Production Technology Requirement of Hong Kong Special Administrative Region on Prefabricated Segment

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Abstract. Prefabricated segmental beam bridge is widely adopted in city construction of Hong Kong, Macao and other developed regions with the advantages of product factory production, high quality control grade, excellent appearance quality, quick and convenient site installation, etc. Short line method prefabrication technology is finally selected, short line matching method technology principle and characteristics are combined for in-depth analysis and summary of template model selection, data monitoring, site casting process, etc. through comparative analysis based on the Hong Kong segmental beam prefabrication project contracted by Dongjiangkou Prefabrication Factory in the paper. Various effective measures are adopted to ensure the production efficiency and product quality of prefabricated parts.

1. Project overview
Dongjiangkou Prefabrication Factory in Machong Town, Dongguan, Guangdong Province undertakes three segmental beam prefabrication projects in Hong Kong. The number of segmental beams is 2838, all beams belong to single box single chamber beams, and they are classified into pier top blocks, standard blocks, steering blocks and PM blocks according to parts. The bottom and top of the box girder are equipped with pre-stressed pipes, and basic dimensions thereof are shown as follows: beam length 2280mm ~ 3400mm, top width 9800mm ~ 17780mm, bottom width 3300mm ~ 8000mm, beam height 2500mm and web thickness 300mm ~ 600mm. The single beam weight is 66 ~ 144t. The client is Hong Kong Special Administrative Region Civil Engineering Development Department and the consultant is AECOM..

2. Main technical quality requirements
1. The project reference specifications mainly include 'General Specification for Civil Engineering in Hong Kong' (GS2006), 'Specification for Concrete Production and Supply Quality' (QSPSC), 'Specification for Steel Reinforcement List, Size, Bending, Blanking and Cutting' (BS8666), 'Hong Kong Engineering Construction Standard' (CS1, CS2 and CS3), and 'Special Specification' (PS). 2. The outer surface finishing grade of the box girder is F5, and the inner surface finishing grade is F2 (as required in GS2006 Specification). 3. C50 concrete with low shrinkage and low creep. 4. Mold removal strength is greater than 20MPa, and lifting strength is greater than 30MPa. 5. Concrete joint error is less than 2mm, and lifting strength is greater than 30MPa. 5. Concrete joint error is less than 2mm, and the pre-stressed pipeline error is less than 5mm.
3. **Comparison and selection of construction technology**

Segmental beam is formed according to close pasting method to ensure that the integrity of adjacent box beam shear keys and the linearity after splicing meet the design requirements. The pouring process of the close pasting method is divided into 'short line method' and 'long line method'.

**Principle of long line method:** prefabricated bottom mold (pedestal) equal to the span length is set, the bottom mold (pedestal) is fixed, the pouring position of side mold moves with the change, which is moved to the next section after the former section is finished. Advantages: linear control of box beam is simple, it is unnecessary to lift the shaped box beam, and less equipment is applied. Disadvantages: it takes up a large site, the requirements on overall site foundation are high, thereby leading to high site treatment costs, and the method is not applicable for small curve radius.

**Principle of short line method:** the linear spatial coordinate system of the bridge beam structure is converted into the prefabricated unit coordinate system, and the adjacent front beam section is used as the matching beam section to control the geometric size and line shape of the to-be-poured beam section, thereby ensuring the matching and splicing accuracy of the adjacent beam section. In the production process, the bottom mold can be moved, the side mold is relatively fixed, and the casting position remains unchanged.

Advantages: it occupies a small area compared with the long line method, concentrated layout is adopted, the method has strong applicability to curved bridge beams, especially horizontal curve and vertical curve bridge beams.

Disadvantages: the method has high control accuracy on template and matching beam, the template and matching beam should be positioned precisely after each demolding, and the prefabricated box beam should be removed from the pedestal in time.

Since the width of box beam in the project is 17.78m, the span of bridge beam is as long as 45m, the maximum beam weight is 144t, short line matching method is more suitable for the project in terms of site layout, cost input, etc.

4. **Key technology of short line matching method**

4.1 **Template design**

When the short line prefabrication method is adopted, the main parts of a standard prefabricated box-beam steel template include: end mold and end mold support system, bottom mold and bottom mold pallet system, side mold system and internal mold system. Template design, as a key link of segmental prefabrication, is directly related to the efficacy of segmental beam prefabrication.

The segmental beam template should be designed as early as possible. The unit should communicate with the bridge beam designer in advance to standardize the size and reduce the variation types. There are many types of segmental beams in the initial drawings in the design process of Liantang template. If a set of templates is matched for each type, the number of templates will be increased greatly, and the cost will be increased. Communication with the designer is needed to reduce the segmental beam types and increase the template universality in the process. Common contents include the follows: box beam structure type, establishment of secondary pouring site, web change,
tension tooth block type, adjustment of beam length and beam width, etc. These factors directly affect the composition of the template.

