AN INTEGRATED ERECTING TECHNIQUE FOR FULLY PRECAST BRIDGES

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ABSTRACT

An integrated erecting technique for fully precast bridges was developed in which precast components are transported via the installed beams. Additionally, beams, bent caps, and columns are installed using the same erecting machine (EM). To increase efficiency further, a new integrated EM with two working faces was also developed. The precast column and bent cap are installed on the front working face, while the precast beam slab is installed on the rear working face. This EM can erect a single-span bridge in four business days. This system requires no temporary construction roads. All the installation processes are completed using the integrated EM. The land bridge of Main Passageway of Ningbo–Zhoushan Port (NZP) is 5.48km long, with high environmental requirements, and no access road for precast components. The new technology has been successfully applied on this project.

KEYWORDS:

fully precast bridges; integrated erecting technique; double working face

INTRODUCTION

Herein, a fully precast bridge refers to one whose piers (composed of columns and bent caps) and upper structure are constructed with precast components but whose foundation is not. In order to improve the construction quality, accelerate the construction speed, full precasting and assembly schemes for bridge piers (including bent caps) and beam slabs have been developed vigorously. The precasting of bridge components in prefabrication plants is relatively immune to disruption and allows for high precision. Additionally, because the upper and lower structures are manufactured concurrently in a streamlined process in prefabrication facilities, the construction period can be controlled. Moreover, on-site assembly of precast bridge components is rapid and can reduce the surrounding environmental and traffic impacts.

In 1979, a construction scheme with fully precast piers (including bent caps) and beam slabs was used to construct the Linn Cove Viaduct in the U.S. state of North Carolina [Muller and Barker (1)]. The grout-sleeve connection scheme used to construct the Edison Bridge in the U.S. state of Florida in 1993 [Culmo (2)] addressed the difficulty in connecting ordinary rebars during rapid construction. This marked a new stage of rapid construction of fully prefabricated land bridges. In the 1990s, China began to investigate full precasting and assembly processes for land structures [Sun et al. (3)]. In 2015, the Jiamin Viaduct [Zhang (4)] was built through a comprehensive full precasting and assembly process.

Conventional erecting techniques for precast piers and beam slabs suffer from considerable limitations. First, large transportation machinery and hoisting equipment, whose operation requires strict road-system conditions, are needed to transport and erect the precast components. For example, thanks to the favorable urban transportation conditions, all the components of the Jiamin Viaduct were transported by large transportation vehicles to the construction site and installed using a 250-t crawler crane during nighttime road closures. Table1 summarizes the road conditions required for a 250-t crawler crane. These are difficult to satisfy in mountainous, sea, or environmental-conservation areas, in which using crawler cranes will incur relatively high economic, environmental, and social costs.

Table1. Technical transportation requirements for a 250-t crawler crane.

Vehicle type	Bearing strength of road [t/m^2]	Road width [m]	Turning radius [m]
250-t crawler crane	>20	>10	>12

Additionally, operators must be extremely skilled to operate crawler cranes or truck-mounted cranes to lift components at construction sites. Lifting large-tonnage components often requires two cranes [the Jiamin Viaduct was erected using a main 250-t crane and an auxiliary 100-t crane [Zhang (4)] and involves high construction risks. Moreover, crawler cranes are affected considerably by environmental factors. Consequently, it is relatively difficult to position a component precisely with a crawler crane.

To address the aforementioned difficulties, an integrated erecting machine (EM) for beam slabs, bent caps, and columns was developed in the present study, along with an integrated erecting technique for fully precast bridges based on the new EM. This technique (i) integrates the transportation, erection, and construction methods for the upper and lower structures, (ii) increases the level of automated construction, and (iii) reduces construction difficulties.

INTEGRATED ERECTING TECHNIQUE

Overall Structure of Integrated EM

The key integrated EM design principles are as follows. Precast bridge components are transported via the T-beams that have already been constructed. An EM is then used to erect the precast components of the upper and lower structures on site. Thus, the transportation, erection, and construction of the upper and lower structures are integrated.

A conventional EM has only one working face, and it takes 4.5d to install the precast components of the upper and lower structures of one bridge span on one working face (see Table2). No other tasks can be performed during the grouting and curing of the column and bent cap.

