Research on Cost Control of Steel Box Girder Fabrication and Installation Based on Refined Management

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Abstract: Steel box girders, as a crucial structural component in modern bridge engineering, have a significant impact on the cost management of construction projects during their fabrication and installation processes. This paper systematically analyzes the main cost components and influencing factors of steel box girder fabrication and installation, based on a specific engineering case study. It proposes comprehensive cost control measures, including refined management of labor, materials, and machinery costs, optimization of construction processes, and strengthening of on-site management. Additionally, the paper emphasizes the critical role of contract management and cost calculation rules, while exploring the potential applications of information technology in cost control. The findings demonstrate that scientific cost control measures can not only effectively reduce project costs but also enhance economic benefits and management efficiency, providing valuable insights for similar projects

***Keywords*:** steel box girder, cost control, construction process, contract management

1. Introduction

Steel box girders play a pivotal role in modern bridge engineering, serving as a crucial structural component in bridge construction [1,2]. The key challenge in bridge project management is how to effectively control the fabrication and installation costs of steel box girders while ensuring the quality and safety of the construction process. Currently, both domestic and international research on the cost management of steel box girder fabrication and installation primarily focuses on establishing models to analyze key influencing factors, with the aim of identifying the optimal cost control strategies from a theoretical perspective [3,4]. These models typically consider various factors such as design schemes, construction processes, material selection, and construction equipment, striving for precise cost predictions through quantitative analysis. However, due to the numerous and complex influencing factors involved in the fabrication and installation of steel box girders, significant time and effort are required in the practical application of these models [5]. To address these issues, this paper combines the construction case study of the Kunes Interchange E Ramp Bridge to explore how refined management measures can effectively control costs during the fabrication and installation of steel box girders, with the aim of providing valuable insights for similar projects.

2. Project Overview

The Kunes Interchange E Ramp Bridge has a span arrangement of (30+40+40+30) meters. The bridge consists of a single span, with the superstructure made of a steel continuous box girder. The bridge is located on a left-hand circular curve with a radius of 125 meters. The cross slope of the bridge deck is -4%, and the longitudinal slope of the profile is -3%. The main girder is a single-box, double-chamber fully welded steel box girder with three longitudinal web plates. The standard height of the beam is 1.8 meters (at the design elevation), with a top plate width of 9 meters and a bottom plate width of 6 meters. The traffic lanes are equipped with 0.5-meter-wide crash barriers on both the inner and outer sides. The top plate thickness ranges from 16 to 22 mm, the web plate is 16 mm thick, and the bottom plate thickness varies between 16 to 24 mm. The steel box girder is designed along the entire route with a total length of 140 meters. To ensure the alignment of the main girder after the bridge completion, a preset camber is applied throughout the bridge. The camber at the mid-span is 4 cm, with a parabolic transition. The cantilever on both sides of the steel box girder is 1.5 meters wide, with a height of 0.5 meters at the root and 0.3 meters at the end. The standard spacing between diaphragms is 1.5 meters, with a thickness of 12 mm. The relevant data for the standard cross-section of the steel box girder is shown in Table.1.

Table 1. Standard Cross-Section of the E Ramp Steel Box Girder

Number	Number of Spans	Span Length (m)	Beam Height (m)	Bridge Width (m)	Weight (t)
1	0#~4#	30+40+40+30	1.8	9	723.1

The overall layout is shown in Figure 1.

