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Construction and Quality Management of Prefabricated Elevated Highway Projects: A Case Study of the Elevated Section of Chongqing Expressway in Qingdao

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Abstract. The prefabricated construction of urban expressway viaducts can reduce on-site wet operation and traffic occupation time, but component prefabrication, transportation, hoisting, and joint construction restrict each other, and the progress and quality are closely related. Taking the viaduct project of Chongqing Expressway in Qingdao as an example, this paper analyzes the collaborative control methods from the aspects of component supply and demand coordination, digital scheduling, night lifting, prefabrication quality, and joint construction. The research shows that the project relies on the smart beam yard and BIM+GIS platform, through the production, inspection, transportation, and erection status with the unique code of components, and forms a dynamic closed loop through "status acquisition - deviation identification - plan rearrangement - resource adjustment - result feedback"; Adjust the production scheduling and transportation batch of the Beam Yard according to the on-site erection rhythm, and take the quality acceptance as the precondition for entering the next process, which can reduce downtime and invalid stockpiling. During night construction, the risk of low illumination and fatigue operation is reduced through measurement review, mutual inspection by two persons, post rotation, and monitoring. The case shows that efficient construction needs to integrate the construction plan, quality gate control, digital scheduling, and multi-party coordination into unified management to realize the synchronization of schedule adjustment and quality control.

Keywords: fabricated viaduct, Progress control, Quality control, Digital construction

1. Introduction

The elevated construction of urban expressway puts forward new requirements for construction period, traffic guarantee and construction environment. Compared with the traditional cast-in-place process, the prefabricated bridge can realize the simultaneous production of components and excavation of foundation pit, save wet operations such as formwork, reinforcement and concrete to a certain extent, and is conducive to the realization of standardized and industrialized construction [1]. However, the prefabricated elevated structure is not simply to move the construction site to the factory workshop, but to consider the coordination of prefabrication, stacking, transportation, hoisting, and joint construction in the whole process; At the same time, component size, connection reliability, and hoisting accuracy directly affect the smooth development of subsequent work, so there is a close relationship between progress and quality [2].

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The main line of the Qingdao Chongqing Road Expressway Viaduct Project is 17.7km long, and the prefabricated assembly rate of the superstructure is more than 90%. There are 2060 prefabricated box girders in the whole section, which is a typical case of prefabricated viaduct construction in large cities [3]. The project is transported and hoisted at night without interruption of the urban trunk road. On this basis, the BIM+GIS digital pipe construction platform and smart beam yard are used to connect the design, manufacturing, transportation, erection, and acceptance [3]. Starting from the influence of quality on the schedule and the restriction of quality problems on the work in the next stage, this paper discusses the internal relationship between the two and puts forward methods that can be used for reference for similar projects.

2. Basis for construction progress and quality control of fabricated viaduct

2.1. Construction characteristics of fabricated viaduct

The fabricated viaduct is generally a combination of factory prefabrication and construction site, but they are independent and coordinated with each other. The reinforcement, formwork, concrete, tensioning, and curing of the box girder, cap beam, pier column, and other components shall be carried out in the prefabrication plant. The construction of pile foundation, bearing platform and other substructures shall be carried out at the construction site, and the transportation, hoisting, splicing and wet joint construction shall be carried out in time [1]. Compared with the traditional cast-in-place method, the construction method has the advantages of industrialized production, ensuring the quality stability of each process, and allowing the prefabrication of components and the construction of on-site foundation to be carried out at the same time to reduce the time of traffic impact [4].

This approach also brings new management constraints. Due to the large volume of components and the impact of urban roads, it is easy to have "fast production, slow erection" or "slow production, site and other materials" between the beam yard and the construction site, resulting in the problem of tempo mismatch. The problems of component size, prestress, interface, and joints shall be solved before delivery, transportation, and erection, which will directly affect the construction period [2]. Therefore, the focus of fabricated viaduct construction is not to speed up the work of a certain link, but to unify the production and transportation time, hoisting conditions, and quality inspection.