Table2. Efficiency analysis of integrated single-working-face erecting machine (EM).

No.	Main process	Effective construction time [d]	Climate influence coefficient (CIC)	Actual construction time [d]
1	Preparation	0.1	1.0	0.1
2	Span-crossing of EM	0.4	1.2	0.48
3	Installation of column	0.6	1.2	0.72
4	Grouting and curing of column	1.0	1.0	1.0
5	Installation of bent cap	0.4	1.2	0.48
6	Grouting and curing of bent cap beam	1.0	1.0	1.0
7	Installation of T-beam	0.6	1.2	0.72
Total		4.1		4.5

To improve efficiency and make better use of the time during the grouting and curing of the column and bent cap, an integrated double-working-face EM approach was designed. The column and bent cap are erected on the front working face, while the beam slab is erected on the rear working face. To implement this approach, two types of EMs were designed based on front-pivot EMs. One type of EM is a tower-crane integrated EM, which is similar to a cantilever crane; in this EM, the front working face is supported by a cable-stayed structure. The other type of EM is a front auxiliary support leg (FASL) integrated EM. This EM is supported by its front auxiliary support legs on the sides of the pile foundation. Figure1 shows the two EM structures.

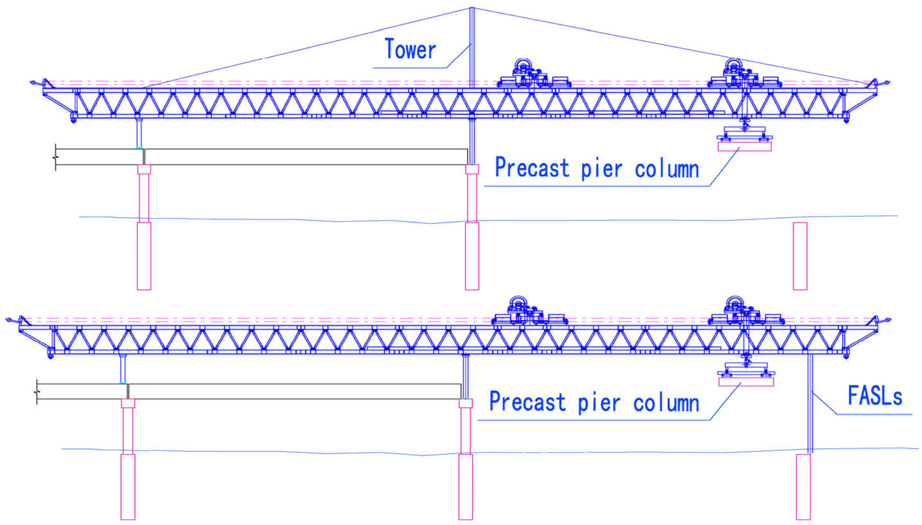


Figure1. General integrated EM structures: tower-crane integrated EM (top); front auxiliary support leg (FASL) integrated EM (bottom).

The tower-crane integrated EM can be used in a wide range of conditions, but its front working face is not particularly stiff and its operating height exceeds 12m. Instead, to reduce the operating risks and meet the span-passing requirements, the FASL integrated EM was used in application. Nevertheless, the tower-crane integrated EM is highly advantageous and merits further investigation and popularization in areas with significant topographic variations (e.g., mountainous, hilly, and sea areas) or where the front-section support is inadequate. Figure2 shows the structure of the FASL integrated EM.

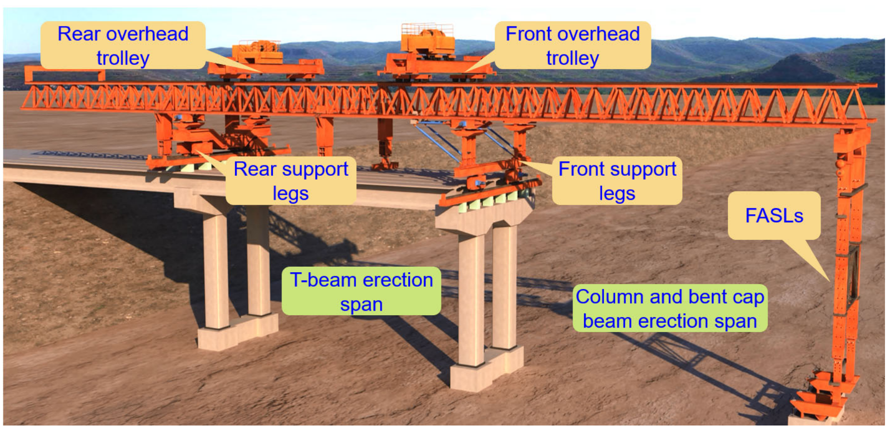


Figure2. Overall structure of FASL integrated EM.