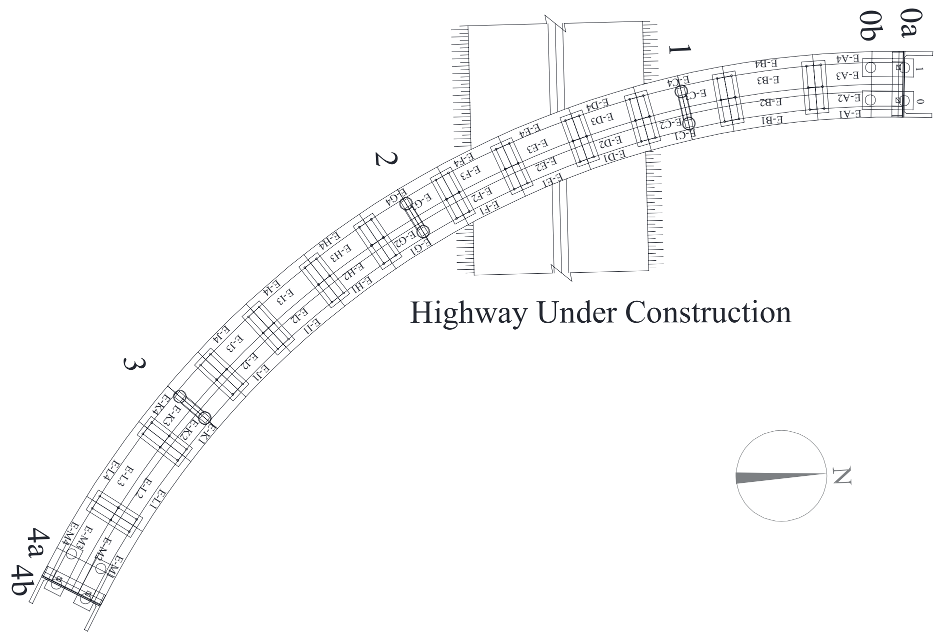

Figure 1. Structural displacement-time curve

3. Cost Control

The fabrication and installation costs of steel box girders consist of steel plate material costs, fabrication costs, testing costs, transportation costs, installation costs, construction site management costs, and electricity costs. The material costs include the main material costs, auxiliary materials, carbon dioxide, oxygen, liquid oxygen, welding wire, ceramic pads, and carbon rods. Fabrication costs consist of pre-treatment, cutting, unit component assembly, in-situ formwork, box assembly, pre-assembly, anti-corrosion coating, and reverse logistics. Testing costs include weld inspection, radiographic testing, and coating thickness measurement. Transportation costs and installation costs include on-site welding, assembly, hoisting, scaffolding, and foundation concrete costs. The construction site management costs consist of both on-site and off-site civil construction management activities.

3.1 Material Cost Control

3.1.1 Material Requirements

According to the design drawings, the materials for this bridge are Q345qE steel, which should be delivered in a normalized or thermomechanical control processing (TMCP) state. The total average thickness of the steel plates must not have negative tolerances, and the negative tolerance of a single batch thickness should not exceed 2%.

3.1.2 Material Requirements Calculation

Based on the design segment division requirements, the steel box girder for this span was further subdivided and material quantities were calculated based on the detailed shop drawings. A total of 75 different specifications of plate sizes and 9 different thicknesses are required, namely 8mm, 10mm, 12mm, 14mm, 16mm, 20mm, 22mm, 24mm, and 30mm, with a total material requirement of 770 tons.

According to the material consumption analysis over the past three years, the required quantities for consumables are as follows: 8 tons of solid core welding wire, 2.8 tons of flux-cored wire, 724 bottles of carbon dioxide (12 kg), 182 bottles of oxygen (40L), 12 bottles of liquid oxygen (195L), 115 bottles of propane (10 kg), 32 boxes of carbon rods for carbon arc gouging, and 723 boxes of single-side welding ceramic pads.

3.1.3 Control of Main Material Costs

To control the costs of steel plate materials, timely price inquiries were conducted to form quotation documents. After comparison, local suppliers such as Baosteel and Jiugang were selected, and a centralized procurement tender was held by the company to determine material prices and supply periods. Through centralized procurement, strategic cooperation agreements were formed with manufacturers or suppliers, thus minimizing the material procurement costs.

3.1.4 Control of Auxiliary Material Costs

Auxiliary materials, such as G49a4u series welding wires (solid THQ50C, flux-cored THY-51B), carbon rods, and ceramic pads, were purchased according to the design requirements. For welding materials, well-known domestic brands such as Jinqiao and Daqiao were selected. For gases (carbon dioxide, oxygen, liquid oxygen), suppliers of liquefied gas within 20 kilometers of Urumqi City were chosen. After inspecting these manufacturers, price negotiations and comparisons were conducted, or material procurement tenders were organized. Suppliers were selected based on a competitive process, and long-term cooperative relationships were established with them. A customer evaluation system was set up to reduce the procurement costs of auxiliary materials.

