Construction Engineering of Phu My Cable-Stayed Bridge, Vietnam

Summary

Abstract

The Phu My Bridge will span the Saigon River between Districts 7 and 2 in Ho Chi Minh City. The bridge will form part of a new ring road currently under construction around Ho Chi Minh City. The ring road will be an important transport link from the southern Mekong delta region to the central and northern parts of Vietnam.

The Phu My Bridge contract includes the design and construction of a 705m long cable stayed main bridge with a clear span of 380m, as well as the approach structures on either side being approximately 758m on District 7 and 638m on District 2.

The main span deck will be 27m wide. Clearance to river traffic is provided with 45m vertical clearance in a 250m wide zone. The pylons carrying the deck are designed as an H frame and are approximately 140m high.

The main bridge deck is designed as an insitu reinforced and partly post tensioned concrete slab supported on longitudinal and transverse beams and suspended from the pylons by the stay cables.

The bridge is being constructed by BBBH Consortium, a joint venture between Bilfinger Berger and Baulderstone Hornibrook. Phu My Bridge Corporation (PMC) as the Client is a private consortium comprising Hanoi Construction Company, Investco, Cienco 620, Thanh Danh Co, and CII. PMC has a thirty year BOT licence to operate the bridge which will be part of a toll road.

This paper describes the bridge, the method used to construct and the construction engineering used for the stage by stage analysis of the bridge and the on site role to control the cable forces and bridge geometry during construction of the bridge.

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Colin has over 15 years experience as an Engineer. He has worked in a variety of countries including UK, Malaysia, Australia and Vietnam. He has particular knowledge of bridge design. His experience covers construction technology as well as design.

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George has more than 16 years experience in design, construction and management of multi-disciplinary infrastructure projects including mass transit, tunnelling, bridges and elevated structure works. He has worked extensively within Europe and has over 10 years experience in the Asian region.
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Synopsis

The Phu My Bridge will span the Saigon River between Districts 7 and 2 in Ho Chi Minh City. The bridge will form part of a new ring road currently under construction around Ho Chi Minh City. The ring road will be an important transport link from the southern Mekong delta region to the central and northern parts of Vietnam.

The Phu My Bridge contract includes the design and construction of a 705m long cable stayed main bridge with a clear span of 380m, as well as the approach structures on either side being approximately 758m on District 7 and 638m on District 2.

The main span deck will be 27m wide. Clearance to river traffic is provided with 45m vertical clearance in a 250m wide zone. The pylons carrying the deck are designed as an H frame and are approximately 140m high.

The bridge is being constructed by BBBH Consortium, a joint venture between Bilfinger Berger and Baulderstone Hornibrook. This paper describes the construction engineering used for the stage by stage analysis of the bridge and the on site role to control the cable forces and bridge geometry during construction of the bridge.
1. Introduction

The Phu My Bridge is a new cable stayed bridge currently under construction in Ho Chi Minh City (HCMC), in Vietnam. The bridge will span the Saigon River between Districts 7 and 2. The bridge will form part of a new ring road currently under construction around Ho Chi Minh City. The ring road will be an important transport link from the southern Mekong delta region to the central and northern parts of Vietnam.

The main port, which is located slightly downstream (or south) of the centre of the city and is forecast to be re-located further downstream within the next 10 years, generates considerable heavy goods traffic. In addition a significant amount of goods from manufacturing in the Mekong Delta also travels up though HCMC. Such traffic currently crosses the Saigon River at the most southerly bridge, the Saigon Bridge, located in the central district of HCMC. A reduction of the traffic congestion in the centre of the city is necessary to insure efficient transportation conditions and will be realized by the creation of an inner ring road, including the large Phu My Bridge over the Saigon River linking the Southeast quadrant to the rest of the city.

The bridge is being constructed by the Bilfinger Berger Baulderstone Hornibrook (BBBH) Consortium. A joint venture between two companies both within the Bilfinger Berger group.

In October 2005 the client, Phu My Bridge Corporation (PMC) signed an agreement with BBBH for the design and construction of the bridge. PMC as the Client is a private consortium comprising Hanoi Construction Company, Investco, Cienco 620, Thanh Danh Co, and CII. PMC has a 30 year BOT license to operate the bridge which will be part of a toll road. The project cost is US$105 million.
2. Project Details
The project involved the design and construction of a 2101m long viaduct. The viaducts consist of a 705m long cable stayed main bridge with a clear span of 380m, as well as the approach viaduct structures on either side of the river being 758m on District 7 and 638m on District 2.