2.2. Main influencing factors of progress control

The schedule risk of the fabricated viaduct project is divided into two categories: external factors and internal management problems. External factors include traffic control, pipeline relocation, land acquisition coordination, and extreme weather, while internal management issues mainly involve the production capacity of the Beam Yard, component storage, transportation time, hoisting machinery, mutual influence of various operations, and communication and cooperation between multiple units [5]. The insufficient or excessive supply of components is caused by the contradiction between the beam yard and the construction site: if the production is delayed, it will lead to work stoppage and waiting for materials; If the production speed is fast, problems such as beam storage, secondary transfer, and component collision will occur. The research on speeding up the construction also shows that the parallel production of prefabricated components must comply with the on-site erection sequence and the use of mechanical equipment, which can become an effective measure to shorten the construction period [6].

Therefore, the schedule should be changed from a one-time fixed plan to a regular update. During the update process, in addition to reading the "planned completed quantity" and "actual completed quantity", it should also read the component quality inspection, whether the on-site pre-process is completed, whether the transportation window and hoisting equipment are available, and so on; Only the components that meet the requirements of quality and site conditions can be included in the transportation and erection operations in the next period of time, so that the components that have not been fully accepted will not be pushed to the next step in advance to catch up with the progress.

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2.3. Key risk points of quality control

According to the technical specification for construction of highway prefabricated concrete bridges JTG/T 3654-2022, the quality control of prefabricated bridges includes prefabrication, transportation, installation, and connection [7]. In the process of prefabrication, attention should be paid to reinforcement positioning, concrete pouring and maintenance, prestressed construction and component size; During transportation, it is necessary to avoid damage or damage caused by overturning or impact caused by unreasonable support; When installing on site, attention should be paid to the temporary support, lifting angle, horizontal curve and plane position; The sleeve grouting, wet joint and other parts of the construction of the connecting part have a great impact on the integrity and durability of the whole bridge [8].

The quality risk has obvious progress conductivity. Unqualified component factory acceptance will affect the transportation arrangement, problems in installation survey review will affect the lifting time, and joint problems will lead to the suspension of follow-up work. Therefore, quality acceptance can not only be regarded as a supplementary link after the schedule, but should be integrated into the production and erection plan and become a "quality gate" when the component state changes.

3. Overview of Qingdao Chongqing Road expressway fabricated elevated project

Qingdao Chongqing Road express route connects Shandong Road to Xianshan Road from south to north, with a total length of about 17.7km, running through Shibei, Licang and Chengyang Districts; The superstructure of the project has a high degree of prefabrication and assembly, reaching more than 90%. A total of 2060 prefabricated box girders are prefabricated in a large-scale intelligent prefabrication Beam Yard [3]. The construction period is tight, the workload is heavy, and the normal traffic of the ground roads must be ensured. Therefore, the construction organization must constantly adjust and optimize the aspects of smooth traffic, night construction, material supply, and the construction progress coordination of each subproject.

The construction difficulties of the project are firstly due to the impact of traffic conditions on the transportation and hoisting window period of the urban trunk road, during which the transportation and hoisting time shall be determined according to the traffic organization; Secondly, the production of components, the erection of substructure and upper part shall be carried out at the same time, and any delay in any link will affect the subsequent links; Moreover, due to the participation of multiple construction units and the simultaneous construction of multiple bid sections, there are many planned connection points; In addition, low illumination at night, low temperature, wind and rain and continuous work will bring great difficulties to the setting out review and manual work [3].

In order to solve these problems, the project adopts the information management method, takes the BIM model as the carrier of the engineering project, and integrates the progress, quality, safety, and other work contents into one platform [3]. The project completed the overhead construction of the main line in only 340 days, and completed the erection of 2060 box girders in 158 days, including the erection of 1006 box girders in one month [3]. This shows the impact of digital collaboration, factory prefabrication, and on-site resource integration on construction speed; rather than a single technology being able to do this, it can reflect the importance of cross-link collaboration for accelerating the construction speed.