During the implementation, management staff maintained a usage ledger to ensure strict process control. For materials, an “old-for-new” exchange system was used for welding wire, with a detailed usage ledger maintained. Additionally, a welding wire and gas usage quota confirmation document was signed with the fabrication teams, with limits set on material allocation and consumption. Reward and penalty measures were put in place to further control the material wastage rate of auxiliary materials.

3.2 Fabrication and Processing Cost Control

3.2.1 Reasonable Segment Division

Based on the structural characteristics, transportation conditions, and actual site conditions of the Kunes Interchange E Ramp Bridge steel box girder, the transverse single segment of the E Ramp is divided into four transport blocks, numbered 1 to 4. The steel box girder is also divided longitudinally into 13 blocks, numbered A to M. The schematic diagrams of the steel box girder’s cross-section and longitudinal division are shown in Figure 1 and Figure 2.

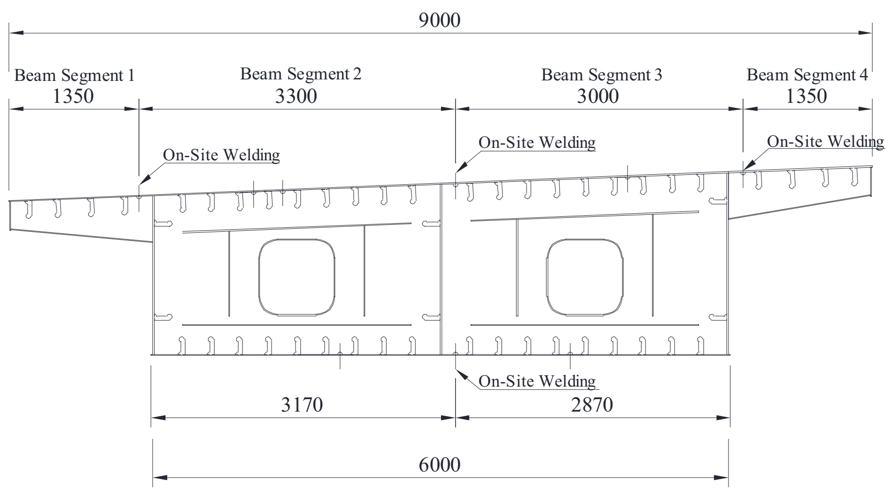

Figure 2. Schematic Diagram of the Transverse Section Division of the E Ramp Steel Box Girder

3.2.2 Material Cutting Cost Control

Before cutting, all component drawings are arranged, and the material loss rate is calculated. The layout drawing is reviewed and then issued to the workshop for production. The remaining frame materials are arranged according to the dimensions of the box girder’s formwork, filler materials, and embedded parts. Prior to cutting, a technical briefing is provided to the cutting personnel, requiring them to classify and store edge strips of different thicknesses (greater than 50 mm) separately, ensuring that materials are sorted and neatly arranged. These materials are intended for secondary use in light steel construction projects.

The optimized material cutting layout is shown in Figure 3.