The FASLs of the integrated EM used in practice are supported by a strut-and-tie system on the sides of the constructed bearing platform. The FASLs of this EM have an adjustable length of 12–27m and can bear loads of up to 170t.

Construction Procedure Using Integrated EM

The erection procedure using the integrated EM is shown in Figure3 and is described below.

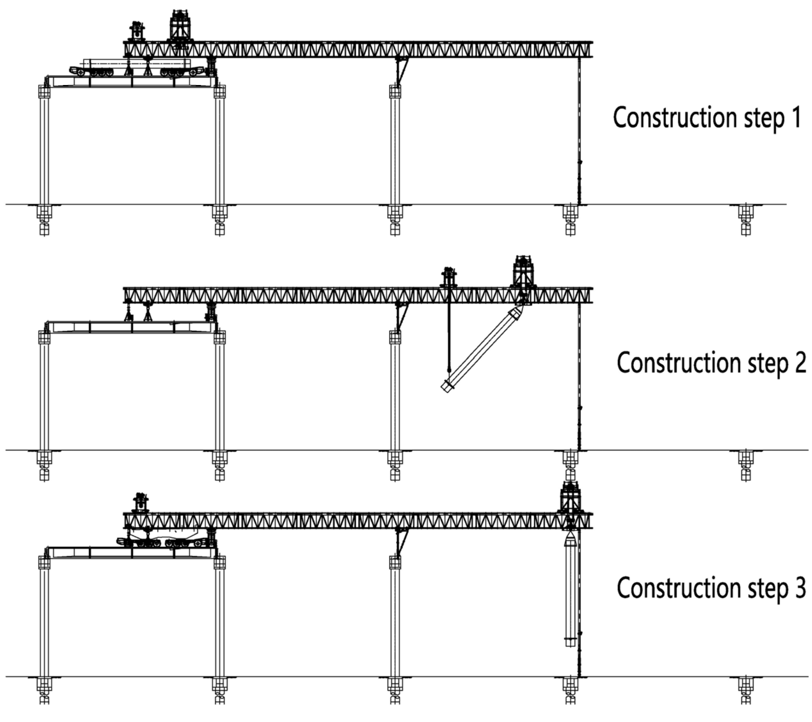
1) The integrated EM installs pier columns, bent caps, and beams span by span.

2) A precast pier column is transported to beneath the EM via the erected beam. The front and rear overhead trolleys are then used to transport the precast pier column horizontally to the front working face. The front and rear overhead trolleys are then coordinated to rotate the pier column by 90° on the vertical plane. After the alignment between the pier column and the bearing platform has been determined to meet the precision requirements, the pier column is fixed and grouted.

3) A precast bent cap is transported to beneath the EM via the erected beams. The front overhead trolley is then used to transport the precast bent cap horizontally to the front working face and then install it after rotating it by 90° on the horizontal plane. After the precision requirements have been met, the bent cap is fixed and grouted.

4) While the grout in the bent cap is solidifying, a precast beam slab is transported to beneath the EM via the erected beams. The front and rear overhead trolleys are then used to transport the precast beam horizontally to the rear working face. After the precision requirements have been met, the beam is lowered onto the bent cap, thereby completing the installation of the beam.

5) After completing the installation of the pier column, bent cap, and beam of a span, the integrated EM moves to the next span and continues the installation process.



