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ARTICLE

Construction Technology of Self-Anchored Suspension Bridges

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ABSTRACT

As a special type of building, the industrialization of bridges is imperative in the context of the new industrialization era. The specific focus of bridge industrialization is to promote prefabricated construction technology in bridge construction. Based on the construction experience of the Dongta Bridge spanning the Hun River in Shenyang City, this article summarizes the construction techniques of prefabricated segmental assembled piers, continuous steel box girders, steel truss bridge towers, cables, and steel bridge deck paving for self anchored suspension bridges, providing experience for similar bridge construction in the future.

1. Project Overview

The Dongta Bridge over the Hun River in Shenyang is a key project in the comprehensive improvement plan of "one river and two banks" in Shenyang. It is the largest single span suspension bridge in the Shenyang area and has been put into use, becoming a local landmark building. The operation diagram of the Dongta Bridge over the Hun River in Shenyang is shown in Figure 1. The main bridge of Dongta Bridge over Hunhe River in Shenyang City is a five span continuous steel truss bridge tower self anchored suspension bridge, with a span arrangement of (40+90+220+90+40) m and a total steel consumption of 20000 tons.

Figure 1 Operation diagram of Dongta Bridge over Hun River in Shenyang City

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1) The main beam is a continuous steel box girder spanning the Hun River, with a width of 43.3m in the cable area and 40m in the non cable area. The beam height in the cable area is 3m, the beam height in the counterweight area is 2.3m, and the beam height in the anchorage area is 4.8m. The steel beam section size is large, and reasonable segmentation, transportation, and hoisting are the key points;

2)The main tower adopts a combination of steel truss tower columns and concrete tower bases. The tower height above the bridge deck is 45m, and the horizontal distance between the center of the main tower and the bridge is 36m. The main tower is composed of a bridge tower concrete tower base, steel truss tower columns, tower top saddle covers, tower top decorative structures, and tower top crossbeams from bottom to top. The tower base is a concrete structure, while the steel truss tower columns, tower top saddle covers, tower top decorations, and tower top crossbeams are all steel structures.

3)The main cable is composed of high-strength galvanized steel wire, with a total of two cables installed throughout the bridge, with a vertical span ratio of 1/5.5 and a center to center distance of 36m in the transverse direction. Each main cable consists of 19 strands, with a single strand consisting of 127 high-strength galvanized steel wires with a diameter of 5.0mm. The amount of steel wire used is 331t, and the diameter of the main cable in the cable clamp is 271mm. The suspension cables are made of epoxy coated steel strands, with a total of 74 cables installed throughout the bridge. The construction of the main cable is a key process of this bridge. How to ensure that the bridge shape and internal stress of each component of the suspension bridge meet the design requirements, as well as the system transformation, is the focus of the cable system construction of the suspension bridge.

4) The steel bridge deck pavement adopts the pouring asphalt pavement technology, with a pavement structure of 41mm high elastic modified asphalt (SMA13) upper layer+30mm pouring asphalt mixture (GA10) lower layer+methyl acrylic resin (MMA) waterproof bonding layer. The pouring asphalt pavement of the steel bridge deck is a special process of this project, and ensuring the quality of the bridge deck pavement is the key;

5) Some bridge piers are assembled using prefabricated segments, with a solid cross-section of 2×2m, a height of 7.5m, and a single weight of 80t. This is the first of its kind in the Northeast region of China. The construction of prefabricated bridge piers belongs to a new technology, and the connection between piers and abutments adopts grouting sleeve connection. The construction process is complex and the construction difficulty is high.

2. Construction technology of prefabricated self anchored suspension bridge

2.1 Prefabricated segmental assembly bridge pier construction technology

Prefabricated segmental assembly of bridge piers, as the name suggests, means that the piers are prefabricated first and then installed on the construction site. Its main construction consists of two sections: prefabrication and assembly.

2.1.1 Prefabrication construction technology for bridge piers

The prefabrication of bridge piers includes steps such as the construction of prefabricated pedestals, the production and installation of steel cages, the installation of overall formwork, concrete pouring, curing, and formwork removal. Here, only the prefabrication of a single pier body is illustrated to illustrate the prefabrication process:

1) Prefabricated pedestal production. Make three prefabricated pedestals on the hardened site near the bridge pier, requiring a flat and open site.