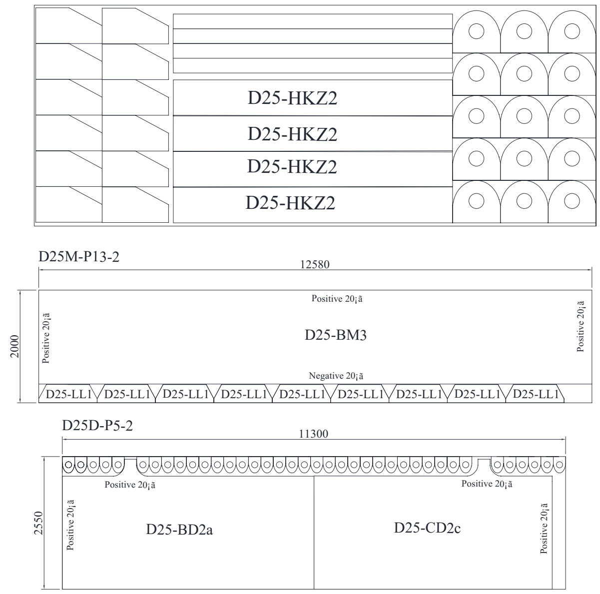

Figure 3. Schematic Diagram of Steel Plate High Utilization Layout

3.2.3 Processing Cost Control

Based on the segmented drawings confirmed with the design unit, technicians separately calculate the quantities of penetrated welds (1947.32 m) and corner welds (3905.16 m). The processing costs are divided into pre-treatment, flattening, cutting, unit assembly, final assembly, pre-assembly, and the logistics costs between each process. The steel box girder is fabricated using a reverse assembly process, following the sequence of "top plate-diaphragm-web plate-cantilever block-bottom plate" to achieve three-dimensional progressive assembly and welding. The outer formwork is the jig, and the diaphragm serves as the inner formwork. The key focus is on controlling the alignment of the bridge, the geometric shape and dimensional accuracy of the steel box girder, and the precise matching of adjacent interfaces.

The processing cost is calculated based on the structural form and complexity of the diaphragm, web plates, and top plates, as well as the number of welds. After predicting the cost, the decision is made to either use in-house teams or subcontract to market teams. A cost-benefit and schedule analysis are conducted for both processing methods, and the best team is selected based on their processing capacity, welding technology, and management level. The processing teams are divided into pre-treatment, cutting, unit assembly, final assembly, and welding groups. Each group performs operations according to the technical specifications set by the technicians, who also assign processing schedules to ensure completion and reduce fixed costs.

3.2.4 Coating Cost Control

The anti-corrosion coating of the steel box girder in this project should meet the requirements of the "Technical Specifications for Anti-Corrosion Coatings of Highway Bridge Steel Structures" (JT/T 722—2008). The coating system is selected according to the C3 moderate corrosion environment, long-term type (15-25 years protection period). The coating system consists of two layers of epoxy zinc-rich primer (80 μm), two layers of intermediate epoxy (cloud iron) paint (160 μm), one layer of polyurethane topcoat (40 μm), and one layer of fluorocarbon topcoat (40 μm), with a total thickness of 320 μm.

Based on the design drawings, well-known domestic anti-corrosion paint brands (such as Nippon, Xian Yongxin, and Xiamen Shuangrui) are selected. The suppliers or direct manufacturers of these brands in the Xinjiang region are thoroughly researched. The paint's application rates, layer thicknesses, and compatibility with advanced spraying equipment are analyzed. The comprehensive cost of the paint is compared, and joint training is conducted with the paint manufacturers for experienced spraying workers. The training focuses on spray techniques, paint and thinner ratios, spraying time, and uniformity. During the coating process, technicians strictly control the amount of paint and thinner used, creating a quantity variance analysis to find efficient spraying methods, aiming to reduce coating costs.

3.2.5 Transportation Cost Control

According to the segmented breakdown table provided by the design unit, the transverse single segment is divided into four transport blocks, and the longitudinal division consists of 13 segments. The transport weight breakdown table is shown in Table 2.