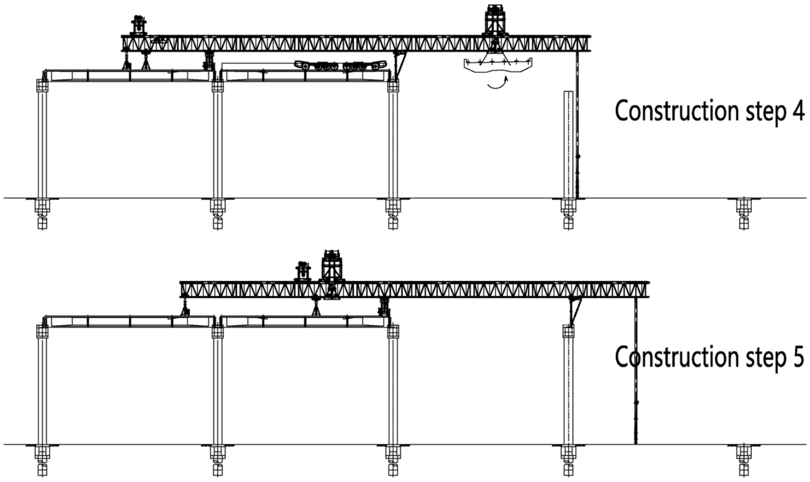


Figure3. Overall construction process with integrated EM.

Automation Technology for Integrated EM

The automatic control systems, such as wireless control system, video monitoring system, synchronous hydraulic system, FASL tilt alarm system, are installed in the integrated EM to maximize its operating efficiency. Supported by these automatic control systems, only six to eight personnel are required to complete all the tasks involved in on-site installation.

Efficiency Analysis

Installation of a single-span T-beam bridge (including columns and bent caps) using the integrated erecting technique requires 3.78d. The integrated EM completes the erection of one bridge span in 0.72d less than does a single-working-face EM. Additionally, using an EM-fixing platform increases the component positioning efficiency and accuracy considerably. Table 3 summarizes the efficiency analysis.

Table3. Efficiency analysis of integrated installation and construction (single span).

No.	Main process	Effective construction time [d]	CIC	Actual construction time [d]
1	Preparation	0.1	1.0	0.1
2	Span-crossing of EM	0.4	1.2	0.48
3	Installation of column	0.6	1.2	0.72
4	Grouting and curing of column	1.0	1.0	1.0
5	Installation of bent cap	0.4	1.2	0.48
6	Grouting and curing of bent cap	1.0	1.0	1.0
7	Installation of T-beam requires 0.6d and can be completed during grouting and curing of column.			
Total		3.5	——	3.78

APPLICATION OF INTEGRATED ERECTING TECHNIQUE IN PROJECT OF MAIN PASSAGEWAY OF NINGBO–ZHOUSHAN PORT

General Information on the Main Passageway of Ningbo-Zhoushan Port Project

Situated in the northeastern Zhoushan Archipelago area, the main passageway of the Ningbo–Zhoushan Port (NZP) connects the largest and second-largest islands of the archipelago, namely Zhoushan and

Daishan Islands, respectively. The design speed on the main passageway of NZP is 100km/h, the standard width of the subgrade of the main passageway of NZP is 26.0m, and the total length of the project is 25.659km, of which 16.734km is over the sea and 8.925km is on land. The total length of the viaducts on land is 5.481km. The land segment of the project traverses coastal suburbs with many farm fields and mountain forests, where there are strict land-use and environmental protection requirements. Limited by its geographic location, the road conditions are poor in this area, with only one general road, namely the Yadong Road. Figure4 shows the geographic locations of the viaducts on land along the main passageway of NZP.