3. Project Team
Construction of the bridge is being done by BBBH Consortium while the approach viaducts have been subcontracted to Vietnamese contractor, Chau Thoi Concrete Corporation 620 under close supervision of BBBH. Freyssinet have been engaged as a specialist subcontractor for the installation of the cable stays, prestress, and heavy lift.

Design of the main bridge and approach structures permanent works was split into two packages. The main bridge design was produced in France by the consultant Arcadis, whilst the approach structures were designed in Australia by Cardno.

A separate package was then created for the design of main bridge temporary work and the construction engineering for the main bridge. This was a combined effort between Cardno and Leonhardt, Andrä und Partner (LAP) from Germany. This paper focuses on these aspects particularly the work carried out prior to construction and the ongoing role during construction.

The chart below shows project organization for the Main Bridge:

![Project Organization Chart]
4. Description of the Main Bridge

The main bridge is a three span cable stayed bridge. The spans are 380 m for central span and 162.50 m for each back span. The total height of the pylons is 134.50 m above top of pile caps levels and 93 m above deck level. Clearance to river traffic is provided with a minimum 45m vertical clearance, at high tide, over a 250m wide zone at the centre of the bridge.

4.1 Substructure

Each Main Bridge pylon is founded on 2 groups of 14 No. 2.05m diameter piles, up to 80m depth, in addition the piles have been base grouted in order to ensure the base capacity of the foundations. Each pylon pile cap is composed of two sections of reinforced mass concrete capping each group of 14 diameter 2.10 m piles. These are locked together by means of a two cell box girder.

The pilecap construction was carried on in many phases. As the pile cap does not lie on the ground, a metallic frame was fixed at the top of the pile, supporting thin (20 cm) concrete slabs, on which a first pour (approximately 1.00 m) was carried out. The rest of the pile cap is then poured when the first lift has reached sufficient capacity to support the loads. The lateral formwork of the pile cap is made of precast skirting panels, which extends below low water keeping the pilecap base above low water level and ensuring a dry working area.
4.2 Towers

The pylons towers are H shaped. Each leg is a box section. The outer dimension varies from 5.50 x 7.00 m to 3.00 x 5.00. The stay anchorages are located inside the box. The legs are linked by 2 cross beams.

4.3 Tie Down Piers

The tie down piers are located at the end of each cable stay back span. The tie down piers are twin rectangular columns with vertical prestress supported on large diameter bored piles. The tie down pier is used to connect the last three stay cables on the back span. The deck slab is solid concrete and is prestressed in both the longitudinal and transverse directions.
4.4 Superstructure

The total width of the main span deck is 27m, this incorporates three lanes of traffic in each direction, two car and truck lanes, a separated motorcycle lane and footways for pedestrians.

The viaduct carriageway is composed of 2 x 3 lanes (including 2 x 1 lanes for motorbikes and bicycles) edged by 2 x 1.50 m wide pavements.

There are two vertical planes of stay cables. The structure of the deck is composed of two longitudinal concrete girders linked by transverse prestressed concrete cross girders at 5m centres. The stay cables are connected to the longitudinal edge beams by precast anchor pods located every 10m.
5. **Construction Method**

6.1 **Tower Construction**

The towers were built using a jump form in 4m lifts. A tower crane was located on the pilecap next to one leg and a hoist was attached to the other. The towers were constructed in the following sequence. The limiting cases on the tower were caused by high wind events and the forces created by the inclined tower legs.

- Construct 56m of tower leg and then install the lower strut/lifting beam 48m above the pilecap. The lower strut was used to control the forces and deflections in the tower leg and also for lifting the lower cross beam and pier table falsework.

- Construct the lower cross beam on the pilecap, attach the pier table falsework and the precast anchor pods for the first segments.

- Use the lower strut to lift the lower cross beam and pier table falsework. This heavy-lift was carried out by Freyssinet and involved lifting the 1200t assembly 30m into the air. Once the cross beam was in its correct position, stitch the lower cross beam to the tower leg;

- Once the lower cross beam was connected and stitched the pier table could be cast. This was done in three stages; first the central 10m was cast followed by the 10m on the side span and then the 10m on the main span. It was important that the deck construction could start as soon as possible and not have to wait until the completion of the towers.