Table 2. Transport Weight Breakdown by Segments

Number	Name	Code	Length (mm)	Width (mm)	Height (mm)	Quantity	Unit Weight (kg)	Total Weight (t)
1	Cantilever	E-A1	12010	1550	500	1	5463.6	5.46
2	Beam Segment	E-A2	12325	3500	1800	1	29399.3	29.40
3	Beam Segment	E-A3	12810	3200	1920	1	24952.3	24.95
4	Cantilever	E-A4	12940	1560	500	1	5751.3	5.75
5	Cantilever	E-B1	11800	1490	500	1	5151.0	5.15
6	Beam Segment	E-B2	12105	3440	1800	1	25976.2	25.98
7	Beam Segment	E-B3	12395	3145	1920	1	21436.3	21.44
8	Cantilever	E-B4	12523	1500	500	1	5351.1	5.35
9	Cantilever	E-C1	11789	1497	500	1	5610.9	5.61
10	Beam Segment	E-C2	12106	3449	1800	1	30119.0	30.12
11	Beam Segment	E-C3	12394	3163	1920	1	25625.1	25.63
12	Cantilever	E-C4	12523	1516	500	1	5926.4	5.93
13	Cantilever	E-D1	8843	1429	500	1	3798.4	3.80
14	Beam Segment	E-D2	9081	3380	1800	1	20192.6	20.19
15	Beam Segment	E-D3	9297	3082	1920	1	16077.1	16.08
16	Cantilever	E-D4	9394	1434	500	1	4013.4	4.01
17	Cantilever	E-E1	9825	1447	500	1	4249.3	4.25
18	Beam Segment	E-E2	10089	3398	1800	1	22010.9	22.01
19	Beam Segment	E-E3	10329	3101	1920	1	18159.3	18.16
20	Cantilever	E-E4	10437	1453	500	1	4489.4	4.49
21	Cantilever	E-F1	8843	1447	500	1	3798.4	3.80
22	Beam Segment	E-F2	9081	3398	1800	1	20192.6	20.19
23	Beam Segment	E-F3	9297	3101	1920	1	16077.1	16.08
24	Cantilever	E-F4	9394	1453	500	1	4035.1	4.04
25	Cantilever	E-G1	11789	1497	500	1	5611.0	5.61
26	Beam Segment	E-G2	12106	3449	1800	1	30119.0	30.12
27	Beam Segment	E-G3	12394	3150	1920	1	25625.1	25.63
28	Cantilever	E-G4	12523	1504	500	1	5926.4	5.93
29	Cantilever	E-H1	8843	1429	500	1	3798.4	3.80
30	Beam Segment	E-H2	9081	3380	1800	1	20192.6	20.19
31	Beam Segment	E-H3	9297	3082	1920	1	14772.3	14.77
32	Cantilever	E-H4	9394	1434	500	1	4013.4	4.01
33	Cantilever	E-I1	9825	1447	500	1	4249.3	4.25
34	Beam Segment	E-I2	10089	3398	1800	1	22010.9	22.01
35	Beam Segment	E-I3	10329	3101	1920	1	18159.3	18.16
36	Cantilever	E-I4	10437	1453	500	1	4489.4	4.49
37	Cantilever	E-J1	8843	1429	500	1	3798.4	3.80
38	Beam Segment	E-J2	9081	3380	1800	1	20192.6	20.19
39	Beam Segment	E-J3	9297	3082	1920	1	16077.1	16.08
40	Cantilever	E-J4	9394	1434	500	1	4035.1	4.04
41	Cantilever	E-K1	11789	1497	500	1	5611.0	5.61
42	Beam Segment	E-K2	12106	3449	1800	1	30119.0	30.12
43	Beam Segment	E-K3	12394	3163	1920	1	23885.2	23.89
44	Cantilever	E-K4	12523	1516	500	1	5926.4	5.93
45	Cantilever	E-L1	11789	1490	500	1	5151.0	5.15
46	Beam Segment	E-L2	12106	3442	1800	1	25976.2	25.98
47	Beam Segment	E-L3	12394	3146	1920	1	21436.3	21.44

Number	Name	Code	Length (mm)	Width (mm)	Height (mm)	Quantity	Unit Weight (kg)	Total Weight (t)
48	Cantilever	E-L4	12523	1499	500	1	5351.1	5.35
49	Cantilever	E-M1	11560	1500	500	1	5351.7	5.35
50	Beam Segment	E-M2	11874	3452	1800	1	28779.2	28.78
51	Beam Segment	E-M3	11961	3156	1920	1	24647.4	24.65
52	Cantilever	E-M4	12089	1510	500	1	5527.4	5.53
53	Total	-	-	-	-	52	-	718.69

For the transportation plan, four 360-horsepower tractor trucks equipped with flatbed trailers matched to the steel box girder segments are selected as the transportation tools. During transportation, the girders must be securely fastened with front and rear restraints to prevent distortion and deformation. If the steel girders need to be temporarily stored at the construction site, they should be placed on wooden blocks to avoid water damage.

The transportation route is as follows: Urumqi Processing Plant-Ronghe South Road-Lianhuo Expressway-Tuhe Expressway-S301-Yiruo Line-Construction Site, covering approximately 586 km. Based on the segmented transport weight table, the number and weight of oversized, overheight, and overweight segments are analyzed first, followed by the analysis of the number and weight of standard segments. A rational allocation of transportation trips for the components is then conducted.

