Research on Key Monitoring and Measurement Parameters in Synchronous Top-Pushing Construction of Steel Box Girders

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Abstract. The synchronous top-pushing method of construction offers advantages such as a relatively short construction period, smooth pushing process, and simplified traffic management. In recent years, it has been widely adopted for constructing overpass bridges on operational highways. Currently, there are no explicit regulations regarding the monitoring and measurement parameters for the synchronous top-pushing construction of steel box girders. This paper, based on an engineering case study, investigates the impact of monitoring and measurement parameters on the primary internal force and geometric state parameters during the synchronous top-pushing of steel box girders. By comparing multiple measured values with theoretical values and evaluating their influence on girder pushing control, it is recommended that key monitoring parameters should focus on the lateral deformation coordination (north-south side displacement difference), deformation coordination between the main girder and guide girder, and settlement of support points.

Keywords: Steel box girder; Top-pushing construction method; Monitoring and measurement; Detection parameters.

1 Introduction

The construction methods for steel box girder bridges crossing operational expressways primarily consist of the jacking method and the hoisting method. The hoisting method imposes stringent requirements on traffic control during construction, extends the construction period, and demands advanced hoisting equipment. While it is relatively suitable for sections with lower traffic volumes, the complexity and unpredictability of the construction process necessitate rigorous monitoring.[1-4] In recent years, as the number of expressway bridge constructions has increased, the synchronous jacking method for steel box girders has evolved into a mature, efficient, and high-quality construction technology.[5-10] However, there are currently no standardized regulations regarding the monitoring and measurement parameters for this technique. This paper examines the impact of monitoring and measurement parameters on the primary internal force and

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geometric state parameters using the example of a 1-60m steel box girder jacking project at a cross-line interchange in Jincheng City, Shanxi Province.

2 Main Control Threshold Selection

According to the "Technical Specifications for Construction of Highway Bridges and Culverts" JTG/T 3650-2020, the threshold conditions are established based on the following warning criteria:

(1)During the jacking process, if welds or node plates of the steel structure beams show signs of detachment or cracking;

(2)If instability phenomena occur during the jacking process, including wind-induced instability, jacking instability, or encroachment on traffic boundaries;

(3)If the instantaneous vertical bending deflection displacement of the steel structure beam exceeds theoretical values or is greater than 0.1% of the span (6mm) within 5 minutes after each construction stage, or if lateral bending deflection exceeds 20mm;

(4)If welds of the steel structure beams crack or stressed steel components exhibit permanent bending deformation.

Through on-site construction monitoring, the following engineering inspection objectives are achieved:

(1)Monitoring the strain in the steel at critical sections of the steel box girder during key jacking processes;

(2)Measuring the deflection of the bridge at critical sections of the steel box girder during key jacking processes;

(3)Issuing warnings based on on-site detection data for potential issues such as longitudinal overturning, wind-induced instability, and bottom plate buckling during the jacking process;

(4)Coordinating with the construction unit to maintain real-time monitoring of each jack, including lifting height, jacking displacement, and jack oil pressure, to ensure synchronized operation of all jacks.

3 Introduction to Engineering Case Studies

This project is located in Jincheng City, Shanxi Province, and involves the construction of an overpass across the G55 ErGuang Expressway Changjin Section using the synchronous jacking method. The box girder features a single-cell, four-compartment section with straight web plates, maintaining a uniform cross-section throughout. The girder height is 2.75 meters, with a top width of 18 meters and a span length of 60 meters. Both the top and bottom slabs have a consistent 2% single-sided slope. The plan view of the box girder is situated within a horizontal curve with a radius of 400 meters, while the longitudinal profile follows a vertical curve with a radius of 1400 meters. The cross-sectional, elevation, and plan views of the box girder are illustrated in Figure 1 to Figure 2.

