Design and Construction of the Hunt's Bay Bridge

By
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Introduction

The Hunt's Bay Bridge in Kingston Jamaica is a 210m crossing of a bay inlet. The bridge structure consists of 5 spans at a spacing of 37.5m-45m-45m-45m-37.5m, with 4 parallel, 2.04m deep composite box-girders for the superstructure, designed to carry 4 lanes of traffic with two shoulders. Each of the 4 piers in the bay use a 4-pile bent with a cap beam just above water level. Concrete-filled, 1.5m driven pipe piles are used below the cap, and reinforced concrete columns above the bent. The land based abutments are stem walls supported on 6 concrete-filled driven pipe piles. The bridge concept was presented as an alternate design to the base-bid structure, which resulted in the successful award to the proposing contractor. The project is currently under construction and the launching operation is anticipated to be complete by the end of November, 2005.

The construction of the bridge utilized the incremental launching process to overcome difficult site conditions, where it is constructed one span at a time on shore and pushed forward into place such that the process can be repeated for the next span. This methodology itself presented unique design challenges, but in addition, the site is subject to large seismic forces adding to the complexity. This paper will describe the process for both the design and construction, and the inseparable accommodations that were implemented.

Superstructure Design Concept and Details

Type Selection

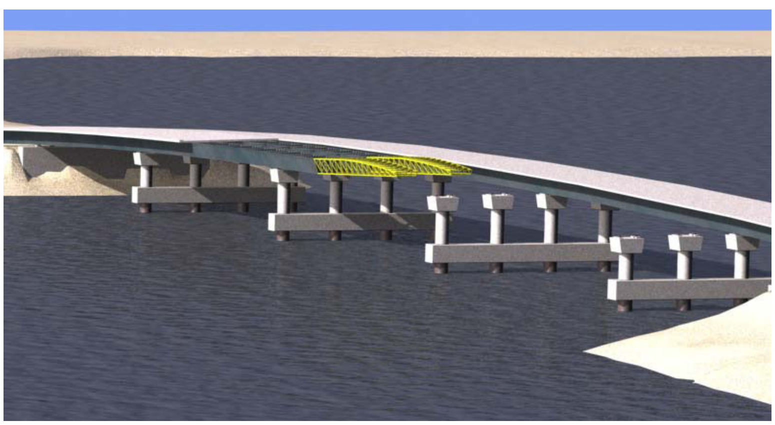

Figure 1

The original proposal for the Hunt's Bay Bridge was a conventional steel I-girder design with reinforced concrete deck over the bay inlet. This concept was taken to a 30% design level and contractors were permitted to consider other options. Upon analysis from one bidder, VSL Corporation Mexico, a number of difficulties were identified regarding the particular site conditions and other concepts were explored. In particular, incremental launching was identified and selected as a good candidate for the site. This process constructs the bridge by assembling essentially one span at a time on land, then pushing it forward to the next pier, and repeating the process until the full length of the bridge is in place. Sliding Teflon bearings are used at each pier to promote the movement. The new bridge is parallel to an existing bridge and an appropriate staging area was available at each of the abutments. This would allow much of the work to be performed on shore and reduce both cost and time to erect the bridge.

Steel box girders with composite deck were selected in place of the I-girders. In past projects steel I-girders have been used for incremental launching, however box-girders have an inherent stability to them when braced on the top. This was especially important with the contractor's preference to launch the bridge with the deck slab cast in advance. These considerations led to the selection of a box-girder superstructure.

Figure 2

For seismic considerations, a concrete superstructure was also investigated but the soil conditions within the bay are poor resulting in a need to lighten the bridge as much as possible. The foundations represented a large portion of the project costs and therefore the lower material costs for a concrete did not represent enough of a savings to use that alternative.

Design Loads

The Hunt's Bay Bridge was designed to AASHTO LRFD, however this particular bridge was part of a large toll project which had already implemented British Standard live loading. Because the owner wanted to maintain a consistent loading assumption project wide, the bridge was designed using the British loading (BS5400, BD37/01) together with the LRFD design code. This approach has obvious potential pitfalls, and some key issues are identified below.