Based on the required number of trips and transportation requirements, high-quality logistics providers near Urumqi are selected. A comprehensive evaluation of the transporters is conducted, including the number of registered vehicles, transportation capacity, performance capabilities, transportation rates, and the ability to handle oversized vehicles. The most cost-effective and reliable transporter is chosen to ensure safe and efficient delivery.

3.2.6 Installation Cost Control

3.2.6.1 Hoisting Cost Control

Before project implementation, technical personnel are actively organized to conduct site surveys. These surveys aim to understand the construction progress of the substructure, the beam storage area, preparatory works (e.g., leveling, utilities), temporary power load requirements, crane placement, and the preconditions for support foundation and setup. A feasible specialized hoisting plan is developed, thoroughly analyzing the current hoisting conditions and surrounding environment while eliminating construction interferences.

Hoisting equipment is selected based on segment weight, crane placement, and boom reach range, with simulations conducted for crane entry, exit, and phased hoisting conditions. This project uses a 300-ton crane for installation. During equipment selection, nearby hoisting equipment manufacturers working on adjacent sections are considered as alternatives. Additional evaluations are conducted for local hoisting equipment suppliers regarding their available equipment, maximum lifting capacity, and delivery timelines.

Cost analysis is performed for two billing methods: daily rental and volume-based calculation. The selection is based on installation schedules, manageable work scope, and a comprehensive comparison to identify the most suitable billing method. This ensures higher equipment reliability and utilization, reduces mechanical costs, minimizes secondary handling, and optimizes the choice of hoisting equipment suppliers.

3.2.6.2 Support System Cost Control

Steel box girder support systems are typically implemented in two ways:

Traditional On-Site Fabricated Supports: These are assembled on-site using conventional methods. However, they often incur high costs due to extensive damage during assembly and disassembly, leading to high repair and transport expenses, especially for rented supports.

Prefabricated Modular Supports: As shown in Figure 4, these supports can be adjusted for longitudinal and transverse spacing based on segment weight and length. They are easy to transport and assemble, requiring a one-time investment in materials and equipment, and can be reused for multiple cycles, making them more cost-effective.

Compared to traditional methods, prefabricated modular supports significantly reduce overall costs. This project adopts prefabricated supports with column specifications of 325*8. The connecting system uses a combination of 20a and 10a channel steel, with M16 bolts for column node connections. This approach effectively lowers costs compared to traditional methods.