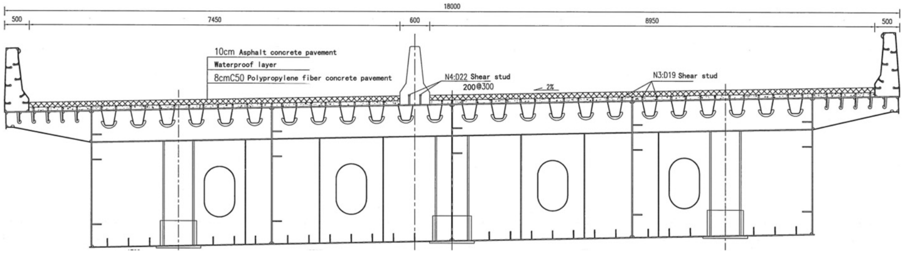


Fig. 1. Typical cross-sectional view of box girder.

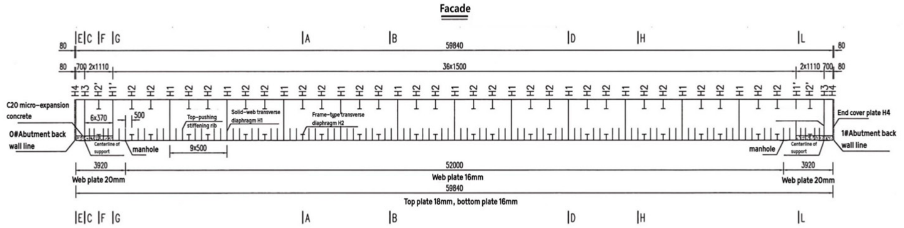


Fig. 2. Elevation view of box girder.

The design of the jacking support for the main jacking construction stage is based on the structural requirements of the jacking equipment and the maximum reaction forces encountered during the jacking process. The schematic diagram of the temporary support structure is shown in Figure 3. A total of seven temporary support points are utilized, with L1 to L5 (spaced 15 meters apart) serving as ground supports. These supports are founded on concrete strip footings measuring 2m*4m*0.8m to accommodate the jacking devices.

For the jacking supports between L6 (15 meters from L5 on the high-speed downward side) and L7 (approximately 29.7 meters from L6 on the high-speed upward side), each group consists of four Φ609*7mm steel pipes arranged in a 2.5m (longitudinal)*2m (transverse) grid. The foundation for these supports is an enlarged footing measuring 5m*5m*0.8m. The connecting system utilizes 14a I-beams, while the top of the columns features a three-piece 40a I-beam transverse distribution beam, spanning 3.5 meters. Above this transverse beam, a five-piece 63a I-beam longitudinal jacking platform, also 3.5 meters long, is installed. The step-by-step jacking equipment is placed on this platform. Along the bridge direction, handover pads are positioned in front of and behind the jacking equipment (as shown in Figure 4). These pads are only activated during jacking handovers to provide length compensation support.

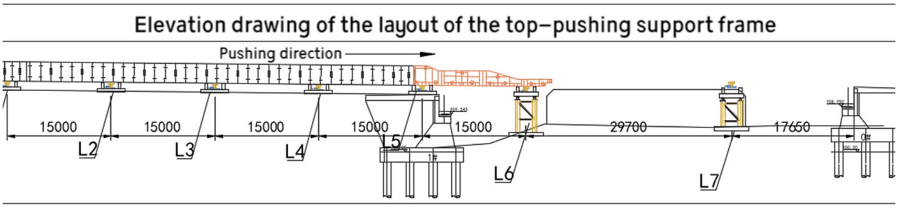


Fig. 3. Temporary support layout diagram.

Fig. 4. Temporary support on-site layout diagram.

4 Monitoring Results and Discussion

The main monitoring parameters for the jacking operation include: monitoring of the external environment during jacking construction, monitoring of the displacement of the beam, monitoring of the strain of the beam, monitoring of the coordination of displacement between the beam and the guide beam during the jacking process, observation of the welds of the beam during jacking, and observation of the displacement of the temporary abutments for jacking.

4.1 Data Testing and Processing

Test control: After applying the jacking load, maintain a static condition for 2 minutes to observe the structural response (including strain, deflection, and alignment). Collect strain and displacement data during this period. Based on the observed data, determine whether it is safe to proceed to the next process and evaluate if the threshold for the next level of load needs adjustment.

Data collection: Following the application of the jacking load, continuous online monitoring of displacement and strain at critical observation points is conducted. Once all monitored data have stabilized, complete the data collection process.