2) Steel cage production. The reinforcement of the pier body is cut, reinforced, and formed in the reinforcement processing yard, and together with the grouting sleeve, it is tied onto the frame to form a complete reinforcement cage.

3) Steel cage hoisting. After the steel cage is made, it will be installed. The steel cage is installed on the prefabricated pedestal using a four point lifting method using a car crane. At the lifting point of the steel cage, reinforced angle steel is added. In addition, the steel cage is connected to the prefabricated pedestal operating frame to ensure the stability of the steel skeleton.

4) Installation of overall template. On the site near the prefabricated pedestal, the formwork is assembled into a whole using a truck crane and fitted onto the installed steel cage. Then, fine adjustments are made to ensure the verticality of the formwork and the joint gap. After passing the inspection, double-sided tape is used to seal the joint between the templates, and sponge strips are used to seal the gap between the prefabricated pedestal bottom plate and the pier body template to prevent leakage of grout. And connect the template with the prefabricated pedestal operation frame to ensure the stability of the steel reinforcement skeleton.

5) Concrete pouring, curing, and formwork removal. The pouring is done in one go. Before pouring, check the position of the steel bars, formwork, and steel bar pro-

tection layer, and adjust any areas that do not meet the requirements. During the pouring process, the concrete should be vibrated and compacted uniformly at all times. After the concrete pouring is completed, the exposed surface of the concrete should be tightly covered and watered for curing in a timely manner. When the concrete strength of the pier body reaches 2.5MPa, the formwork can be removed.

2.1.2 Bridge pier assembly construction technology

After the prefabrication of the bridge pier is completed, a large tonnage crane is used for on-site assembly. The assembly of the bridge pier includes steps such as the construction of the grouting layer, the hoisting and positioning of the pier body, and the grouting of the sleeve. Here, only the assembly of a single pier body is illustrated to explain the assembly process:

1) Construction of the grout layer. Firstly, remove cement slurry, thin film, loose sand and gravel, oil stains and other debris from the support platform and surface of the steel bars in the connection area. Then, install a grout stop ring on the connection steel bars to prevent grout from entering the sleeve during grouting. At the same time, make a grout stop template. Pour the slurry into the slurry area.

2) Lift the pier body into place. Before the slurry solidifies, a large tonnage crane is used to lift the pier body from the prefabricated pedestal to the bearing platform for installation, and the plane position of the pier body is adjusted. In addition, use precision adjustment devices and mechanical jacks to adjust the verticality and elevation of the pier body. When the slurry reaches the required strength, remove the mechanical jack and fine adjustment device, as shown in Figure 2.

3) Sleeve grouting construction. The grouting equipment adopts a pressure grouting machine, and the grouting material adopts high-strength non shrinkage cement grouting material. Sleeve grouting mainly includes slurry preparation and grouting. To ensure dense grouting, clean the debris inside the sleeve with clean water before grouting, and then pour the mixed grout into the grouting machine to start grouting. After grouting is completed, maintenance should be carried out. During the maintenance period, the pier body should not be disturbed by earthquakes, collisions, or other impacts.

2.2 Construction technology of continuous steel box girder

The continuous steel box girder is erected using the bracket method. The steel box girder is divided into sections according to the module, processed into lifting unit blocks in the processing plant, and transported to the site for lifting and welding.

Figure 2 Pier body lifting diagram

2.2.1 Division technology of steel box girder segments

In order to reduce the circumferential joint of the beam segments and facilitate the installation, the standard section of the main bridge is vertically divided and integrated by a length of 12 meters, which is an integer multiple of the spacing between partitions of 3 meters. After the division, the longitudinal beam segments are changed from the original design of 53 beam segments to 43 beam segments, and the horizontal segments are divided into 10 unit blocks between the top and bottom plate U ribs; The original H, G, and F sections of the self anchored special section are divided into upper and lower layers. The upper layer is equipped with plate units and delivered to the site, and the bridge position is assembled separately. The lower layer is lifted horizontally in blocks according to the standard beam segment segmentation scheme; During the assembly and manufacturing of the box body in the beam section, temporary tie rods and dowels are used to connect the horizontal segments of each beam section. When hoisting the steel box girder unit block, bolt lifting ears are used.The longitudinal steel beams are assembled as a whole on both the north and south banks every 4 sections in the factory, with the middle section serving as the closure section. The steel beams are processed and manufactured in a total of 11 rounds. After each round of steel beam production is completed, they are shipped and lifted at any time according to the on-site lifting plan requirements.