- Continue building the tower legs and install the intermediate strut 70m above the pilecap. Remove lower strut. The intermediate strut is a needle beam used to control the forces in the tower legs. It is also used to support a catch platform for safety during the construction of the upper cross beam;

- Install upper strut. The upper strut acts as both a brace for the tower legs and to support the formwork for the upper cross beam. Construct the upper cross beam, remove the intermediate and upper strut and complete the tower legs construction.

- Install and stress the first stays between the pier table and the tower. Release and lower the pier table formwork and then lift the form travellers into position ready to start deck construction. At this stage the geometry of the deck is controlled by the length of the stays more than the force since the deck was free to pivot on the bearing. The stays were installed in 25% increments up to 75% of their installation force. At this stage another survey was carried out prior to making a final adjustment to the cable length.
6.2 Deck Construction

The following overall construction sequence was used for the main bridge.

a) - Build deck out from D7 Tower
The deck is constructed one segment at a time starting on the river side. The sequence between the two sides is partially offset to reduce the out of balance moments and speed up the construction, i.e. the traveller on the river side is launched to the next segment prior to casting the land side.

b) - Install Buffeting Cables
After 7 segments are cast on either side the buffeting cables are installed. Only the land side is tensioned. The river side is kept slack unless high winds occur (greater than 20m/s gust at 10m elevation). This limits the bending moments in the tower at deck level.

c) - Install Temporary Tie Down Cables
After 11 segments the temporary tie down cables are installed on the land side. The land side buffeting cables are released and the river side ones tensioned. This then limits the bending moments in the whole tower.

d) - D7 Sidespan Closure
After 15 segments are cast the 1.5m long side span closure is cast. A survey is carried out prior to the closure and the deck is position by releasing the temporary tie down cable. The pour is carried out in the evening to limit the temperature effects on the new concrete.

e) - Move travellers and Repeat for D2 Deck
After the sidespan closure is complete the three remaining river side segments are cast and the travellers moved to the D2 side to repeat the process.

f) - Main Span closure
The 10m main span closure is cast using one of the travellers. A full survey and adjustment of the stay cables is carried out prior to casting. After casting the SDL loads are placed and any further stay adjustments are carried out if necessary.
6.3 Deck Erection Cycle

The deck is constructed in balanced cantilever starting from each tower. 10m long segments are cast using a form traveller. The typical erection sequence is as follows:

- Cast new Segment, on the morning after casting carry out as built survey;
- Move rolling beam and stress front cross girder. Required concrete strength 30MPa;
- Destress and remove stressbars at anchor pods and restress stay cable. Required concrete strength 30MPa.
- Remove longitudinal strut. Lower Traveller and stress rear cross girder. Required concrete strength 35MPa;
- Launch Traveller halfway towards new position;
- Install precast anchor pods during the launch;
- Complete launch and raise traveller. Survey position of traveller and make adjustment to alignment if required;
- Place precast cross girders and edge beam reinforcement cages. Required concrete strength 40MPa;
- Start fixing deck reinforcement. Up to 25t of rebar could be placed before stay installation;
- Install longitudinal strut between anchor pods to the previous segment;
- Install and stress stay cable. The stay cable is attached to the anchor pod which is stressed to the traveller. The horizontal component of the load is transferred to the previous segment via the longitudinal strut. The vertical load component of this first stay force is kept constant at about 100t for each stay, which helped support the traveller during casting of the concrete. Required concrete strength 45MPa;
- Complete deck reinforcement and carry out prepour survey and cast new Segment.

After the initial learning phase this cycle was regularly achieved in 5 days with the sidespan cycle lagging 2 days behind the main span cycle.
6. Construction Engineer Role – Design Phase

BBBH engaged Cardno and LAP to carry out the construction engineering and the design of some of the major temporary works. Prior to construction commencing on site the Construction Engineer agrees with the contractor the following:

- Weights and requirements for major temporary works items;
- The best estimate of the time required for construction, as it was important to accurately determine the time dependant effects;
- When to install the stay cable;
- When to install the temporary tie-down cables and when and how often to restress;
- When to dismantle the forms and supports at the pier tables for both the tower and the hold down pier;
- Exact local sequences, for typical segment construction as well as for side span and main span closure procedures.

Once this is done the Construction Engineer models the sequence including consideration of the time dependant effects. To do this a sophisticated stage by stage analysis of the bridge was carried out.