5 Data Temperature Correction

During the jacking process of the steel beam, continuous temperature monitoring was conducted. The results indicated that the lowest temperature reached -2℃ and the highest temperature reached 23℃ during the jacking process. Based on the measured stress, displacement, and temperature data, corrections were made to account for the variations in steel structure stress and linearity within this temperature range.

Throughout the 24-hour monitoring period, both displacement and temperature changes were recorded, as shown in Figure 5. The temperature difference between the interior and exterior of the beam was approximately 10℃. To accurately capture the small displacements, an automated dynamic data acquisition system equipped with dynamic strain sensors was employed for detailed analysis.

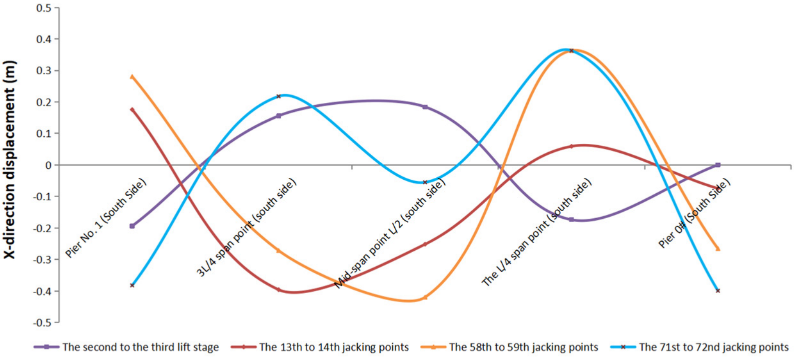


Fig. 5. Test values of temperature changes inside and outside the beam body.

The temperature changes inside and outside the beam and the overall displacement of the beam were observed. The observation results are detailed in the attachment. A graph of the temperature difference of the beam versus the overall displacement of the beam was drawn. On this basis, the polynomial regression analysis method was used to fit the relationship between temperature and beam displacement, and the temperature correction curve of the beam was obtained.

5.1 Monitoring of Beam Displacement

Due to significant variations in beam displacement across different working conditions during the jacking construction, as well as considerable differences in the stabilization time of beam displacement and the jacking or moving time in each jacking process, the stage displacement monitoring primarily adopts the change value between two consecutive jacking completions as the detection result. Additionally, the influence of steel plates placed on the upper part of temporary support points is considered. For this analysis, typical working conditions within each interval from working condition 1 to working condition 9 are selected.The monitoring results of the transverse displacement (X direction) of the beam body during the top-pushing construction stage are shown in Figure 6 to Figure 7.

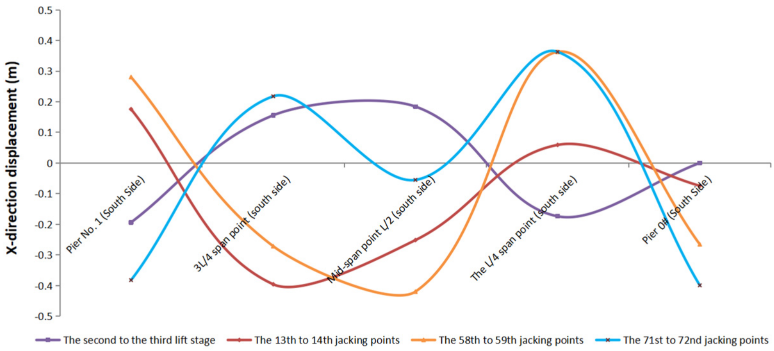


Fig. 6. Monitoring of beam body displacement in the X direction during the top push process from 0 to 30 meters.

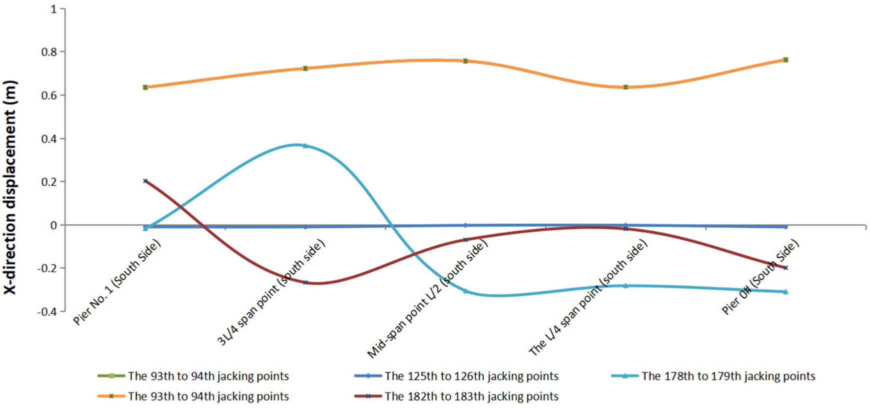


Fig. 7. Monitoring of beam body displacement in the X direction during the top push process from 30 to 60 m.