2.2.2 Steel box girder segment lifting technology

The steel box girder is installed using a large tonnage crane, and is installed from the north and south banks towards the middle of the main bridge span. The main steps are as follows:

1) Island construction. Consider building islands within the river channel, taking into account the space for transporting beams and crane stations. The elevation of the island construction is 2 meters higher than the normal water level, and the width of the island construction is twice the width of the steel beam. Local areas will be widened, and a drainage channel will be reserved in the main river channel. Temporary supports will be set up on the entire island construction surface. When the steel box girder is erected in the drainage area of the main river channel, the completed side span area will be excavated and diverted, and the reserved drainage channel will be filled with soil for island construction. The steel box girder unit blocks are directly transported to the bridge site by flatbed trucks in the factory, and lifted on the island surface by crawler cranes. The large section steel beams are segmented and directly lifted on the island surface.

2) Lifting and alignment. After lifting the unit block into place, measure the centerline, elevation, and diagonal difference between the sections of the bridge, adjust the deviation in a timely manner, and then level the joints in the order of web plate → top plate → bottom plate. When leveling, it is advisable to first level the corners of the box mouth with high rigidity (web plate and bottom plate corners, web plate and top plate corners), and then fix the remaining parts to ensure that the misalignment of the joint plate surface is not greater than 1.0mm. After welding the positioning plate, loosen the hook, and weld according to the welding requirements of the bridge position after loosening the hook, as shown in Figure 3.

Figure 3 Hoisting diagram of steel box girder

2.2.3 Steel box girder closure technology

When the steel beams are erected to the closure section, all the steel beams on both sides of the north and south banks are welded. The dimensions and elevation between the closure openings are repeatedly measured during fixed time periods in the morning, middle, and evening, and the measurement time temperature is recorded. Finally, the closure temperature and dimensions are analyzed and determined, and the dimensions are fed back to the processing plant to process the steel box girder of the closure section. The appropriate temperature is selected, and the steel box girder closure section is installed to achieve the closure of the steel box girder.

2.3 Construction technology of steel truss bridge tower

When making the steel truss bridge tower, it is divided into five sections from bottom to top along the height direction, including GT1-GT5, with a length of 6m to 12m. Among them, GT1 has a height of 6m and is a steel-concrete joint section of the tower column. In addition, the top beam of the tower is divided into three sections for hoisting.

During installation, GT1~GT5, bridge tower saddle cover, crossbeam and other components are installed in sequence. When installing GT1 and GT2 steel tower columns, the crane lifts them on the island surface. When installing GT3~GT5 and crossbeam, the crane lifts them on the steel bridge deck. Steel plate supports are used at the crane lifting station to protect the steel structure bridge deck, as shown in Figure 4. Considering the installation accuracy of steel tower columns, matching parts are used for connection during the production of steel tower columns to ensure the construction accuracy on site.

Figure 4: Main Tower Lifting Diagram

2.4 Cable construction technology

The main cable is constructed using the prefabricated parallel steel wire strand method (PPWS). During the installation, the direct traction method is used to first install a three span continuous catwalk. After the steel box girder is closed, single line reciprocating traction systems are arranged on both sides of the catwalk, and unit cable strands and other cable strands are installed. The tower top cable strands are horizontally moved into the saddle, anchored with north-south locks, tightened, and the catwalk system is converted. The main cable unit cable strand installation adopts single line reciprocating traction, with one set of traction system arranged upstream and downstream.