4. Collaborative practice of schedule control and quality of Qingdao- Chongqing Road expressway project

4.1. Multi-process parallel and component supply and demand closed loop

The project adopts the parallel organization mode of "prefabrication at the rear and assembly at the front", so that the production of the beam yard and the construction of pile foundations, bearing platform, pier column, etc. can be carried out at the same time, from the original queue to multiple working faces at the same time [3]. The goal of the construction period management is not to simply pursue the full load production of the

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beam yard, but to arrange the components required for the corresponding position on the basis of the pier position and erection sequence on site, so that the production, inspection, delivery, transportation and hoisting of components are linked [2]. Only after passing the quality inspection for a certain period of time can the components change from "produced" to "ex-factory". Only after meeting the conditions on site can they become "transportable" and "erected". Therefore, the quality inspection directly affects the construction period [9].

In this paper, the dynamic adjustment of component supply and demand is summarized as "state acquisition - deviation identification - plan rearrangement - resource adjustment - result write back". Under the assumption that continuous rainfall causes a three-day suspension of on-site erection, the affected working face shall suspend the beam delivery and transportation of the corresponding components, and feed back the information such as the number of unerected beams, the status of the corresponding pier location's previous process, component inspection results, storage location, transportation window and available hoisting equipment to the platform; The planning layer will redetermine the priority of components according to the principle of "qualified quality and satisfied preconditions", and adjust the production scheduling and transportation batch of Beam Yard to other constructable sections, so as to avoid beam stacking caused by the centralized delivery of blocked beam numbers. After the weather improves, restore the original working face and update the rolling plan according to the remaining lifting capacity on site. This mechanism reflects the reverse regulation of schedule deviation on production and transportation organization, and ensures that the quality acceptance conditions are not broken due to rushing.

4.2. BIM+GIS digital progress control and dynamic adjustment

Project digital construction management is based on a BIM model, which links progress, quality, and construction site management work on engineering components to form an information platform for multi-party cooperation [3]. For prefabricated components, a unique number can be used to record their production, inspection, transportation, and erection, so that planners can know not only "how many beams have been completed", but also "which beams have been accepted, where and when they can be shipped, and whether the corresponding piers and abutments meet the erection requirements". Digital management in the whole life cycle shows that organizing information based on component information can reduce the gap between design, production, storage, transportation, and field installation [2].

The effect of a digital platform should be achieved by optimizing its plan, not limited to three-dimensional display. Several sections of the Chongqing Road project were constructed at the same time. A total of 2060 box girders were erected in 158 days, and up to 1006 box girders were erected in a month or even a month [3]. For such a large-scale construction project, if some transportation routes or hoisting positions are temporarily unavailable due to traffic control, weather conditions, or the influence of previous processes, the platform can select "transportable- erectable " components according to the status of each component and the situation of the working surface, and arrange vehicles and hoisting equipment to the positions with such requirements, so as to avoid too long idle time of the equipment. This greatly improves work efficiency and simplifies the original process of requiring people to call and fill in various forms and submit them for review layer by layer to constantly adjust in the same information environment.

BIM and digital twin can be used to simulate the lifting position, equipment capacity, and on-site collision. The digital twin model of precast bridge deck hoisting proposed by Jang et al. Shows that the optimal hoisting position and equipment quantity can be obtained through the three-dimensional site, BIM components, and crane model; that is, the digital model has the foundation from "visualization" to construction scheme optimization [4].

4.3. Night construction schedule organization and misoperation prevention mechanism

The maintenance of urban trunk roads makes it necessary to carry out some large-scale transportation and hoisting at night. The construction at night can make full use of the limited time for erection to ensure

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continuity, but low illumination, temperature differences, and worker fatigue will adversely affect the construction progress and even affect the construction quality and safety [10]. Therefore, the construction at night can not be completed simply by working overtime. It is also necessary to consider the survey, command, and human conditions as preconditions for whether to enter the hoisting.

