Research On Control Of Precast Alignment Of Short-line Method Precast Segmental Concrete Bridges Based On The Theory Of Four-point Distance

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Abstract: The short-line precast segmental concrete bridge is a concrete bridge which assembles the concrete segments made in advance by the factory through reliable connection, the key of its construction is the linear control in the prefabrication stage, generally, six point coordinate control system is used in cooperation with total station. In this paper, a new four-point distance control system is proposed to coordinate with the level gauge and steel tape for the linear control in the prefabrication stage, which has the advantages of high efficiency, simple operation and no need of measuring tower and target tower, etc. It has been successfully applied in the prefabrication stage of the main beam of the non navigable span bridge of Yueqingwan bridge, which can be used for reference in related projects.

1. Preface
In recent years, with the rapid development of China's economic construction, China's bridge construction industry has entered a stage of rapid development. Large bridges continue to emerge. In the future, bridge construction will be in the direction of standardization and industrialization of component production; structural assembly and assembly; construction equipment mechanization. The short-line precast segmental concrete bridge is a concrete bridge assembled by the factory prefabricated concrete segments through reliable connection. It has the characteristics of less construction prefabricated land, fast construction speed, high control accuracy and small traffic impact under the bridge. After the factory operation, the production equipment can be reused, less consumables, saving resources and costs, mechanization process High degree, labor saving. Because the bridge span structure is divided into several segmental beams from the whole span to form a segmental beam group, the construction method requires high precision of construction work. How to control the position relationship between the segmental beams in the whole construction process has become the key technology of short-line precast cantilever bridge construction[1].

2. Six point coordinate control system
The six point coordinate control system is the most commonly used at home and abroad for the linear control of short-term segment prefact and assembled concrete bridge in the prefact stage. The core is
to select six control points to complete the control of the spatial alignment of the segmental beam and the cross slope of the bridge deck. The specific location of the control point is shown in the figure below.

The line of JHM-JQM is used as the horizontal control line to reflect the arbitrary change of the central axis of the segment beam, so as to control the segment beam group in X-Y Attitude in the plane; the lines of JHL-JQL and JHR-JQR are used as elevation control lines on the left and right sides respectively, reflecting any surface change that may occur on the upper surface of the segment beam, so as to control the attitude of the segment beam group in the X-Z plane and the cross slope attitude of the segment beam group.

The key of the six point coordinate control system is that the three-dimensional coordinate system based on the axis of "measuring tower target tower" does not change during the pouring process. However, there are various uncertainties in the construction site, especially when the prefabrication site is built on the soft soil foundation, it may cause the axis of "measuring tower target tower" to change.

As shown in Figure 2: after the pouring of segment beam i, although the target tower has a $\Delta Y$ displacement relative to the measuring tower, the relative position relationship between the matching beam i-1 and the cast-in-place beam i in the X-Y plane has not changed, that is to say, the horizontal pouring result of segment beam i is perfect, and its attitude in the X-Y plane fully conforms to the control target. For the perfectly poured beam segment I, when it matches the prefabricated beam segment i + 1 of the next segment, it only needs to provide it with the control target calculated in the early stage, without any adjustment measures.

However, the axis of "measuring tower target tower" does not change before and after the default pouring process of the six point coordinate control system. Therefore, the plane displacement $\Delta Y$ of the target tower relative to the measuring tower cannot be reflected in the back measurement data collected by the total station, only the plane displacement $y_0$ of the fixed end mold midpoint O relative to the axis of "measuring tower target tower" can be measured. The "six point coordinate" control system will determine by itself: during the pouring process of segment beam i, the beam making pedestal and matching beam i-1 are perpendicular to the axis direction of "measuring tower target tower", and $y_0$ offset occurs at the same time. After the system corrects the offset $y_0$, as shown in Figure 3 below.
Due to the six point coordinate control system, the original angle of \( \theta_i \) on the axis of "measuring tower target tower" was mistakenly judged as the redundant angle of \( \theta_i \) between the axis of matching beam \( i-1 \) and the axis of cast-in-place beam \( i \). According to the "six point method" control theory, the attitude of the segment beam in the X-Y plane needs to be adjusted. For the convenience of understanding, take the straight bridge as an example, that is, the attitude control line in the X-Y plane of the short-line precast segmental beam group is a straight segment.