From the displacement of the beam body before and after each typical jacking stage under various working conditions, it can be known that the displacement of the beam body is relatively large at different stages. When the beam body moves to the position where it leaves the rear support point and enters the new temporary support pier, the displacement is relatively large. The displacement range of the beam body is within [-0.4, 1.0], and the maximum displacement of the beam body is within the set threshold of 6mm. Moreover, the synchronous jacking process is relatively stable.

From the displacements of the beam body before and after each typical jacking stage under various working conditions, it can be known that the beam body has relatively large displacements at different stages. When the beam body moves to the position where it leaves the rear support point and enters the new temporary support pier, the displacement is relatively large. The displacement range of the beam body is within [-0.4, 1.0], and the maximum displacement of the beam body is within the set threshold of 2mm.

A control analysis is conducted on the Z-direction displacement difference between the north and south side beams under the aforementioned typical working conditions. The analysis results are presented in Figure 8.

From the analysis results of the Z-direction displacement difference between the north and south sides of the beam shown in Figure 8, it is evident that the maximum displacement difference during the typical jacking stage is 0.024 mm, which remains within the set threshold.

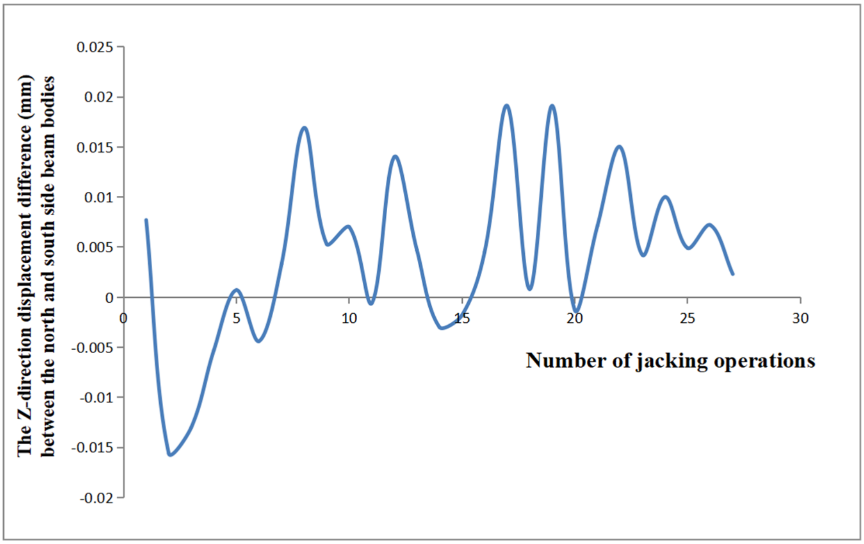


Fig. 8. The Z-direction displacement difference of the beam body during the top-pushing process.

The maximum displacements during each jacking, pushing, and lowering construction phase were recorded using an automated data acquisition system. The results indicate that the maximum dynamic displacement in the Z-direction at the bottom observation points of the beam during each jacking stage is 9.4 mm. Ignoring the influence of the beam bottom slab elevation, the displacements at all observation points are generally within normal limits. However, during the on-site jacking process, significant variations in the height of the steel plate cushion layer caused substantial displacements, particularly when the jacking route deviated from the designed path at the lower part of the web reinforcement section.

An automated data acquisition system was used to analyze the displacement of the beam during a single jacking stage. The time-history curve for a typical stage is presented in Figure 9. The results show that the displacement of the beam during the typical stage remains within the normal range, with no significant fluctuations observed.

