most unfavorable working condition of the bridge builder is the walking condition. It can be seen from Figure 9(b) that the maximum stress of the bridge builder is 252 MPa, which occurs at the web member of the front nose beam. It can be seen from the calculation that under standard segment pouring condition, the maximum stress of bridge builder is 197MPa, which appears at the main beam position; The maximum stress of the bridge builder under hoisting condition of reinforcement parts is 197 MPa, which appears at the top chord of the longitudinal beam of the mobile plant. The results show that the stress in the whole working process of the bridge builder is less than the strength design value of 295 MPa, and the strength and stiffness meet the stress requirements[11].

## 5 Conclusion

The integrated bridge builder based on mobile factory adopts the integrated and industrial design concept, and the construction of cast-in-place box beams has the characteristics of relatively fixed construction procedures, convenient installation of steel parts, high degree of pouring automation, good concrete maintenance environment, low labor intensity of workers, and no need for a lot of basic treatment work before construction. The construction process does not affect the traffic under the bridge. Factory construction conditions greatly improve the working environment of workers and concrete maintenance conditions, improve the quality of construction. It is suitable for the construction of super wide cast-in-place beam, especially for the construction of urban viaduct, and has high popularization and application value.

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