As shown in Fig. 4: after determining the deflection angle of \( \theta_i \) between beam section I axis and target axis, when precast beam section \( i + 1 \), reverse deflection \( (\theta_i + \theta_{i+1}) \) angle; after perfect pouring, when precast beam section \( i+2 \), deflection angle of \( \theta_{i+1} \) again, so as to achieve the linear attitude adjustment of segment beam group in X-Y plane. However, because the system misjudges the actual situation of the pouring site, the actual situation of the axial control line in the segment beam group is shown in Figure 5 after the adjustment [5][6][7].

In order to avoid this kind of error and improve the efficiency, the four point distance control system can be used for the linear control in the prefabrication stage.

3. Four point distance control system

(1) Elevation and attitude control of pouring section

In the four point distance control system, for the elevation and attitude control of segment beam group, an elevation control line is set on the left and right of the upper surface of segment beam, and two elevation control points are set on each control line. The "JHL" point on the upper surface of the cast-in-place beam segment is taken as the elevation datum point under the local coordinate system, as shown in Fig. 6.

The precise level is used to replace the total station as the measuring instrument for the control point elevation measurement. The level is erected on the beam making pedestal, and the height difference between the other seven elevation control points and the "JHL" points is measured respectively. Through the height difference between the elevation control points, the relationship between the matching beam and the cast-in-place beam is reflected, and finally the elevation attitude control data of the segment beam group is obtained.
(2) Horizontal attitude control of pouring section

In the four-point distance control system, there is no need to measure tower and target tower, and a new horizontal attitude control coordinate system is used. For the elevation lines on the left and right sides of the pouring section, the positions of the elevation control points are relative. If two corresponding points can be ensured without relative displacement before and after the pouring process of the pouring section, the connection between them can be regarded as one axis. For this reason, special L-shaped embedded parts and cover plates are designed.

Before the concrete pouring, place the embedded L-shaped components on the four positioning points JHL, JHR, JQL and JQR of the pouring section in advance, and fix them by connecting with the fixed end formwork and the embedded cover plate on the matching section. As shown in Fig. 7 and Fig. 8.

Due to the use of matched prefabricated components, the location points JHL and JHR at the fixed end formwork side did not change with respect to the fixed end formwork before and after the segmental beam pouring. Connect points JHL and JHR to obtain line L1, which is the vertical bisector of line L1, so that the line is the X-axis of local coordinate system; project the middle point M1 of line L1 along the x-axis to the upper surface edge of cast-in-place beam (fixed end formwork side), so as to obtain point O1 as the origin of local coordinate system; make a line parallel to line L1 through point O1, so that the line is the Y-axis of coordinate system. As shown in Fig. 9.
Therefore, the problem of horizontal attitude control in the pouring section is transformed into the problem of measuring the distance between the positioning points in the X-Y plane. The steel tape is used to measure the distance and control the horizontal attitude of the pouring section.

The segment beam after pouring is regarded as a rigid body, that is to say, for the matched beam, the relationship between the four positioning control points on its upper surface is determined. Therefore, we only need to control the plane coordinates of two positioning points on the matching beam to determine its plane attitude in the local coordinate system. In the setting out stage, considering the safety and convenience of the construction setting out, PHL and PHR control points are selected as the setting out targets, and \(L_{JHL-PHL}, L_{JHR-PHR}, L_{JHL-PHR}, L_{JHR-PHL}\) are selected as the setting out control data, as shown in Figure 10. In the construction backtesting stage after the completion of pouring, PQL and PQR control points are selected as backtesting targets, and the length of \(L_{JHL-PQL}, L_{JHL-PQR}, L_{JHR-POL}, L_{JHR-PQR}\) of the line section is measured, so as to achieve the positioning purpose of matching beam after the completion of pouring, as shown in Fig.11.

The four point distance control system uses level and steel tape instead of the traditional total station, which has high efficiency and simple method. The local coordinate system is transformed from the external datum of the measuring tower to the internal datum of the cast-in-place section (fixed end formwork). It avoids the influence of the settlement, deflection, fixed end formwork settlement and deflection of the measuring tower on the precision of segment prefabrication, which is inevitable in the six point control system and has a great influence on the precision of prefabrication.