2.4.1 Installation and construction of catwalk

The overall structure of the catwalk adopts a three span continuous structure, parallel to the main cable's empty cable shape, with a distance of 1.2m from the center of the main cable. The net width of the catwalk is 3.0m, and both ends are anchored to the top surface of the box girder. To increase the wind resistance stability of the catwalk, two transverse overpasses and eight wind resistant vibration control cables are set up in the mid span catwalk, and four wind resistant cables are set up on each side span. The catwalk is composed of load-bearing cables, crossbeams, surface mesh, handrails, handrail ropes, safety ropes, horizontal overpasses, wind resistant cables, and other structures. Install the load-bearing cable anchorage end distribution beam → symmetrically install the catwalk load-bearing cable one by one → adjust the load-bearing cable line shape → install the handrail cable and railing → install the wind resistant cable → inspect and accept the catwalk.

2.4.2 Construction of Traction System

The function of the traction system is to lift the anchor end of the unit cable over obstacles. The main process flow is as follows: Install the main cable tugboat on the catwalk crossbeam → Install the saddle slide at the top rod hole of the main cable saddle to allow the cable strands to pass through the main cable saddle smoothly → Adjust the tower top suspension structure, place the steel rails on both sides horizontally, and use them as anchor end bearing cables at the vertical support points of the tower top → Erect the anchor end bearing cables, with a height of about 3.0m from the catwalk, anchored at both ends to the anchor beam → Install the main traction cable, auxiliary traction cable, open pulley, etc. on the catwalk → Debug the system operation status.

2.4.3 Benchmark Cable Installation

The main steps of benchmark cable construction include cable traction, shaping, saddle insertion, anchor head insertion, and linear adjustment.

1) Rope traction. Use a winch to pull and unfold the anchor head of the unit cable strand from the cable reel to the starting end of the catwalk, then pass the cable strand through two tower tops to reach the anchor box position on the other side, and make a mark on the main cable strand to place the unit cable strand reasonably.

2) Plastic surgery and saddle insertion. After the cable is pulled in place, use a square fixture to organize the cable from a regular hexagon into a square shape in a stress free state, and then move the cable horizontally into the saddle.

3) Anchor head into anchor. After the cable is inserted into the saddle, the anchor begins to step into the anchor. After the anchor head is anchored, the traction work of the next cable strand begins.

4) Linear adjustment. The adjustment of stock demand is generally based on the principle of first mid span and then mid span. Specifically divided into initial adjustments during the day and precise adjustments at night. There is a significant temperature difference during the day, so according to calculations, adjust the cable strands to a controlled height at an appropriate temperature; The temperature difference at night is small, so according to the calculation, adjust the cable strand accurately to the control height.

2.4.4 Ordinary cable installation

The common strand shall be erected according to the erection process of the benchmark strand, but the alignment of the common strand shall be controlled by relative deflection and sag, that is, by referring to the alignment of the benchmark strand, supplemented by a special caliper, the strand erected on the previous day shall be adjusted before the temperature rises significantly in the morning every day. For each layer of cable, the height of the cable should be half a strand higher than that of the next layer. The two layers of cable that directly overlap should be kept in a flexible state, slightly higher by 0-5 mm, and should not press down on the lower layer of cable. After all cable strands are erected, check the height of all cable strands and make overall adjustments to those with significant deviations until they meet the requirements.

2.4.5 Cable tightening

Tightening cables are divided into two parts: pre tensioning cables and formal tensioning cables. Tightening the cable first starts from the mid span towards the top of the two towers, and when it is about 50m away from the top of the tower, it starts from the top downwards; At the edge span, it is only necessary to move from the bridge surface to the top of the tower. It is agreed to change the direction from the top of the tower to the bottom when it is about 50m away from the top of the tower. Pre tensioning cable is to compress the hexagonal strands in situ into a circular shape through a pre tensioning cable machine; When formally tightening the cable, use a cable tightening machine to round the main cable and achieve the specified void ratio. The quality of the tight cable is controlled by the void ratio and roundness.

2.4.6 Cable clamp installation

After the main cable is tightened, install the cable clamp. The installation of cable clamps uses a hanging basket as the working platform, and the lifting is carried out by a steamship crane. The difficulty in installing cable clamps is the tightening of cable clamp bolts, which is carried out in two stages. When installing the cable clamp in place, use a wrench to pre tighten it, and then use a torque wrench to firmly fasten it for the first time. After the suspension cable is loaded, use a torque wrench to tighten it for the second time. The installation sequence of cable clamps is from the mid span to the top of the tower, and from the vicinity of the anchoring point to the top of the tower for the side spans. After the installation of the cable clamp is completed, proceed with the installation of the suspension rod.