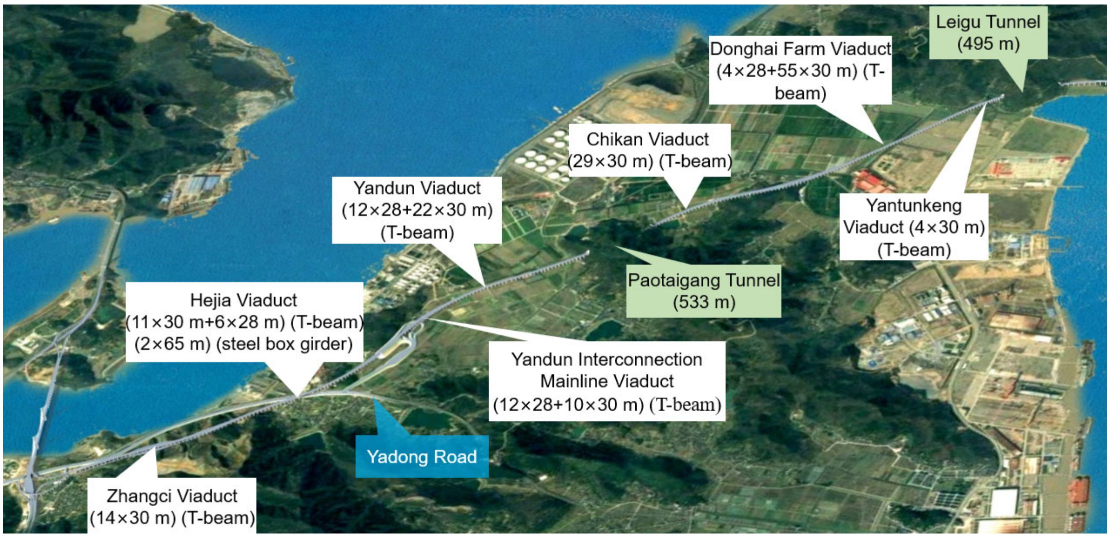


Figure4. Geographic locations of viaducts on land along main Passageway of Ningbo–Zhoushan port (NZP).

Thus, from the perspectives of structural durability, construction quality, and environmental protection, both the upper and lower structures of the main passageway of NZP were constructed by assembling fully precast concrete components. Except for the one over the Yadong Road, each viaduct on land consisted of an upper 358 standard-spans (30m/28m) (total for the two decks) T-beam structure and a lower structure constructed with precast columns and bent caps. Additionally, the pier components were connected by grout sleeves. In total, the main passageway of NZP was constructed with 2,148 precast T-beams and 320 precast piers. Figure5 shows the standard section of the viaducts, and Table4 gives the specifications of the pier structure.

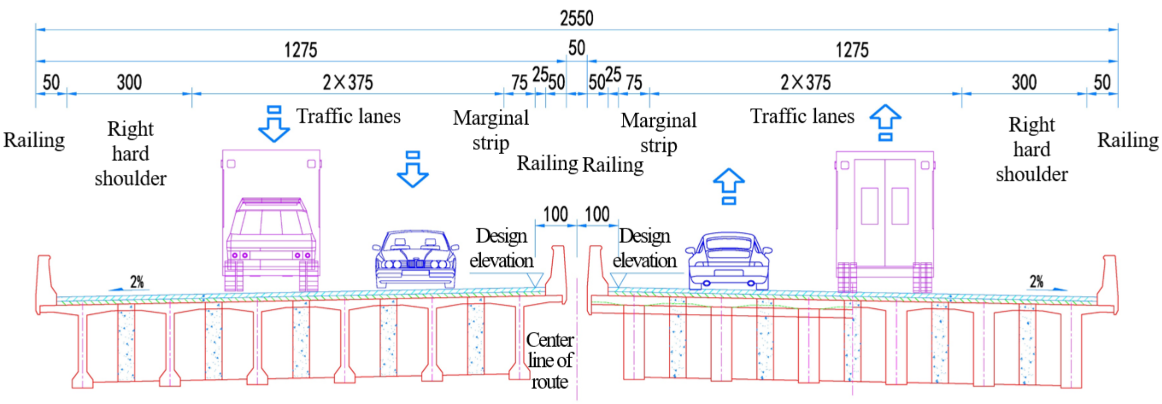
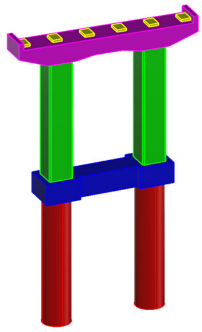


Figure5. Standard section of T-beam.

Table4. Specifications of pier structure.

Pier height [m]	Bent-cap width [m]	Column side length [m]	Pile diameter [m]	Schematic
<10m	1.7/1.9	1.2	1.6	
10–20m	1.7/1.9	1.5	1.8	
20–25m	1.7/1.9	1.5	1.8	

The maximum height and maximum installed weight of a column are 20.1m and 117t, respectively. The weight of a bent cap is 84t and that of a single T-beam is approximately 78t. Table5 summarizes the proportions of columns of various heights.

Table5. Height statistics of precast columns.

