Bai Chay Bridge, Vietnam

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Summary

The Bai Chay Bridge, spanning a strait within sight of Ha Long Bay, Vietnam's premier World Heritage site, has the world's longest center span length of 435 m, as a single plane cable-stayed prestressed concrete bridge, with a bridge length of 903 m.

The foundations for the main piers were constructed by the pneumatic caisson method. Form travelers were used for the cast-in-situ box girder erection by the balanced cantilever method. The main pylons, which extend 91,5 m in height above the deck level and which incorporate 28 stay cables and anchorages each side, were constructed using a climbing formwork system.

The design wind speed for the bridge is 50 m/s over a ten-minute averaging period at 50 m above sea level. Wind tunnel tests, using a three-dimensional (3D) full bridge model, were conducted to examine the structural stability against strong winds. The box girder is lightweight with internal steel pipe bracing and prestressing tendons. Technologically advanced vibration control devices, such as reduced-section high-density polyethylene (HDPE) ducts and internal radial dampers for the stay cables together with tuned liquid dampers for the pylons, were incorporated into the construction.

Keywords: Ha Long Bay; World Heritage; Single plane cable-stayed prestressed concrete bridge; World's longest span.

Fig. 1: Bai Chay Bridge

Introduction

Ha Long Bay, in Northern Vietnam, was registered by UNESCO as one of five World Heritage sites in the country due to the natural beauty and spectacular seascape of its thousands of small limestone islands and islets. National Highway No.18 (total length 319 km), which connects the International Airport of the capital city, Hanoi, with the town of Mong Cai on the Chinese border; has long been interrupted at almost its mid-point by a narrow strait in Ha Long Bay. Until now, the only means for road traffic to cross the strait was by way of a limited number of ferries.

The Bai Chay Bridge (*Fig. 1*) spanning this strait has been built with a loan provided by the Japan Bank for International Cooperation (JBIC). It has the world's longest center span length of 435 m, as a single plane cable-stayed prestressed concrete bridge, with a bridge length of 903 m (*Fig. 2*). The navigation clearance beneath the bridge is 200 m in width and 50 m in height, thus permitting large vessels to enter Cai Lan Port located inside the bay. Cai Lan Port, which was recently upgraded with another loan provided by JBIC has the deepest water in Northern Vietnam. As the piers are constructed in the shoreline, and not in the strait, the Bai Chay Bridge has an aesthetic feature that naturally merges it with the surrounding scenery.

Bai Chay Bridge

Construction

Construction of the Bai Chay Bridge commenced in August 2003. The main pier foundations were constructed by the pneumatic caisson method, where compressed air pressurizes the inside of the working chamber to compensate for the water pressure encountered during excavation (*Fig. 3*). The maximum excavation depth was 27,7 m

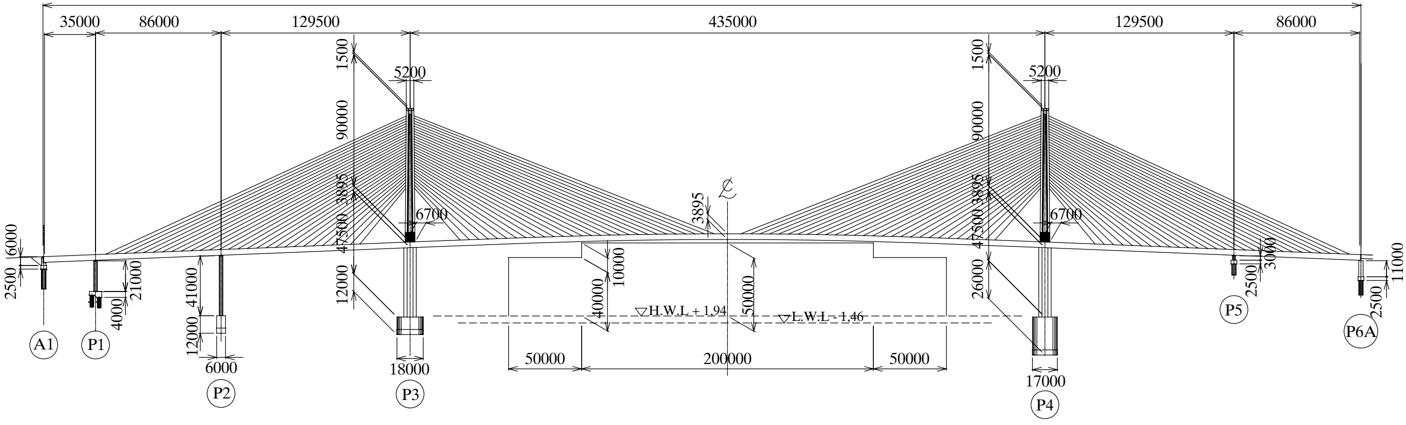

Fig. 2: Side view (Units: mm)

Fig. 3: Pneumatic caisson foundation

Fig. 5: Steel pipe bracing

Fig. 6: Wind tunnel test (Univ. of Tokyo)

at Pier P4 where the air pressure was recorded at 0,245 MPa. For the construction of the superstructure, form travelers were used for the cast-in-situ girder that was erected using the balanced cantilever method, concurrently with the construction of the pylon and erection of the stay cables (*Fig. 4*).

