Research on Key Technology of Rapid Integrated Construction of Fully Prefabricated Rigid Frame Bridge

Chao Yuan, Feng Li, Min Wang, and Fei Tian

Abstract Based on the reconstruction and expansion project of an expressway, a set of rapid construction technology for integrated erection of fully prefabricated rigid frame bridges is proposed, which solves the problems of unmatched work efficiency of each working face in the conventional integrated bridge erectors and long construction period of traditional suspension assembly technology. This method realizes the rapid construction of this type of bridges in highly urbanized areas. In this method, a new bridge girder integrated erection machine is used to synchronously install precast segmental beams, pier top blocks and precast pier column. At the same time, precast segmental beams near the middle pier are assembled by conventional cantilever assembly method, and the installation method of the precast segmental beams near the transition pier is optimized from the half span suspension assembly method to the cantilever assembly method by temporarily fixing the pier top block and arranging temporary prestressed tendons. This new integrated construction method improves the construction efficiency from 39.5d/unit to 32d/unit, and reduces the interference to traffic and environment.

Keywords Assembled Bridge · Rigid Frame System · Integrated Construction · Full Cantilever Assembly Technology

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1 Introduction

At present, the construction of concrete bridges in China is still dominated by cast-in-situ technology, which has many disadvantages such as great environmental impact, long construction period, and not guaranteed construction quality. For this reason, the superiority of prefabricated bridges are more and more prominent in municipal projects with strict environmental regulations, high traffic safety demand and high construction efficiency demand [1, 2]. With the active promotion of the policy of developing prefabricated structures in China and the mature development of prefabricated bridge structures, prefabricated bridges are gradually widely used in the field of municipal engineering. In many projects, full prefabrication and assembly of piers, bent caps and main beams have been achieved, such as Jiamin Elevated Road and S7 Highway Project in Shanghai, Chengpeng Elevated Road in Chengdu, Xiangfu Road in Changsha, Fengxiang Road Rapid Reconstruction in Wuxi, etc. [3–5].

In the currently completed prefabricated bridge projects, the precast piers and bent caps are mostly installed by crawler cranes. This method has the defects of scattered working surfaces, large temporary land occupation for construction, and large traffic interference under the bridge, which cannot give full play to the advantages of prefabricated bridges. Therefore, the integrated installation method and equipment have started to be popularized and applied in domestic and foreign prefabricated bridge projects [6, 7]. The coastal viaduct project in Cartagena, Colombia needs to cross the environmental protection zone. In order to reduce environmental interference, the project adopts a fully prefabricated prefabricated bridge structure from pile foundation to main beam, and uses a cantilever integrated bridge erection machine to install all prefabricated components, realizing the integrated flow installation of fully prefabricated prefabricated bridges. In addition, there is no need to set up access roads along the project, which realizes zero interference to the environment during the construction period.. Subsequently, the Washington Elevations in the United States adopted the same structural form and construction technology. In the Yangang East Flyover Project in Shenzhen, China, in order to reduce the interference to the surrounding road traffic during the construction process, a new type of bridge girder integrated erection machine with landing front leg is used to erect concrete segmental beams and precast pier columns, and prefabricated components are transported and delivered on the completed bridge deck to the tail of the bridge erection machine, and the temporary land occupation for construction is small, and the traffic recovery is fast [8].

The integrated erection method allocates different types of prefabricated components to each working face of the bridge girder integrated erection machine for installation, and matches the installation efficiency of each working face, thus realizing the flow process of the entire installation. However, for rigid frame bridges with pier-beam consolidation, the installation of pier columns and the consolidation of pier and beams take a long time (10 days in total), which is lower than the installation efficiency of main beams (7 days). Therefore, it is difficult to achieve the efficiency matching of each working face by using conventional bridge girder integrated erection machines.

In view of the above problems, taking the reconstruction and expansion project of an expressway as the background, the conventional bridge girder integrated erection machine is upgraded to bridge girder integrated erection machines with dual landing front leg, and a rapid construction technology based on this new integrated bridge erection machine is proposed to realize the integrated flow construction of fabricated rigid frame bridge. Further more, the integrated installation efficiency was further improved by optimizing the conventional cantilever assembly method of segmental beam to the full cantilever assembly method.