The common combination is found through analysis and optimization of the drawings. Liantang class A box beam is adopted as an example. Templates of segmental beams are divided into three types, LAP, LAT and LAM respectively. LAP template is mainly used for pouring hollow shell segmental beam at the top of the pier (AP650), which is also applicable to standard (AS350, AS500 and AS650). LAT template is mainly used for pouring standard block segmental beam (AS350, AS500, AS600 and AS500G); LAM template is mainly used for MJ segmental beam. The types of templates have been greatly reduced after optimization.

The end mold system is mainly composed of a fixed end mold, a movable end mold, an end mold support and accessory members. The end mold is used for forming pre-stressed box beam shear key and the mold faces of the pre-stressed tube ports. Since the fixed end mold is the reference of geometric control, the end face perpendicularity and the level of the top surface must meet the design accuracy requirements during installation, and the end mold support must be stiff enough to avoid plane deformation and geometric deviation.

The bottom mold is mainly used for matching the supporting structure of the beam and the template bottom surface of the pouring beam section. The bottom mold control system will be pulled by the bottom mold trolley to the ground track for longitudinal movement and provide three-dimensional adjustment. The bottom mold pallet is equipped with vertical and horizontal hydraulic cylinders, which are controlled by the hydraulic system to realize three-dimensional adjustment of the bottom mold. After the adjustment is completed, the bottom mold will be supported by the adjustable screw system to prevent the template dislocation caused by the pressure relief of the hydraulic system.

The side mold include a side mold and a side mold support. The side mold forms web outside face of the prefabricated box beam and flange bottom face, which is fixed on both sides of the pouring beam. Template movement adjustment function can be realized through the screw rod so that the side mold, the bottom mold and the matching beam are seamlessly fit. The side mold support is divided into an ordinary support structure and an overstatic support structure. The ordinary support structure has low requirements for operators, which is easy to master. However, it is easy to cause local deformation of the template. The overstatic support structure support structure has higher requirements for operators, which is difficult to master, but the efficiency is higher after it is well mastered. In addition, hydraulic adjustability can be adopted if there are enough segmental beams, thereby improving the efficiency greatly.

The internal mold system is used for forming the internal surface of the beam section, including an internal mold, an internal mold sliding support frame, a hydraulic cylinder and an adjusting screw. The internal mold structure is relatively complex, and different box beams can be poured through the coordination and cooperation between among all components of the internal mold.

The concrete surface dislocation is less than 2mm, and the the flatness of 2m range is less than 3mm according to the requirements of F5 surface in GS specification. Moreover, the concrete is compact, uniform in color and smooth in surface without slurry, cracking or flaw. Higher requirements are required on template, especially the exposed surfaces. Therefore, the template design should be carefully considered in terms of material and template precision. The bottom plate and side mold panel are made of Q235 ordinary steel plates aiming at the first template, and they are easy to rust and deform. It is difficult to guarantee assembly accuracy. Q345B cold-rolled steel plate is adopted in the later stage, the template stiffness is improved, and the steel plate is not easy to rust, thereby guaranteeing the apparent quality of segmental beam.

4.2 Steel bar

The segmental beam reinforcement cage is formed on a special pedestal. The pedestal is constructed by welding section steel, which is designed and processed according to the maximum section size of segmental beam. The requirements on reinforcement cage machining precision are high due to varied dimensions and large volume of box beams. It is necessary to repeatedly check plane dimension,
diagonal dimension, elevation and other data. In addition, it is also necessary to set auxiliary marks, active positioning cards and positioning rods, thereby meeting the requirements of binding different beam section reinforcement cages and hoisting reinforcement cage. A multi-point steel frame is adopted for reinforcement cage hoisting. Two rows of hoisting points (18 in total) are set. The force balance of each hoisting point is adjusted by pulling the pulley by hands, thereby ensuring no deformation of the reinforcement cage. The stress is analyzed for the reinforcement cage hanging bracket, thereby ensuring the rigidity and safety.

4.3 Concrete pouring technology
Concrete construction is the final and most critical procedure of component prefabrication. It is necessary to control vibration and casting sequence plans, thereby ensuring the appearance and quality of finished products.

Combination of immersion vibrator and attached vibrator is adopted for concrete vibration. The attached vibrator is mainly arranged on the outside mold of the web. Immersion vibration is mainly applied. When concrete is poured to the joint of the roof and the web, the attached vibrator is opened, and the vibration time is controlled at 10 ~ 15s twice. Installation comparison of attached vibrator is shown as follows.