Pier height h [m]	h ≤ 10	10 < h ≤ 15	15 < h ≤ 18	h ≥ 18	Total
Quantity	232	256	118	34	640
Proportion	36.25%	40%	18.44%	5.3%	100%

Construction Planning

Three integrated EMs were used to construct the entire main passageway of NZP. Figure6 shows the erecting scheme with the EMs.

1) EMs1 and 2 were used to install viaducts, one on the left-deck side and the other on the right-deck side, from the end of the Yandun Viaduct. Successively, the Yandun Viaduct, the Yandun Interconnection Mainline Viaduct, the Hejia Viaduct, and the Zhangci Viaduct were installed. Afterwards, these two EMs were transported and used to install the Chikan Viaduct. A total of 232 viaduct spans were installed using EMs1 and 2.

2) EM3 was used in single-deck installation of viaducts from the left deck of piers41–43 of beam-lifting station2 for the Donghai Farm Viaduct. After the Yantunkeng Viaduct was installed, EM3 was used to install the left deck of the Donghai Farm Viaduct. Finally, EM3 was used to install the right deck of the Donghai Farm Viaduct. A total of 125 viaduct spans were installed using EM3.

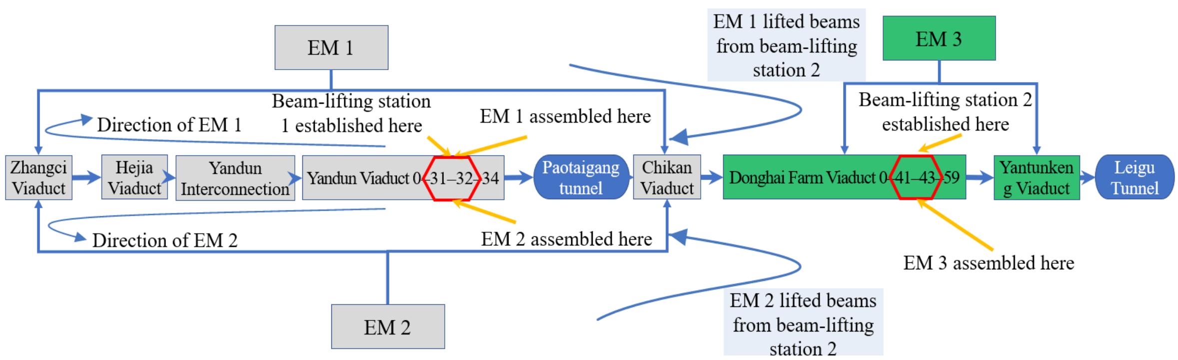


Figure6. Overall planning of construction with integrated EMs.

Beam-lifting station1 was established in the Yandun suburb near the village roads. Beam-lifting station2 was established in the sparsely populated planned Dinghai Industrial Park Zone. Columns, bent caps, and T-beams were lifted by a girder-lifting gantry crane to the transportation vehicles on the viaduct and were subsequently transported to the construction site. It took approximately 480 d to complete the installation of the viaduct spans.

Results of Applying Integrated Erecting Technique

Construction Efficiency

The integrated erection of the main passageway of NZP began in late June 2018. On average, it took 4 days to complete the erection of the upper and lower structures of one viaduct span. This was consistent with the expected efficiency. The erection of all the viaducts on land was expected to be completed by the end of 2019.

Environmental Protection

The construction road requirements of the integrated erecting technique are relatively less demanding. Comparing the temporary construction roads required for pile foundation construction and the high-class construction roads required by crawler cranes for hoisting shows that the integrated erecting technique saved a construction road area of approximately 27,000m^2 for the entire main passageway of NZP project. Considering the costs for foundation treatment, temporary land acquisition, land rehabilitation, and compensation, using the integrated erecting technique saved approximately CNY 20 million (approximately USD 2.83 million) of investment.

Impacts on Local Traffic Conditions

The impacts of the integrated erecting technique on the traffic conditions in the surrounding area were minimized. The two beam-lifting stations were established in the Yandun suburb near the village roads and the sparsely populated planned Dinghai Industrial Park Zone, respectively. Components were transported on the erected viaducts, and assembling the EMs basically required none of the valuable local transportation resources.