2.4.7 System Conversion

System conversion is the process of installing and tensioning suspension cables. Before installing the sling, calculate the optimal loading program based on the stiffness and self weight of the main beam and cable. And during the construction process, adjust the tension force.

Temporary working support feet and connecting rods are required for the tensioning of slings. Eight through hole jacks are used for symmetrical tensioning from the tower column and anchor head. During homework, the connecting rod is connected to the internal thread of the anchor cup at the bottom of the sling, and the sling is fixed to the anchor plate through the anchor cup. Apply 1/4 of the design force during the first tensioning to temporarily lock each sling; Apply the full design force to tension the suspension cables for the second time, then check the actual load of each suspension cable, and finally make specific adjustments to each suspension rod based on the design force. During the tensioning process of the suspension cable, based on actual observation and calculation analysis, the saddle is pushed upwards. After repeating this process, the tensioning force of each suspension cable is adjusted to the design value.

2.5 Construction Technology for Steel Bridge Deck Pavement

2.5.1 Sandblasting and Waterproofing Construction of Bridge Deck

After the installation of the steel box girder is completed, the bridge deck pavement will be carried out. The foundation of bridge deck paving is sandblasting of steel bridge deck. Sandblasting mainly uses sandblasting machines, and for the vertical parts of edges and road edges that cannot be reached by sandblasting machines, manual sandblasting is used. Before operating the sandblasting machine, manual sandblasting must be completed first. After the sandblasting of the steel bridge deck is completed, it is necessary to form a continuous flow of work with the waterproof construction, that is, to timely apply the waterproof primer to avoid exposure for more than the specified time.

After the construction of the steel bridge deck primer is completed, the spraying construction of the waterproof layer begins. Before spraying construction, wrap the structures at the construction boundary with plastic film for protection to prevent waterproof materials from splashing onto them and causing pollution. After the construction of the waterproof layer, the construction of the bonding layer shall be carried out.

2.5.2 Construction of poured asphalt

Cast asphalt is a self forming asphalt that does not require rolling. It is transported using a cooler truck with heating and mixing devices, and spread using a dedicated asphalt paver, as shown in Figures 5 and 6.

Figure 5 Cooker car

Figure 6 Special pouring asphalt paver

Based on the structural characteristics of asphalt pavers, a 60-150cm wide edge strip is reserved for manual paving during pouring asphalt paving, while dedicated pavers are used for paving in other areas. Spread the edge strip before mechanical paving. During mechanical paving, after the pouring asphalt self mixing plant discharges the material, it is transported to the construction site by a cooler truck and continuously spread throughout the bridge from one end to the other using a paver. After pouring asphalt paving, timely spread asphalt pre mixed crushed stone and embed it into the surface of the pouring asphalt mixture. Apply joint strips at the joints and boundaries of the pouring paving to ensure that the joints are tight and leak proof.

2.5.3 Surface layer SMA asphalt mixture construction

SMA asphalt mixture is spread using a dual machine joint paving method, completing half the width of the bridge in one paving. When paving, the distance between the two machines should not exceed 10 meters, and the roller should be organized to compact the SMA asphalt mixture on the steel bridge deck according to the principle of "closely following, slow rolling, high frequency, and low amplitude". The surface layer SMA paving and leveling adopts non-contact balanced beam automatic leveling to ensure that the flatness meets the requirements.

3. Conclusion

In response to the construction of the Dongta Cross Hun River Bridge in Shenyang, the new technology of prefabricated segment assembly, continuous steel box girder erection construction, steel truss bridge tower construction, cable construction, and steel bridge deck paving were adopted to solve the problems of prefabricated bridge piers, wide section steel box girders, large tonnage steel truss bridge towers, main cables, and steel bridge deck paving. This project was completed quickly, safely, and efficiently, and has a good reference value for similar engineering constructions. The successful application of prefabricated segmental assembled bridge piers in this project is of great significance for promoting the transformation of concrete bridge piers from conventional cast-in-place technology to factory prefabricated technology in the special environment of the north.

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