Plan 1: Two sets are arranged in the middle with a horizontal spacing of 1700mm;
Plan 2: Three sets are arranged in the shape of a plum blossom with horizontal spacing of 1700mm and vertical spacing of 700mm.

The vibration effect of plan 2 is more compact and uniform in color with less surface bubbles through the comparison of vibration under the same conditions.

Pouring sequence: concrete is poured from bottom to top symmetrically and horizontally at different layers. The maximum layer thickness is not more than 50cm. Casting sequence comparison is shown as follows: Plan 1: web casting → bottom plate → panel; Plan 2: bottom plate → web casting → panel;
Chamfering and tooth block honeycomb pitted surface can be avoided according to casting sequence of plan 1 through comparison and selection, and the phenomenon of reverse slurry in the floating mold can be avoided.

4.4 Pre-stressed pipeline

It is necessary to ensure the flatness pre-stressed pipeline and smooth passing of steel strand during segmental assembly. Different pre-stressed systems are divided into temporary pre-stressed systems and permanent pre-stressed systems (as shown in FIG. 13). The internal diameter of the temporary pre-stressed pipeline is 75mm. The permanent pre-stressed pipeline is divided into two types: outer diameter of 87mm and inner diameter of 80mm as well as outer diameter of 107mm and inner diameter of 100mm.

The fixed end face mainly forms a pipeline orifice through the plug plan, which is divided into steel plug, plastic plug and rubber plug. Rubber plug is adopted generally for temporary pre-stressed system, and steel plug or plastic plug is adopted for permanent pre-stressed system. The plug is fixed on the fixed end mold surface of the positioning hole through screws and sealed with tape as shown in the figure:

![Figure 5. Pre-stressed plug splicing figure and field prefabrication picture](image)

The pre-stressed holes between the matching beam and the filling beam are formed by inflatable capsules. The inflatable capsules are divided into pure gum inflatable capsules and trapping inflatable capsules. The design pressure of pure gum inflatable capsule is small, which has little influence on the corrugated pipeline in the curve section. It is not easy to deform the pipe, which has low requirements on pipeline fixation. Therefore, it is suitable for the pipeline in the curve section. The trapping inflatable capsules have larger design pressure, which can effectively prevent the pipeline deformation, but it is easy to hold the curved section of the pipeline straight. It is suitable for straight pipeline. The air pressure should be controlled in inflatable capsules. Pallet should be set to prevent the inflatable capsule from dragging the pipeline during the inflating process. The size of the corrugated pipe is generally 40 ~ 50mm smaller than the designed size so as to ensure the cone-shaped surface at the pipeline orifice, and ensure damage on the corrugated pipe and pipeline plugging when the steel strand passes through the pipeline.

4.5 Prefabrication linear control

Short line method prefabrication control refers that the design linearity of beam body can be ensured by adjusting the spatial position of matching beam each time, including two aspects: matching beam theory installation position and compensation correction of fabrication errors each time. It is assumed that the design linearity of the beam body is the overall coordinate, the to-be-poured adjacent segments are regarded as local coordinates, it is necessary to carry out coordinate transformation for determining the theoretical installation position of the matching beam. Linear control directly affects the quality of the project. Precise measurement and correct regulation of the relative position between the adjacent segments and new segmental template in order to achieve the ideal goal. Stable observation towers and target towers are set in the prefabricated plant firstly. Measuring instruments are installed on the
observation towers, which can be used as the observation stations to measure the control point value on the top surface of the beam of the pedestal. The observation tower, the target tower and measuring instruments on the observation tower should not be displaced during segment prefabrication, or the measuring control system must be re-established. The end template must be vertical, horizontal and square. All line control should be based on the prefabrication curve of bridge beam design target line, thereby moving and adjusting the existing segment (matching segment). Relevant plane and elevation layout are shown in figure 18 and figure 19. After the first segment is poured with concrete, and the top surface is level, four elevation markers and two middle line markers must be completed immediately (see attached figure 20 for details). The above-mentioned six points are measured and recorded again before the matching prefabrication, and then the segment can undergo splicing matching prefabrication.

5. Conclusions
The template is constantly optimized and improved with the progress of the project. The single beam prefabrication efficiency is increased from 7d/piece • single set of template to 3d/piece • single set of template with the improvement of worker operating proficiency, thereby substantially increasing the segmental beam prefabrication efficiency, meeting the owners' higher quality and progress requirements on segmental beam, getting affirmation from Hong Kong owners, and laying a solid foundation for finally finishing contract performance. The quality of the pre-stressed pipeline on site has been significantly improved through continuous technology improvement, and the deviation can be basically controlled within ±5mm during efficiency improvement, thereby meeting the requirements of Hong Kong GS specification.

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