EXTENSION OF AND THOUGHTS ON THE INTEGRATED ERECTING TECHNIQUE

Single-EM, Double-deck Erecting Technique

Based on the integrated erecting technique developed in this study, one EM can be used to erect a double-deck viaduct by transverse shifting. The main construction control procedure is as follows, and Table6 summarizes the efficiency of the single-EM, double-deck erecting technique.

1) After the column of the left deck of the viaduct on the front working face has been installed, the EM is shifted to the right-deck side of the viaduct and used to install the column of the right deck while the column of the left deck is curing.

2) While the column of the right deck is curing, the EM is used to install the T-beam of the right deck and subsequently the bent cap of the right deck.

3) The EM is shifted to the left-deck side and used to install the bent cap of the left deck and subsequently the T-beam of the left deck while the bent cap is curing.

Table6. Efficiency analysis of integrated construction (erection of one span of each of the left and right decks).

No.	Main process	Effective construction time [d]	CIC	Actual construction time [d]
1	Preparation	0.1	1.0	0.1
2	Span-passing of EM	0.4	1.2	0.48
3	Installation of column of left deck	0.6	1.2	0.72
4	Shifting of EM to right-deck side	0.2	1.2	0.24
5	Installation of column of right deck	0.6	1.2	0.72
6	Grouting and curing of column of right deck	1.0	1.2	1.2
7	Installation of bent cap of right deck	0.4	1.2	0.48
8	Installation of T-beam of right deck requires 0.6d and can be completed during grouting and curing of column of right deck.			
9	Shifting of EM to left-deck side	0.2	1.2	0.24
10	Installation of bent cap of left deck	0.4	1.2	0.48
11	Grouting and curing of bent cap of left deck	1.0	1.0	1.0
12	Installation of T-beam of left deck requires 0.6d and can be completed during grouting and curing of column of left deck.			
Total		4.9	——	5.66

If three EMs are similarly used, the single-EM, double-deck erecting technique can save approximately 120d of construction time compared to the single-EM, single-deck erecting technique (i.e., the erection of the control line takes approximately 360d) on the main passageway of NZP project. However, the single-EM, double-deck erecting technique requires the EM to be shifted twice between the left and right decks during the erection process. Because it was the first time that integrated erecting was implemented, from a reliability perspective, the single-EM, double-deck erecting technique was only used to erect one viaduct span in the supporting project.

Erection of High-pier Viaducts

The EM investigated in this study performs best when the T-beam, bent cap, and column are similar in weight. A column length slightly shorter than the beam length is conducive to rotating and installing the column. For high-pier viaducts, considering the FASL stability, it is necessary to install the columns segment by segment and increase their stability. Consequently, appealing options are (i) tower-crane integrated EMs without FASLs or (ii) integrated EMs with a displacement compensation system.

Limitations in Streamlined Construction

Installation and construction with crawler cranes is relatively more flexible. In that process, each column is installed followed by each bent cap and each T-beam. If problems occur at a pier construction site, then it is possible to continue construction at other sites. In comparison, limited by the overall shifting capacity of the EM, the integrated erecting technique can only construct one pier after another. For a double-deck viaduct, if an accident occurs at a certain pier site, then components can still be transported via the other deck. However, if a problem occurs at the construction site of a single-deck viaduct or if problems occur on both decks of a double-deck viaduct, then an additional beam-lifting station must be established to continue the construction process. In follow-up research on improving the integrated erecting technique developed in this study, a collapsible technology and a more powerful self-moving technology could be introduced to allow the EM to move more flexibly.

CONCLUSIONS

In this article, an integrated erecting technique for fully precast bridges is introduced. For the first time in China, this technique enabled one-step, construction-road-free installation of the upper and lower structures of viaducts on land. Aided by an automated information system, this new technique is easy to implement and has high positioning efficiency and, overall, high construction efficiency. Additionally, this technique does not require construction roads and has insignificant impacts on the surrounding traffic and environment. This green, industrialized construction technique can be popularized in areas where sea bridges or urban highways are required, as well as in mountainous and environmentally sensitive areas.

ACKNOWLEDGMENTS

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NOTATION

ZJIC is the Zhejiang Provincial Transportation Planning and Design Institute Co., Ltd.

EM is the erecting machine

NZP is the Ningbo–Zhoushan Port

FASL is the front auxiliary support leg

CIC is the Climate influence coefficient

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