4. Engineering application
Yueqing Bay Bridge and connection project in Zhejiang Province starts from Shatoumen, South Town of Wenling City, and connects to Taizhou Bay Bridge and connection project in Zhejiang Province. The superstructure of non navigable span bridge adopts: prestressed concrete prefabricated continuous
box girder, standard joint length of 5 spans and one joint (5 × 60m), and 3808 beams of non navigable span bridge, all of which adopt segmental prefabricated cantilever structure.

![Figure 12. Cross section of box girder of non navigable span bridge of YueQingwan Bridge(unit: cm)](image)

In order to compare the differences between the two in the horizontal attitude control of prefabricated segments, two systems are used for back measurement after the completion of a certain piece of casting. The total station measurement of six point coordinate control system adopts two rounds of forward and backward mirror measurement to take the average value. The four point distance control system considers temperature correction, length correction, vertical curvature correction and tension correction. The data of 1 # block axis deviation and beam length calculated by two kinds of measurement results are as follows.

| Item          | Six point coordinate control system | Four point distance control system |
|---------------|------------------------------------|-----------------------------------|
| Axis deviation (mm) | -3.1                               | -2.6                              |
| Beam length (m)    | 2.4930                             | 2.4932                            |

The deviation of axis of a certain 1 # block obtained by the six point coordinate control system and the four point distance control system is 0.5mm, and the beam length difference is 0.2mm. Therefore, the six point coordinate control system and four point distance control system are used to control the alignment of the prefabricated section of the non navigable span bridge of YueQingwan bridge.

5. Conclusions
In the prefabrication stage of short-line precast segmental concrete bridge, the total station and six point coordinate control system are usually used to control the alignment. The key of the six point coordinate control system is that the three-dimensional coordinate system based on the axis of "measuring tower target tower" does not change during the pouring process. However, there are various uncertainties in the construction site, especially when the prefabrication site is built on the soft soil foundation, which may cause the axis of "measuring tower target tower" to change, and the prefabrication error caused by it is difficult to find and will be accumulated section by section. This paper discusses a new four point distance control system, which does not need measuring tower and target tower, uses level to control elevation, uses four point distance to control axis deviation and beam length, and has the characteristics of convenient operation and high efficiency. In the prefabrication stage of the main girder of the non navigable span bridge of YueQingwan bridge, two kinds of control systems are used simultaneously to control the prefabrication alignment, and good results are obtained, which can provide reference for relevant projects.

References
[1] Tiedong Qi, Yantao Du, Bo Peng. Sensitivity Analysis of Cantilever Construction Process of Long-Span Continuous V-Structure Composite Bridge[J]. IOP Conference Series: Earth and Environmental Science, 2019(5):052045.
[2] Li Qiyong, Tian Shengyu, Feng Yuanlin, Li Jie. Analysis on the influencing factors of short-line
precast segmental and assembly [J]. Highway, 2019 (12): 156-161.

[3] Yang Sheng, Yang Wei. Research on Key Technology Control of Prefabrication and Assembly of Urban Bridges Using Short-Line Method [J]. Journal of China & Foreign Highway, 2019 (4): 89-96.

[4] Zhou Lingyu, Zheng Heng, Hou Wenqi, Yin Guowei. Improved adjustment method for linear error of precasting segmental box girder by short-line match method[J]. Journal of Huazhong University of Science and Technology(Natural Science Edition), 2016 (9): 99-104.

[5] Li pingjie, Huang Guozhong, Dai Yuwen. Geometric Alignment Control Method in Bridge Segmental Pre-production and Programming [J]. Construction Technology, 2017 (s): 862-865.

[6] Wang Dianwei. Construction Techniques for PC Box Girder Prefabricated by Short-Line Match Casting Method [J]. World bridges, 2016 (3): 25-29.

[7] Liu Haidong, Hou Wenqi, Luo Jin. Three-dimensional geometric alignment control method for short-line matching segmental precast girder assembling bridge [J]. Journal of Railway Science and Engineering, 2017 (4): 769-778.