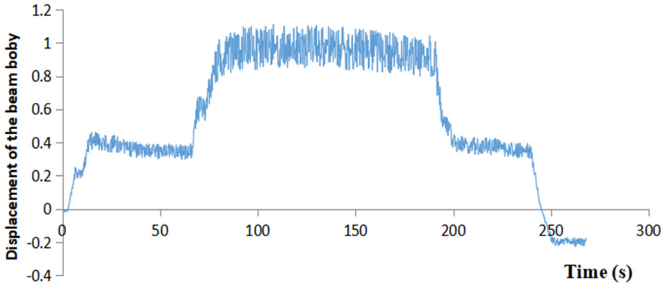


Fig. 9. Time-history curve of beam displacement in the Z direction during a single stage of the top-pushing process.

5.2 Strain Monitoring of the Beam Body

The stress monitoring during each stage of the jacking construction primarily depends on the stress changes observed at each construction phase. The stress variations in the main beam are measured using intelligent string-type strain gauges pre-welded at designated sections of the beam. Measurements are conducted according to the specified frequency. Given the numerous construction conditions that require monitoring, data from selected conditions were used to generate the stage-specific stress-displacement diagram of the beam as shown in Figure 10.

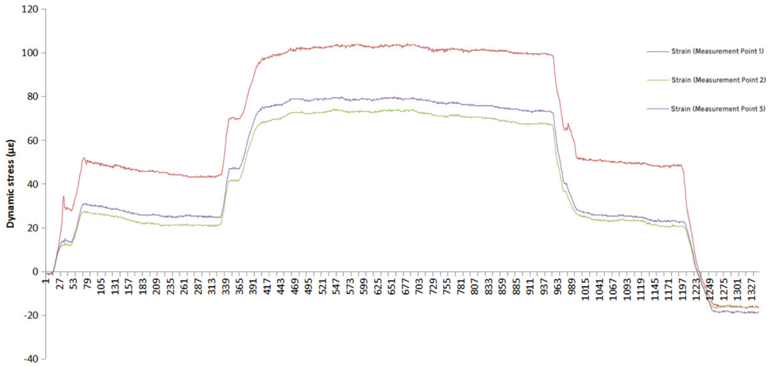


Fig. 10. Stress diagram of the main beam's stress control section.

5.3 Analysis of the Displacement Coordination Between the Beam Body and Guide Beam During the Jacking Process

Steel guide beams serve as a critical component in the jacking construction of steel box girders, fulfilling roles in guiding, supporting, and transmitting forces. Current research on the construction monitoring of guide beams during the jacking of steel box girder bridges primarily focuses on structural displacement monitoring and stress monitoring.

By analyzing the monitoring data, the force state of the structure can be comprehensively understood, providing a basis for construction adjustments and safety assessments.

In this study, particular attention is given to the displacement coordination between the guide beam and the main girder during the jacking process. After the guide beam enters the support phase, typical jacking conditions are selected to record the displacement difference between the main girder and the guide beam, thereby evaluating the related issues of displacement coordination. During data collection, since the displacement difference between the main girder and the guide beam is relatively small, stress sensors are welded to both components. The difference in the data changes from these stress sensors serves as the basis for judgment. The monitoring results are presented in Figure 11 below.

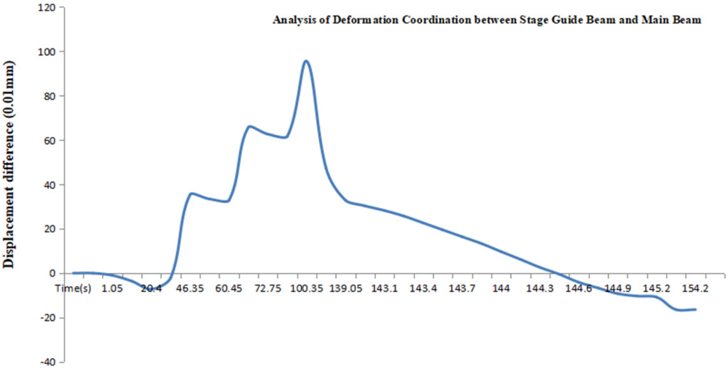


Fig. 11. Analysis of Displacement Coordination between Guide Beam and Main Beam.