The box girder, constructed in segment lengths of 6,5 m, is lightweight in nature with additional rigidity being provided by internal steel pipe bracing (*Fig. 5*). Two types of steel pipe bracing, square pipe (250 × 250 × 16 mm) and round pipe (D267,4 × 9,3 mm), were installed alternately at 3,25 m intervals. Prestressing tendons (12 × 15,2 mm) were installed in the square steel pipe brace to resist the tensile force of the stay cables at their anchorage locations. Each half of the centre span box girder consists of 32 segments while the side span consists of 31 segments. The typical cycle time for the casting of a pair of new segments, including erection of the stay cables, was eight days. From the commencement of the first segment erection to completion of the centre closure took approximately one year.

The main pylons, which stand 91,5 m above the deck level, have varying hollow sections. Construction was divided into twenty four lifts, varying in height from 2,1 m to 4,2 m plus one parapet lift, 1,5 m in height. To maximize speed and quality of concrete finish a climbing formwork system was utilized. In order to satisfy the safety factor of 1,3 for the wind load at the mean wind speed of 50 m/sec., together with minimizing the possibility of cracking at the mean wind speed of 45 m/sec., vertical prestressing tendons (12 × 12,7 mm) and high-strength (yield strength 490 MPa) large-diameter (51 mm) reinforcement bars were installed in the lower sections of the pylon.

Fig. 4: Cantilever erection

Each main pylon incorporates 56 stay cables, 28 on either side, with individual stay cables consisting of 35–71 strands (15,7 mm) installed inside a colored HDPE duct. After erection of the HDPE duct and the master strand (first strand), strand by strand installation commenced at the bottom of the stay cable. A single-strand jack was used for stressing of each strand. A load cell attached to the master strand enabled the stressing of all strands within any one stay cable to be balanced. For geometry control purposes, all strands were initially stressed to 80% of their target force. After completing the geometry control check of the girder in the following morning, the strands were subsequently stressed to 100% of the target force.

Wind Tunnel Testing

As typhoons are not uncommon within Northern Vietnam, the design wind speed is set at 50 m/s over a 10-minute averaging period at 50 m above sea level. Wind tunnel tests, using a 3D-full bridge model (scale 1/150), were carried out at the University of Tokyo to examine the bridge's structural stability against high winds (*Fig. 6*). The model represented the dynamic characteristics of the actual bridge, including modal parameters, damping characteristics, and sectional areas. The results obtained from the testing showed that aerodynamic instability, such as fluttering, galloping or similar phenomenon, would not occur, and the wind loading parameters to be used in the design were appropriate. In November 2006, immediately prior to opening the bridge to traffic, the bridge experienced a maximum instantaneous wind speed of 48,1 m/s at deck level, but the bridge exhibited no adverse effects.

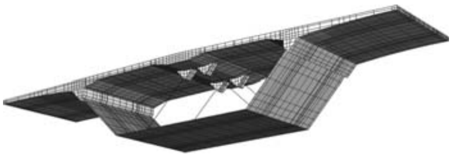

Fig. 7: 3D-FEM model

Girder Cross Sections

Prior to commencement of erection of the superstructure by the balanced cantilever method, local stresses within the girder cross sections were checked by 3D-FEM analysis. In this analysis, local stresses at every stage of the cantilever construction were calculated using an overall bridge structure model composed of detailed 3D-solid elements (*Fig. 7*). The results obtained lead to several modifications to the steel pipe braces in order to accommodate local stresses in the cross sections. These modifications included the introduction of square steel pipe braces for increasing its rigidity and adding prestressing tendons inside the square steel pipe braces at the stay cable anchorage position (*Fig. 8*).

Latest Devices

Compact Duct

HDPE ducts for the stay cables vary from 150 mm to 200 mm in diameter with wall thicknesses varying from 6 to 6,2 mm. The ducts used on the bridge, known as Compact Ducts, are 20% less in diameter than standard ducts and are provided with double helical ribs on the exterior surface. This reduced diameter decreases the projection area of the ducts, while the helical ribs are designed to reduce rain vibrations of the stay cables. The Bai Chay Bridge is the first project in the world where this