In terms of survey review, the control point inspection, instrument calibration, and benchmark retest in the hoisting area shall be carried out under the condition that the temperature is relatively stable in white weather. At night, the total station shall be used under a fixed light source for review, and the axis, elevation, and support position shall be checked in the way of "rough positioning - fine adjustment - Review and confirmation"; When the distance measurement, steel member size, and grouting material are changed due to the influence of temperature, it is necessary to record the situation at that time and recheck after the member is stable. It is not allowed to release based only on visual judgment. For important dimensions and shapes, the lifting hook can be loosened, or the next step can be carried out only after the joint signature of the measuring personnel and the quality inspection personnel.

From the perspective of human factors management, the night shift needs to achieve disclosure before the shift, the rotation of important posts, and the only exit of operation instructions. The crane driver, rigger, surveyor, and on-site commander use the unified password and repeat the confirmation; Rotation shall be arranged during continuous high-intensity work, and positions with reduced attention and slow response shall be replaced immediately. UAV or high-altitude video surveillance can assist with blind-spot views, but it cannot replace on-site measurement and two-person review. "Personnel in good condition and survey review in good condition" is the condition for continuous erection, so as to prevent expanding the error probability in order to catch up with the skylight at night.

4.4. Main constraints in progress control

From the perspective of project implementation, the progress of fabricated viaduct is affected by traffic organization, bad weather, release speed of working face, and cross-unit interface [3]. Therefore, even if there is a digital platform to improve information transparency, these external factors themselves cannot be changed. The core of schedule control is to reduce the time from problem discovery to response, rather than assuming that the plan will not change. In case of heavy rain or snow, temporary traffic control or rework of quality problems, it is necessary to ensure the quality and hoisting safety of important links, and then adjust the working face, transportation batch arrangement, and rolling production scheduling of the Beam Yard to solve the schedule delay.

5. Quality control and progress feedback practice of Qingdao Chongqing Road expressway project

5.1. Source control of prefabrication quality in smart beam yard

The prefabrication quality of components is the basic condition for the subsequent transportation and erection of fabricated viaduct. The Smart Beam Yard uses the unified formwork, reinforcement positioning, concrete vibration, maintenance and tensioning processes to ensure the consistency of the production process, and binds the production information and quality inspection information with the component identification code [2]. If the size, appearance, strength, or prestress of the component does not meet the standards, it will be in "pending treatment" and will not be delivered or transported as quality control to prevent the unqualified products from flowing to the construction site [7].

In the prefabrication stage, the results of reinforcement positioning, formwork installation, concrete pouring and curing, prestress tensioning, geometric dimension, and appearance inspection shall be included in the same component file, and the acceptance results shall be used as the basis for factory release [7]. For the deviation found in the inspection, the member status shall be updated after the beam field is processed and re-inspected; The transportation and site erection plan can only be continued after the status changes to

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"accepted". In this way, the quality of components can be controlled from the source, and the quality information can be timely transmitted to the subsequent schedule, so as to realize the linkage between the prefabrication quality and the construction pace.

5.2. Quality control and progress linkage of transportation and hoisting

During the transportation of large-scale prefabricated components on urban roads, attention should be paid to supporting, fixing, turning, and braking. During the transportation, the transportation route and time are restricted by the local urban roads [3]. Therefore, the transportation permit must be based on the quality of the component itself, the quality of the vehicle and its supporting devices, and the selection of the transportation route and the time of arrival. In case of collision or problems during transportation, it is necessary to immediately check and modify the status of components before unloading and lifting at the construction site. The idea that "the vehicle has arrived at the site" cannot be used as a reason to reduce the product quality.

Before site hoisting, the crane position, turning radius, parking place of transport vehicles, and hoisting sequence of components can be checked based on the BIM model, and the axis, elevation, support, and alignment can be rechecked immediately after hoisting [9]. If any deviation is found, the subsequent splicing of the component shall be stopped, and the subsequent hoisting time shall be occupied or rescheduled immediately; Otherwise, the splicing operation shall be carried out after the review is qualified. In this way, the quality inspection results will affect the status of components marked as "constructable" in the schedule. The workload reflected in the schedule is the part that can be constructed, rather than the part that has been lifted or arrived at the site.