2 Engineering Overview

The full rigid frame system is adopted for the main bridge of an expressway extension project, that is, the bearing less system with pier-beam consolidated is adopted for the middle pier and the transition pier. The span layout of this bridge is 45 m + 2 × 50 m + 45 m, as shown in Fig. 1.

The bridge is a fully prefabricated structure. The superstructure is single-box double-cell segment prefabricated box girder with a width of 20 m, which is erected by cantilever assembly method, as shown in Fig. 2. The middle pier and transition pier of the substructure are prefabricated curved column piers. Along the bridge, the middle pier is single column pier, and the transition pier is double column pier, as shown in Figs. 3 and 4

Most sections of the project are located in hills and water source protection areas. It is difficult to transport and deliver prefabricated components under the bridge. Therefore, prefabricated components need to be transported on the bridge deck and delivered from the tail of the bridge girder erection machine. Considering the construction conditions and structural characteristics of the supporting project, the integrated erection method is a reasonable process to realize the rapid construction of the project.

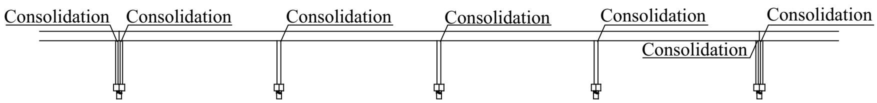
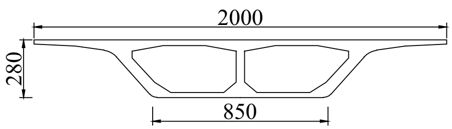


Fig. 1 Layout of full rigid frame bridge

Fig. 2 Sectional view of precast segmental box girder



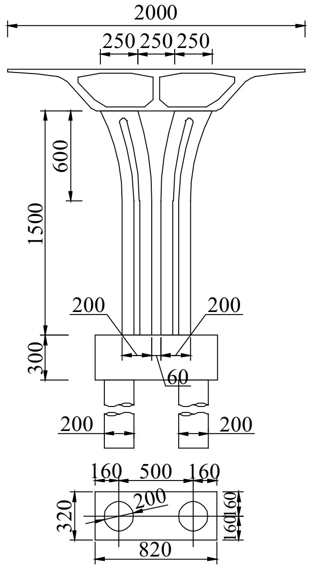


Fig. 3 Structural diagram of middle pier

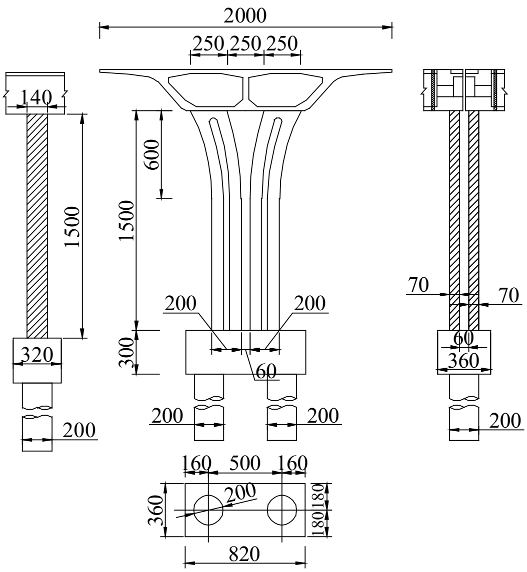


Fig. 4 Structural diagram of middle pie

3 Rapid Integrated Construction Method

3.1 New Bridge Girder Integrated Erection Machine

The conventional bridge girder integrated erection machine consists of three spans. The front span is used to install the pier column and pier top block, and the middle span is used to install the main beam, and the tail span is used to lift the components, as shown in Fig. 5. The installation efficiency of each working face of the bridge girder erection machine is matched to realize the integrated flow construction. However, for the fabricated rigid frame bridge with pier-beam consolidation, the installation of pier column takes 3 days, and the consolidation of pier and beam takes 7 days, which takes 10 days in total, lower than the installation efficiency of main beam (7 days). Therefore, if the conventional integrated bridge erection machine is used, it is difficult to match the installation efficiency of the front span and the middle span, which will affect the efficiency of the construction.