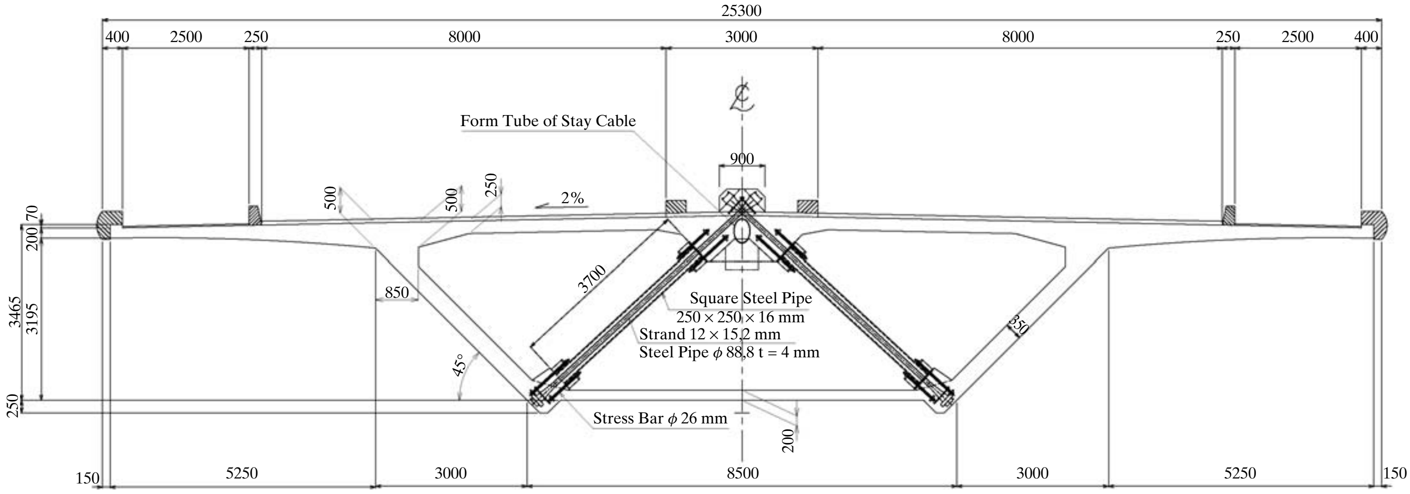

Fig. 8: Girder cross section (Units: mm)

new technology has been adopted. To enhance durability characteristics, the stay cable strand, known as a Compact Strand, was manufactured with three external layers; galvanized, waxed, and HDPE coated (1,2 mm). No grouting is required inside the duct. Prior to the actual installation on site, extensive tests were conducted to ensure the Compact Strands could actually be installed within the Compact Duct.

Vibration Control Devices

The Bai Chay Bridge is the first prestressed concrete cable-stayed bridge to incorporate the use of permanent Tuned Liquid Dampers inside the pylon. Each Tuned Liquid Damper is made of Fibre-reinforced plastic (FRP) box (80 mm high) filled with water. 344 units of these dampers were installed in each pylon (*Fig. 9*). Vibration testing showed that the logarithmic decrement of damping in the first mode increased from 0,03 to 0,07 and the dynamic acceleration response of the pylon decreased by 58%. These factors meant that the maximum deflection at the top of pylon, at the design wind speed, decreased by 14%.

Vibration control of the stay cables was achieved by the installation of dampers at the deck level. The types of dampers installed varied according to the length of the stay cable; for the shorter length cables (32 number) High Damping Rubber (HDR) dampers were installed, for the medium length cables (40 number) Internal Hydraulic Dampers (IHD) were adopted while Internal Radial Dampers (IRD) were utilized for the 40 longer cables. The IRD, which were installed on a bridge for only the second time in the world, are a hydraulic damper with a minimum stroke of 80 mm. Vibration tests using an actuator (50 kN) showed that the logarithmic decrement of damping in the first to the third modes increased from around 0,005 to 0,03–0,04.

Integrated Bridge Monitoring System

In addition to the conventional monitoring systems employed during bridge construction, supplementary monitoring devices, such as optical fiber sensors, anemometers, thermocouples, accelerometers, inclinometers, load cells, strain gauges, CCD cameras, etc., were installed to develop an integrated bridge monitoring system. The strain-deflection monitoring system used during construction, consisting of optical fiber sensors (B-OTDR) with a length of 2500 m, is the first attempt at such a system in the world. This system will subsequently be utilized for the permanent monitoring of the bridge.

Fig. 9: Tuned liquid dampers

Fig. 10: Bridge illumination

Conclusion

The Bai Chay Bridge was opened for traffic in early December 2006. Completion of the bridge will not only enhance tourism to the World Heritage site of Ha Long Bay located close by, but will also improve trade links between Vietnam and Southern China thus encouraging further development within the region (*Fig. 10*).

SEI Data Block

Owner:
No.18 Projects Management Unit
Ministry of Transport, Vietnam

Design, Consultant:
Japan Bridge & Structure Institute, Inc., Tokyo, Japan
Pacific Consultants International, Tokyo, Japan
Transport Engineering Design Incorporation, Hanoi, Vietnam
Hyder Consulting-CDC Ltd., Hanoi, Vietnam

Contractor:
Shimizu Corporation, Tokyo, Japan
Sumitomo Mitsui Construction Co., Ltd., Tokyo, Japan

Concrete (m^3):	25240
Reinforcing steel (t):	4000
Prestressing steel (t):	430
Stay cables (t):	1020
Structural steel (t):	320
Total cost (EUR millions):	53
Service date:	December 2006