It software program also possesses a powerful solver which can determine the forces to be applied to each stay at installation such that the forces at the end of construction are the same as those calculated by the permanent works designer. This is done by the program which solves a set of simultaneous equations with the constraints being the final stay forces, tower forces, etc. The input variables are the stay stressing forces and other adjustments such as jacking prior to the closure pours.

Once the stay forces are calculated the camber curves and support reactions will be calculated. The purpose of the analysis was to achieve a clear understanding of the following;

- Exact forces and deflections of all parts during all erection stages;
- Forces in the buffeting cables and temporary tie down cables;
- Forces in the temporary falsework at the hold down pier

The analysis also calculates Adjustment values to account for variations in

- Temperature conditions;
- Variation in construction live loads.

The erection analysis was based on the results of the permanent works design and took into account the most accurate actual parameters, dimensions and weights. In doing this special care was taken to address

- Dead weight, actual concrete density and reinforcement content;
- Section properties;
- P/T forces;
- Shrinkage and creep values
The object of the analysis is to meet the reality as close as possible, both in the position of the bridge and in the built in forces provided by the permanent works design, which must be achieved to be consistent with the final design assumptions. In addition an erection stress analysis was carried out to ensure that the structural capacity of all the bridge elements will not be exceeded at any of the individual erection stages.

Based on their previous experience of cable stay bridges and working in Vietnam BBBH had a clear view of how they wished to construct the bridge such that it would be quick and economical to build.

7. Construction Engineer Role – Construction Phase

During the construction the role of the construction engineer included the following:

- Monitor the survey results
- Adjust traveller shim values to create the correct precamber
- Adjust restress force to account for deck loading, temperature, stay force, survey results.
- Advise contractor on possible changes to construction sequence
- Review temporary works designs

In the morning following the casting of a deck segment the following information is obtained:

- A survey is carried out of the last four segments on the leading edge plus the tower.
- In addition a load map is taken of the major loading on the deck such as reinforcement stock, strand, mobile crane
- A lift off test is done on the cable on the new segment to determine the stay force.
The survey is compared to the predicted position of the deck and tower for that stage. An adjustment is made for the actual loads on the deck, cable stay force and temperature. From this analysis the Construction Engineer determines the restress length of the stay cable and the appropriate shim values for the next traveller position. This information was required by site within a few hours so as not to delay the construction cycle.

Adjustments to the traveller shims affect the local curvature while changes to the stay force have a greater effect on the overall geometry of the bridge. During construction the results from the survey were studied to check the accuracy of the analysis, some of the variables for which sensitivity analysis was carried out included:

- Variation in traveller weight. The design had assumed a traveller weight of 210t. When this was lifted to the deck the weight of the traveller was calculated to be 235t. An update of the analysis was therefore carried out to calculate revised precambers and stay forces;
- Deck stiffness. The deflections of the deck depend on the modulus of elasticity of the concrete used and also the effective width of the deck section.
- Stay stiffness. The strand used is provided with test certificates giving the area and modulus of the strand;
- Deck weight. The deck weight included in the design allowed for the reinforcement used. A comparison was carried out with the density of actual concrete used and the original assumption;
- Traveller stiffness. The traveller was modeled separately using a 3-D package with all the members to calculate its stiffness. The stiffness of the traveller was compared to the results found on site when loads were applied to the traveller.

During the construction of the bridge deck it was noted that the deflections of the bridge were greater than that predicted by the model. As noted there are several possible reasons for this occurring, however, one of the more likely seemed to be an increase in the traveller weight and deck weight. During the erection of the bridge the stay forces were increased by 1.5% above their design values to balance these deflections.
8. Conclusion

In summary this paper highlights some of the features used for the speedy construction of a cable stay bridge.

The project required significant planning and design to agree and optimize the construction methods. This involved a lot of collaboration between the contractor and construction engineer and has resulted in relatively few issues occurring during the construction process and a rapid achievement of the 5 day construction cycle with a short ‘learning process’. The role of the construction engineer both in the preconstruction and construction phase forms an important part of this team.

A contract duration of 34 months was originally anticipated with the project scheduled to be open to traffic by the end of 2009. At the time of writing it is planned to complete the bridge in 32 months. This will allow the bridge to be opened for traffic in October 2009.

The main span closure is due to take place in June 2009.