In order to solve the above problems, it is considered to separate the working face of pier column and pier top block, and the bridge girder integrated erection machine with double landing front legs is proposed, as shown in Fig. 6. The main beam of the bridge girder erection machine adopts a double triangular truss structure, which is arranged from left to right in the order of component lifting section, main beam installation section, pier top block installation section and pier shaft installation section. The outrigger structure consists of 1# front leg, 2# front leg, 1# middle leg, 2# middle leg and the rear leg. During construction, the front leg is supported on the corbel, and the corbel structure is temporarily anchored to the cushion cap. The front leg of the bridge girder erection machine is equipped with a hydraulic pin system, which can adjust the height and fold. The front and rear lifting crane can rotate 360 degrees. The front lifting crane is specially used for the installation of pier column and pier top block, and the rear lifting crane is specially used for the installation of main beam.

Compared with the conventional bridge girder integrated erection machine, the supporting structure of the new bridge girder erection machine has an additional

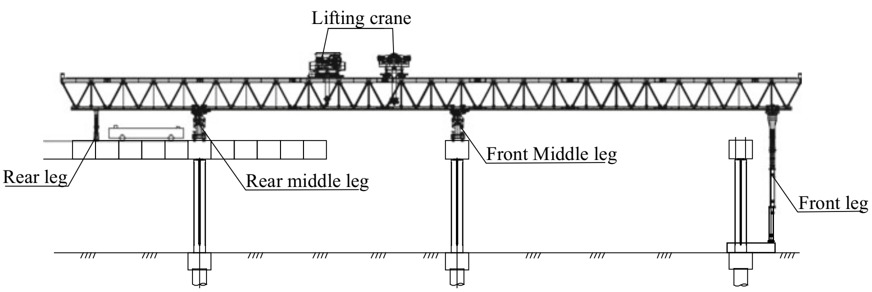


Fig. 5 Schematic diagram of common integrated bridge erecting machine

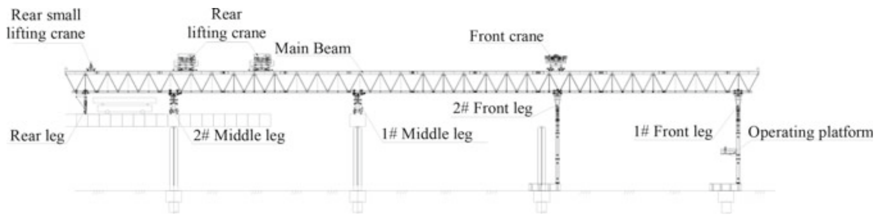


Fig. 6 Schematic diagram of new integrated bridge erecting machine

landing front leg. This additional span of bridge girder erection machine is used to erect the pier column of the previous span of the bridge, so as to separate the working face of pier column and pier top block, thus solving the problem of mismatched work efficiency.

3.2 *Full Cantilever Assembly Method of T-Frame of Transition Pier*

During the erection of the main beam of the rigid frame bridge, the segmental beam near the middle pier is generally installed by conventional cantilever assembly method, while the segmental beam near the transition pier is usually installed by half span suspension assembly method, which means that after the completion of the T-frame of the middle pier, the half span of the transition pier is installed by overall suspension, and then the bridge is completed after tensioning the prestress, as shown in Fig. 7. This construction method is the most widely used and mature construction method in balanced cantilever construction in China [9, 10]. However, the half span suspension assembly method for the side span of the transition pier will significantly increase the construction period. At the same time, this method has higher requirements on the lifting weight of the bridge girder erection machine.