5.3. Quality control of key processes of joints

Sleeve grouting, wet joints, and other connection processes are important steps for the formation of an integral stress system for fabricated bridges. During construction, attention should be paid to surface treatment, material quality, grouting plumpness, curing, and process records [8]. For concealed works, photography, material numbering, and test reports shall be carried out to form traceable data, and the next process can be carried out only after the acceptance is qualified; If there are problems such as loose grouting, improper surface treatment, or early cracks, these problems should be solved first, and then the follow-up work should be arranged, instead of ignoring the inspection due to the progress problem.

For the joint material, UHPC and other high-performance materials can be used in combination with the design and construction conditions to improve the crack resistance and bearing capacity of the connection part. The specific application should still be subject to the engineering design requirements and field inspection results [11, 12].

5.4. Feedback closed loop of abnormal quality to the schedule

The core of quality and schedule coordination is to make the quality results "affect the plan". During the prefabrication of components, the failure of quality supervision means that the corresponding beam number cannot enter the transportation queue; During hoisting, the unqualified survey and recheck means that the joint construction of the beam number cannot be carried out; During splicing, unqualified concealed acceptance will prevent subsequent bridge deck and ancillary operations [2]. Therefore, the status of components on the platform can not only be "completed" or "not completed", but also have a variety of statuses, such as "production completed to be inspected, qualified to be delivered, in transit, erected to be reviewed, qualified to be spliced, splicing acceptance completed".

Once a quality problem occurs, the site quality personnel need to feed back the location of the problem, the component number, and the treatment to the shared platform, and the planners can re-determine the construction sequence of adjacent areas and subsequent beam numbers based on this; If only a single component is affected, other released beam numbers can be called to use the equipment. If the problem is the

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same raw material or the same processing technology, the inspection scope needs to be expanded, and the next work of the batch needs to be stopped. So, to achieve "quality discovery - state freezing - cause finding - re-inspection and release - plan adjustment", so that the construction period can not break through the quality barrier, and also avoid the chaos caused to the whole construction section after the quality problem is found.

6. Conclusion

The construction process of the fabricated Viaduct of Chongqing Expressway in Qingdao shows that the key to rapid construction is not simply to improve the production efficiency of the beam yard or the speed of on-site erection, but to form an integrated component supply chain of prefabrication, quality inspection, transportation, hoisting, and connection that can be dynamically scheduled. With components as the basic management unit, the production scheduling, transportation batch, and hoisting sequence of Beam Yard can be adjusted according to the on-site operation surface, transportation window, and component quality status; At the same time, the prefabrication acceptance, delivery inspection, installation measurement, and connection acceptance are set as the "quality gate" of state transition, and only the components that meet the quality conditions can enter the next process. Thus, the quality constraints can be directly embedded into the schedule, so that the schedule lag can be digested through resource rearrangement and plan adjustment, rather than reducing the quality requirements in exchange for the duration.

On this basis, the role of the digital platform should be further shifted from information display to state identification and collaborative decision-making. By unifying component coding, state definition, and problem closed-loop, the digital platform can connect girder field, transportation, construction, supervision, and other participants to improve the efficiency of abnormal information transmission and plan adjustment. For the nighttime construction of urban trunk roads, the precise measurement review, unified lifting instructions, double confirmation, and post-rotation should be implemented in combination with the time window to reduce the risks caused by low illumination, temperature differences, and fatigue operation; For key concealed processes such as joints, process records, acceptance, and re-inspection shall be taken as the basis for release. In general, the collaborative control of progress and quality of the fabricated viaduct should take the dynamic plan as the main line, the quality gate control as the constraint, the digital platform as the support, and the multi-party coordination as the guarantee, to realize the effective allocation of resources and the target control of the construction period under the premise of ensuring the construction quality.

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