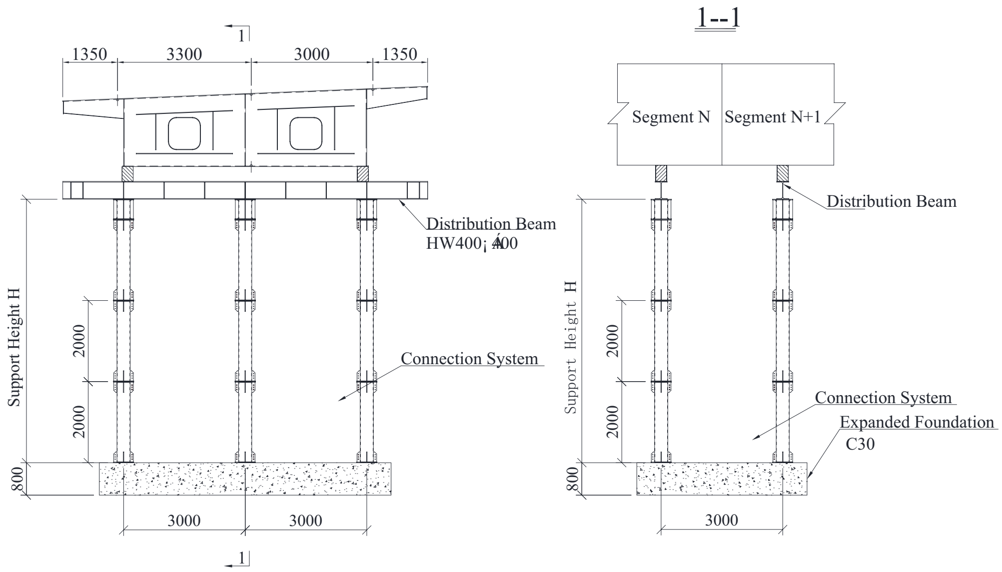

Figure 4. Prefabricated Modular Support System

3.2.6.3 Labor Cost Control for Installation

The primary tasks of on-site installation labor include horizontal circumferential welds, longitudinal welds, assisting with mechanical hoisting, assembly and disassembly of supports, loading and unloading, box girder splicing and assembly, and other construction-related tasks. The allocation of installation personnel is determined based on the workload of on-site welds, project schedule, and the utilization rate of hoisting equipment.

For this project, with a total on-site weld length of 455 meters, the number of assembly workers and welders is planned to meet the operational requirements and fully optimize the utilization of hoisting equipment. During implementation, labor quotas are carefully managed to ensure efficient use of manpower, reducing non-productive labor and idle work. Labor refinement management is emphasized, and high-quality labor teams are selected to achieve better efficiency and cost control.

4. Contract Management

4.1 Contract Management

Before project implementation, it is crucial to clearly delineate the responsibilities and work boundaries of both parties, defining their respective rights and obligations. All fabrication and installation work must strictly adhere to the agreed scope of work, with particular attention paid to payment terms such as advance payments and progress payment ratios. In the early stages of purchasing materials for steel box girders, costs can account for as much as 65% of the total project cost. If payment terms are unclear or the proportion of early-stage payments is too low, it can lead to increased intangible financial costs, reduced cash flow efficiency, and a significant decrease in the time value of early-stage investments.

4.2 Measurement and Settlement Management

4.2.1 Quantity Verification

Verify whether the quantities in the design drawings and material tables are based on the theoretical net weight of the components or the weight of the components' bounding rectangles. This verification serves as the basis for bidding or pricing analysis.

4.2.2 Quantity Calculation Rules

According to the "Highway Bridge Steel Structure Engineering Budget Norms (2022)," the quantities for steel structure fabrication are calculated based on the theoretical net weight indicated in the design drawings, excluding welds and bolt weights. The quantities for steel structure transportation are calculated based on the total weight of the steel structure segments transported off-site. The quantities for steel structure installation are calculated based on the total weight of the assembled steel box composite girder, including bottom plates, web plates, diaphragms (beams), stiffeners, and welds. The quantities for shear stud installation are calculated based on the number specified in the design. Contract personnel are required to strengthen their understanding and application of quantity calculation rules to avoid significant errors in measurement and settlement.

5. Conclusion

In summary, the cost control of steel box girder fabrication and installation is a complex and systematic challenge that involves comprehensive management across multiple processes and factors. Effective cost control requires a thorough understanding of the fabrication and installation processes and an in-depth analysis of the cost formation mechanisms at each stage. This paper has analyzed the key cost components in the fabrication and installation of steel box girders and explored practical experiences in contract management and quantity calculation rules. It provides effective management strategies and methods, offering valuable insights and references for engineering practices in related fields.

References

[1] Koji HOMMA. Development of Application Technolo gies for Bridge High-Performance Steel BHS [R]. Nip pon Steel Technical Report, 2008, (97): 51-57.

[2] NISHIMURA Kimihiro. High Performance Steel Plates for Bridge Construction-High Strength Steel Plates with Excellent Weldability Realizing Advanced Design for Rationalized Fabrication of Bridges [R]. JFE Techni cal Report, 2005, (5): 25-30.

[3] Huang, Y. Study on the construction cost scheme of separation of transportation and erection of 40 m simply supported box girder on high-speed railway. Journal of Railway Science and Engineering, 2021, 18(8), 2013–2020. https://doi.org/10.19713/j.cnki.43-1423/u.T20210263

[4] Miki C. Homma K, Tominaga T. High strength and high performance steels and their use in bridge structures [J]. Journal of Constructional Steel Research, 2002, 58(1): 3-20.

[5] Marc Hever Falko Schroter. Modern Stee l High Per formance Material for High Performance Bridges [C]. 5th International Symposium on Steel Bridges. Barcelo na: European Convention for Constractional Seelwork, 2003: 80-91.