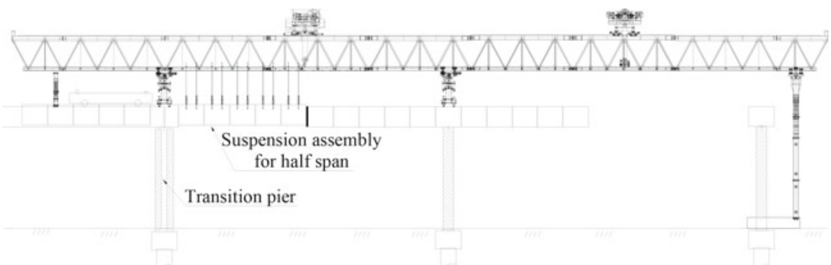


Fig. 7 Schematic diagram of integral suspension assembly for half span of side span at transition pier

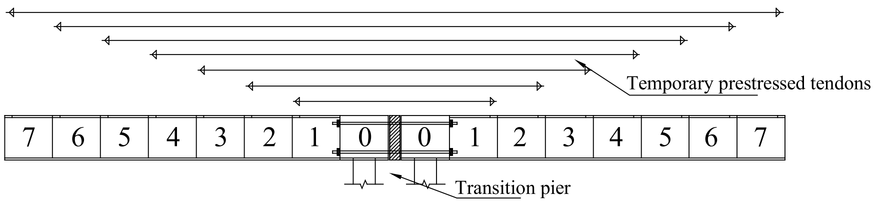


Fig. 8 Schematic diagram of T-structure formation of transition pier

In order to further improve the installation efficiency of segmental beam by using cantilever assembly method, a full cantilever assembly method is proposed to realize the cantilever assembly of segmental beam near the transition pier. In this method, the pier top block is temporarily fixed, and the cantilever assembled side span is formed by arranging temporary prestressed tendons, as shown in Fig. 8; When the side span is closed and the permanent prestress is tensioned, the temporary prestress and temporary fixation can be removed and the system transformation can be completed. This construction method can realize the full cantilever construction of rigid frame bridge and effectively shorten the construction period.

3.2.1 Temporary Fixation of Pier Top Block of the Transition Pier.

In order to ensure that the segmental beam near the transition pier form a T-frame structure and then adopt the cantilever assembly method, the pier top block of the transition pier shall be temporarily fixed. This pier top block is a prefabricated shell structure. Only one part of this pier top block is consolidated with the pier top, and the other part is suspended from the pier and supported on the bracket installed on the top of the transition pier. Cushion blocks shall be set in the intersection joints of transition piers. In order to facilitate removal in the future, hardwood blocks or steel plates that meeting the strength requirements can be filled in the intersection joints. At the same time, in order to reserve a certain amount of compressive stress at the joint after the installation of the pier top block, the fining twisted steel bar should be tensioned at the diaphragm of the transition pier. The details of temporary fixation is shown in Fig. 9.

3.2.2 Layout of Temporary Prestressed Tendons of T-Frame of the Transition Pier

The first type is the form of the top plate being grooved. In the process of cantilever assembly, the temporary prestressed tendons can be arranged in a straight line. The temporary prestressed tendons shall be arranged within the thickness range of the top plate according to the specification, and temporary prestressed ducts shall be reserved during the prefabrication of segmental beams. At the same time, reserved slots shall