5.4 Displacement Analysis of Temporary Piers During Top-Pushing Construction

Table 1. Displacement Table for Temporary Piers in Typical Top-Pushing Condition

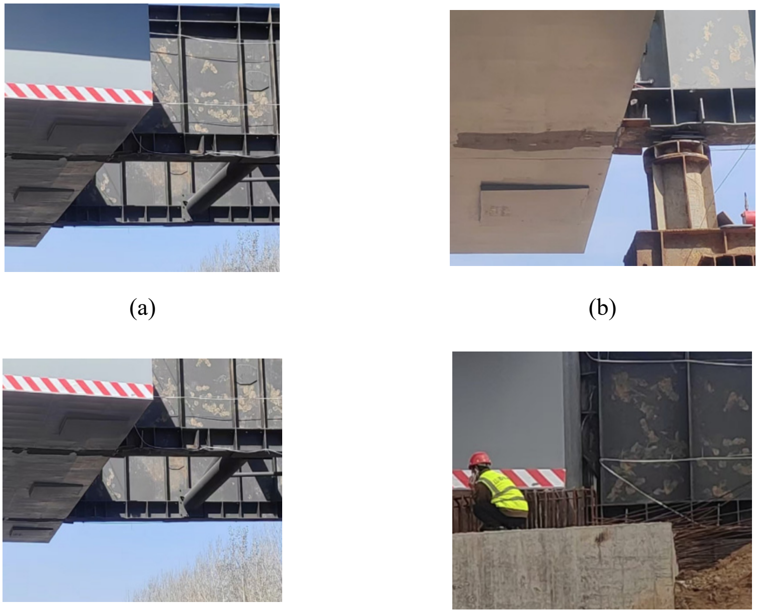
The number of vertices	Location	X (mm)	Z (mm)	The number of vertices	Location	X (mm)	Z (mm)
The 72nd to 73rd ones	Upper part	-5.4	-0.3	The 72nd to 73rd ones	Upper part	-5.4	-0.3
	Central region	-5.0	-0.3		Central region	-5.0	-0.3
	Lower part	-4.8	0.2		Lower part	-4.8	0.2

During the top-pushing process of the beam, particular attention was focused on the displacement of the No. 1 temporary pier. To this end, displacement monitoring points were established at the upper, middle, and lower sections of the No. 1 pier, and data were collected at key stages before and after the beam reached the pier. The results are summarized in Table 1. The primary direction of inclination for the temporary pier aligned with the movement of the beam, with a maximum displacement of 5.4 mm.

Settlement of the temporary pier was relatively minor, with a maximum settlement of 0.7 mm.

5.5 Weld Seam Inspection of the Beam During the Jacking Process

In addition to performing ultrasonic testing of the welds before and after the jacking process, stress monitoring and visual inspection of the weld areas were conducted during the jacking. No significant damage was observed in the weld regions of the beam both prior to and following the jacking. Figure 12 present relevant photographs of the welds taken during the jacking process.



(a) (b)

(c) (d)

Fig. 12. Weld seams of the beam during the jacking process

6 Conclusion

Based on the results and discussions presented above, the conclusions are obtained as below:

(1)During the beam jacking process, vertical displacement, lateral displacement, and the differential displacement between the north and south sides were all maintained within the specified limits. Given that X and Z direction displacements can be monitored through on-site observations and jacking pressure, it is recommended to prioritize the difference in deformation between the north and south sides (deformation coordination) as a key monitoring parameter. The X and Z direction displacements should serve as auxiliary detection parameters, while deformation coordination of the north and south sides should be considered a critical monitoring parameter.

(2)Stress levels at each test section of the main beam during the bridge jacking construction remained within the safe control range, and the stress control results met both design and specification requirements.

(3)Once the leading beam and the main beam enter the cooperative load-bearing phase, particular attention should be given to the deformation coordination of the combined structure.

(4)No significant damage was observed in the welds of the beam before and after jacking. It is recommended to classify weld inspection as an auxiliary parameter.

The primary inclination and movement direction of the temporary abutment align with the beam's movement direction, with a maximum displacement of 5.3 mm and a maximum settlement of 0.7 mm. It is recommended to prioritize this as a key monitoring parameter.

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