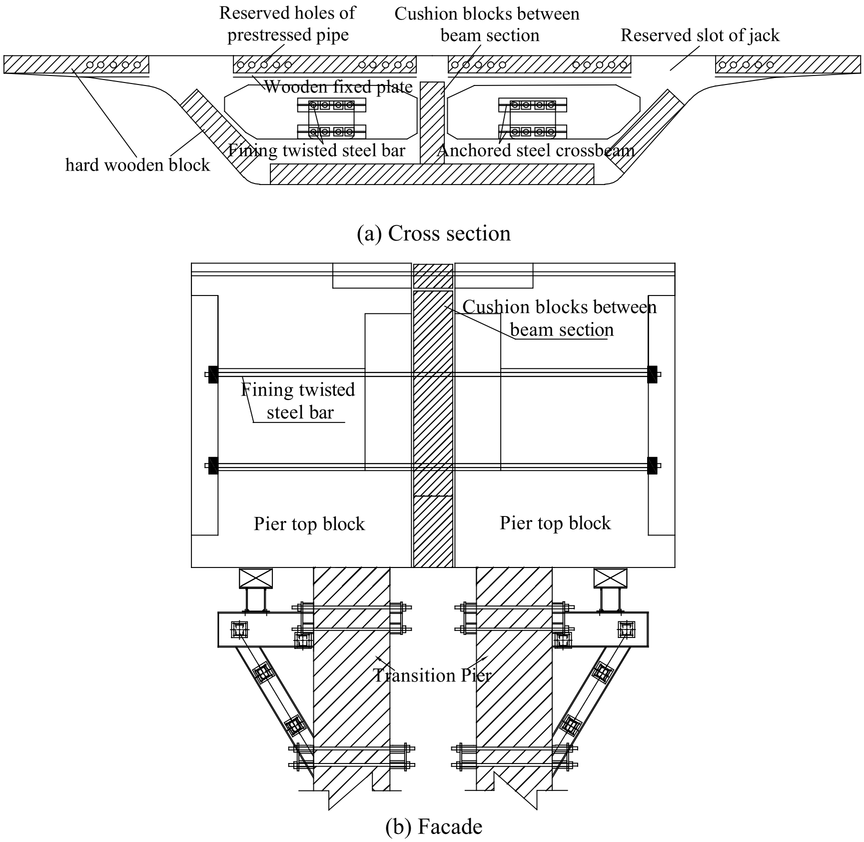


Fig. 9 Temporary anchoring measures for top block of transition pier

be set within a certain length range at the back end of the top plate to leave space for anchoring the temporary prestressed tendons and facilitate subsequent releasing and removal of the temporary prestressed tendons. Since the elongation of the prestressed tendon after tensioning is 30 cm, in order to facilitate extension of connector and releasing of prestressed tendons, the longitudinal size of the reserved slot should be greater than the length of the releasing of prestressed tendons, so it is advisable to reserve more than 50 cm. The structure and process are shown in Fig. 10.

The second type is the Form of tooth block. The anchorage end of the temporary prestressed tendon can also adopt form of tooth block, as shown in Fig. 11. At this time, the tensioning and removal operations are carried out inside the box room, and the temporary structure increases the self weight of the segment beam to a certain extent.

When the form of tooth block is adopted, the prefabricated members need to add reinforcement of anchor block and formwork of anchor block, which will increase the process. When the form of the top plate being grooved is adopted, there is no

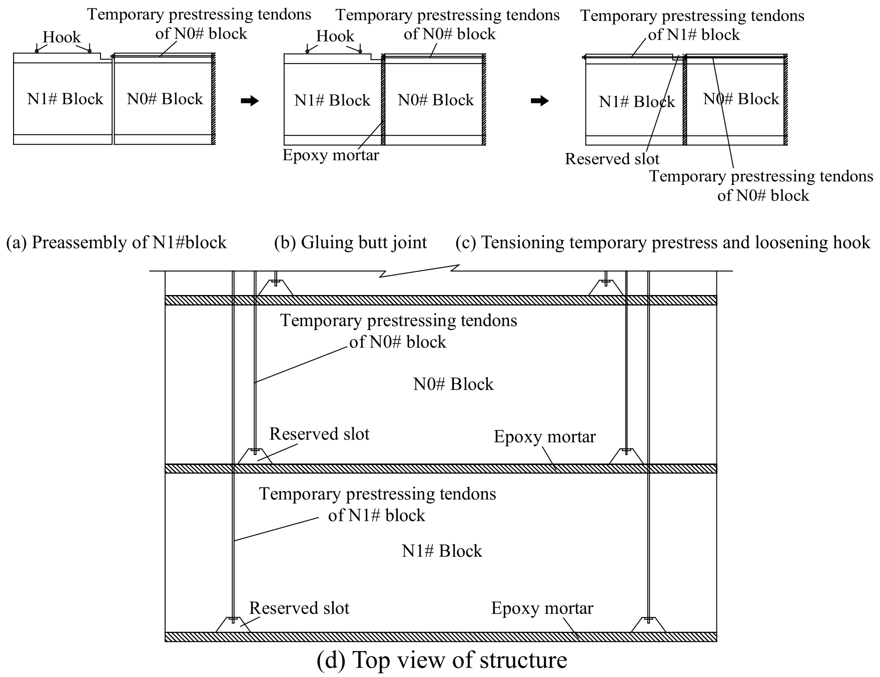


Fig. 10 Schematic diagram of slotted temporary prestressed anchorage at the top plate

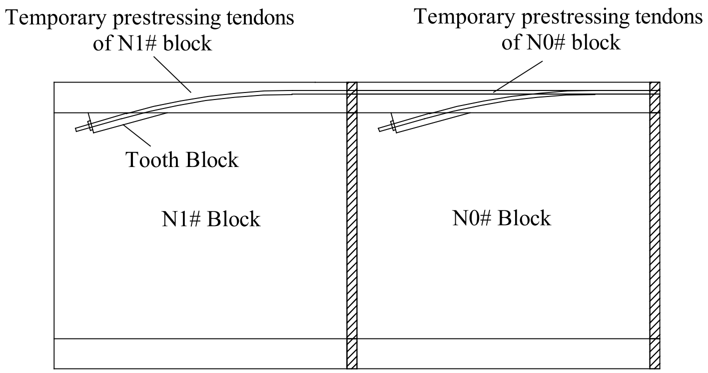


Fig. 11 Schematic diagram of temporary prestressed anchorage of tooth block form

need to add temporary anchor tooth blocks, and the temporary prestressed tendons can be tensioned directly at the roof. At this time, the construction efficiency is good. Therefore, it is recommended to adopt the form of the top plate being grooved for the temporary prestressed tendons of T-frame of the transition pier.

3.3 Rapid Integrated Construction Method Based on New Bridge Girder Integrated Erection Machine

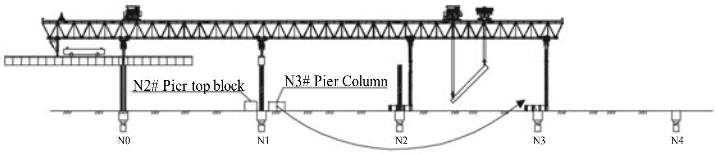
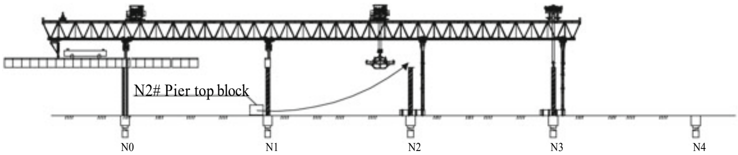
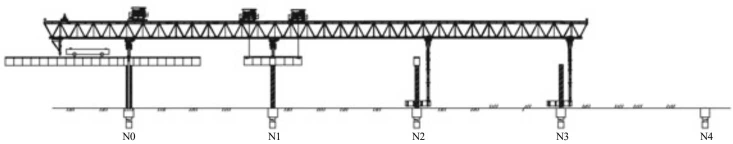
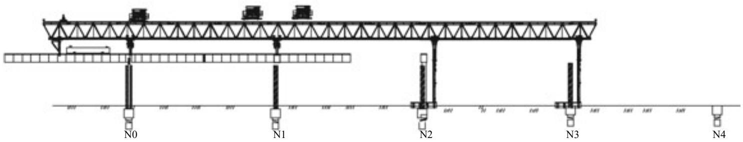
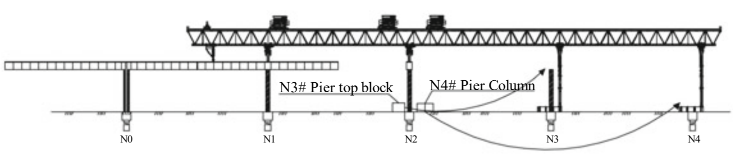
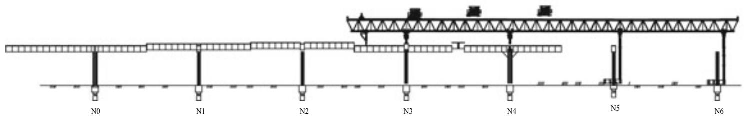
According to the above discussion and the background project, a rapid integrated construction method with full cantilever assembly of rigid frame bridge based on bridge girder integrated erection machine with double landing front legs is proposed. The overall process is as follows:

(1) The N3 # precast pier column that has been temporarily stored at the platform of N1 # pier is lifted to the forward most span by two cranes, and the pier column is turned over and installed in place, and then the grouting connection between the pier column and the platform is started.
(2) While the first two cranes install the N3# pier column and conduct grouting connection between the pier column and the platform, the rear cranes lifts the N2# pier top block that has been temporarily stored at the platform of N1# pier to the top of the N2# pier, and then installs the pier top block of N2# pier. When the pier top block is aligned, the pier and beam is consolidated.
(3) While connecting the pier column with the platform and the pier top block with the pier column and waiting for the strength to meet the requirements, the T-frame of N1# pier is assembled with a bridge girder erection machine by symmetrical cantilever assembly method, and the shear cone is used to temporarily fix the segmental beam. After that, the permanent prestressed tendons are tensioned, and then the temporary prestressed tendons are removed, and the bridge girder erection machine loosens the hook.
(4) According to the previous step, the T-frame of N1 # pier is symmetrically assembled to the maximum cantilever position. After that, the cantilever of T-frame of N0# pier and N1 # pier is closed, and the wet joint is poured and cured. After the strength reaches the standard, the permanent prestressed tendons will be tensioned, and the construction for the T-frame of N1# pier will be completed. Then the temporary prestressed tendons of T-frame of N0# transition pier and the temporary fixing measures between the two top blocks of N0# transition pier are removed.
(5) 2# middle leg is moved forward to the top block of N2# pier, the rear leg is moved forward to the top block of N # transition pier, and 2# front leg is moved forward to the corbel of platform of N3 # pier and temporarily connected with 1# front legs. Then the top block of N3# pier and N4 # pier column are lifted from the tail of the bridge girder erection machine and transported on the bridge deck, and they are finally temporarily stored at the platform of N2# pier. After that, the main beam and rear leg of the bridge girder erection machine are moved forward, and then 1# front leg is moved forward to the corbel of platform of N4# pier, and the 2# front leg is folded up, moved forward across N3# pier, and supported on the corbel of platform of N3# pier. So the crossing span of the bridge girder erection machine is completed.
(6) Repeat steps 1 to 5 until the construction of T-frame of N4# transition pier is completed, that is, the construction of one-coupling bridge (N0# ~ N4#) is

completed. (No temporary fixing measures are required for the top block of middle pier).

The schematic diagram of the above construction process is shown in Table 1.

Table 1 Schematic diagram of rapid integrated installation process

Order number	Schematic diagram
1	
2	
3	
4	
5	
6	

4 Comparison and Analysis of Work Efficiency

Taking the four-span one-coupling prefabricated rigid frame bridge of the background project as the object, one side of the T-frame of a main beam is divided into seven sections, and three construction schemes are considered respectively. First, cantilever assembly of middle pier + half span suspension assembly of side span of transition pier + common integrated bridge girder erection machine; Second, cantilever assembly of middle pier + half span suspension assembly of side span of transition pier + new integrated bridge girder erection machine; Third, full cantilever assembly + new integrated bridge girder erection machine. The construction efficiency analysis of the above schemes is shown in Table 2–4. The brackets in the table indicate that the process time does not occupy the key path.

The following contents can be analyzed from Tables 2, 3, 4. First, the new integrated bridge girder erection machine separates the working face of installation of pier column and pier top block, which realizes the matching of the installation efficiency of the substructure and superstructure, and shortens the time that the installation of pier shaft and pier top block occupies the key path of flow construction from 10 days to 7.5 days, effectively improving the construction efficiency. Second, when the half span suspension assembly method is adopted for the segmental beam near the transition pier of side span, the construction period is significantly increased, and the integrated flow construction is discontinuous, which significantly reduces the construction efficiency. Third, based on the new bridge girder integrated erection machine and the full cantilever assembly method, the continuity of integrated flow construction is ensured, which effectively shortens the installation period and improves the installation efficiency from 39.5 days/unit to 32 days/unit.

Table 2 Construction efficiency analysis (Cantilever assembly of middle pier + Half span suspension assembly of side span of transition pier + common integrated bridge erecting machine)

Order number	Main procedure	Duration(day)	Remarks
1	Install N2# pier column and wait for the connection strength to meet the requirements	3	
2	Install N2# pier top block and wait for the connection strength to meet the requirements	7	
3	Install segmental beam of T-frame of N1# pier by cantilever assembly method	(7)	Start synchronously with step 1

(continued)

Table 2 (continued)

Order number	Main procedure	Duration(day)	Remarks
4	Install segmental beam of side span of N0# transition pier by half span suspension assembly method	4(7)	Immediately after the step 3, occupy the critical route for 4 days
5	Crossing span of the bridge girder erection machine	0.5	
6	Close T-frame cantilever, pour wet joint and maintain	(1)	Start synchronously with step 5
7	Repeat steps 1 ~ 3 and 5 ~ 6, continue to complete the construction of T-frame of N2# and N3# middle pier		
8	Repeat steps 4 ~ 6, complete the construction of side span of N4# transition pier by half span suspension method, that is, the construction of one-coupling bridge is completed		
Total		14.5 + 10.5 + 14.5 = 39.5	

Table 3 Construction efficiency analysis (Cantilever assembly of middle pier + Half span suspension assembly of side span of transition pier + new integrated bridge erecting machine)

Order number	Main procedure	Duration(day)	Remarks
1	Install N3# pier column	0.5	
2	Wait for the connection strength of N3# pier column and platform to meet the requirements	(2.5)	
3	Install N2# pier top block and wait for the connection strength to meet the requirements	7	Start synchronously with step 2
4	Install segmental beam of T-frame of N1# pier by cantilever assembly method	(7)	Start synchronously with step 3

(continued)

Table 3 (continued)

Order number	Main procedure	Duration(day)	Remarks
5	Install segmental beam of side span of N0# transition pier by half span suspension assembly method	7	Immediately after step 4
6	Crossing span of the bridge girder erection machine	0.5	
7	Close T-frame cantilever, pour wet joint and maintain	(1)	Start synchronously with step 6
8	Repeat steps 1 ~ 4 and 6 ~ 7, continue to complete the construction of T-frame of N2# and N3# middle pier		
9	Repeat steps 4 ~ 6, complete the construction of side span of N4# transition pier by half span suspension method, that is, the construction of one-coupling bridge is completed		
Total		15 + 8 + 15 = 38	

Table 4 Construction efficiency analysis (Full cantilever assembly + new integrated bridge erecting machine)

Order Number	Main procedure	Duration(day)	Remarks
1	Install N3# pier column	0.5	
2	Wait for the connection strength of N3# pier column and platform to meet the requirements	(2.5)	
3	Install N2# pier top block and wait for the connection strength to meet the requirements	7	Start synchronously with step 2
4	Install segmental beam of T-frame of N1# pier by cantilever assembly method	(7)	Start synchronously with step 3
5	Crossing span of the bridge girder erection machine	0.5	
6	Close T-frame cantilever, pour wet joint and maintain	(1)	Start synchronously with step 5
7	The next T-frame shall be constructed according to steps 1 to 6 until the completion of T-frame of N4# transition pier,that is,the construction of one-coupling bridge is completed		
Total		4×8=32	

5 Conclusion

At present, the conventional bridge girder integrated erection machine is not suitable for fully prefabricated rigid frame bridges. Due to the mismatch of the installation efficiency of the substructure and superstructure, enforced idleness may occur on the working face.

Aiming at the fully prefabricated rigid frame bridges in highly urbanized areas, a rapid construction technology of this type bridges based on the new bridge girder integrated erection machine with double landing front legs is proposed, which realizes the matching of the installation efficiency of the substructure and superstructure, and shortens the time that the installation of pier column and pier top blocks occupies the key path of flow construction from 10 days to 7.5 days, which effectively improves the construction efficiency and reduces the interference to the surrounding environment and traffic during the construction period.

For the precast segmental beam near the transition pier of side span, the conventional half span suspension assembly method is optimized to full cantilever assembly method, which ensures the continuity of the integrated flow construction, further improves the installation efficiency from 39.5d/unit to 32d/unit.

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