The first is to maintain a consistent approach, to the fullest extent possible, with the load combinations and related design factors. In many ways strength design can be considered fairly uniform regarding the capacity calculations, but loads and load combinations are calibrated and correlated, and replacing load cases can be very difficult. This includes keeping consistent the loads which are related to each other, such as using the BS5400 approach for vehicle braking in conjunction with the live loads that will develop the same braking. In addition, special consideration should be given where the design equations are linked to the loading. This is the case with fatigue, where the allowable stress ranges in AASHTO and BS5400 are assumed to come from the same fatigue truck. Therefore for cases like these, the loading should be consistent with the design approach.

This requirement provided a unique challenge for this project, however was resolved by taking a meticulous approach to understanding the intentions of both codes and maintaining consistency to the greatest extent possible.

Superstructure Details

The bridge deck is a total of 26.6m wide out-to-out. It carries a total of 4 lanes of traffic (2 in each direction), with 3.5m wide lanes and 2, 1.5m shoulders. In addition to the edge steel barrier railings is a central concrete barrier. The concrete deck is typically 0.24m thick, with a tapered overhang that reduces to 0.18m thick. Of note, the deck is post-tensioned in the transverse direction. This is commonly used in concrete box-girders and has shown to have very favorable long-term benefits in addition to being cost competitive.

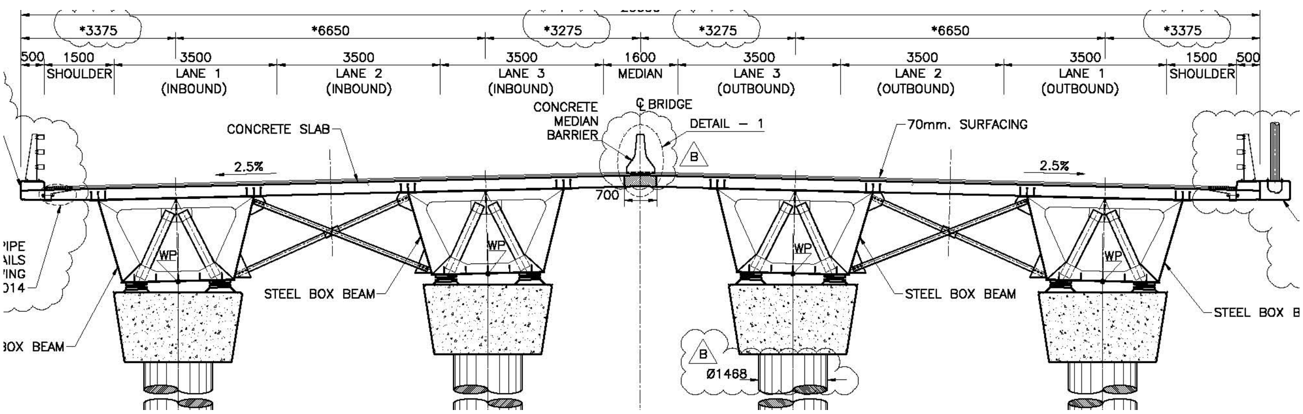

Figure 3

The steel box-girders themselves use 50ksi steel and are 1.8m deep, with 19mm bottom flanges, 16mm webs, and 22mm top flanges. A total of 4 girders are used and spaced transversely at 6.65m. Large diaphragm members were required at the piers to carry the high seismic loading characteristic of the site. The box-girders were fabricated in Mexico is sections and shipped by boat to the site in Jamaica.

A special feature of the design was the casting of the deck slab in advance of launching the spans. This was done to avoid casting the deck over water to the greatest extent possible, however special caution was taken to consider the additional load on the structure. For the case of the first span, the presence of the launching nose resulted in additional weight and therefore the slab for this span couldn't be cast until the launching trusses were removed. Note that the slab was cast for two adjacent box-girders, which were launched simultaneously. Once launching is complete, the two sets will be stitched together by a short cast in place section at the transverse midpoint.

Figure 4

Because of the special loading conditions for this bridge, a non-traditional arrangement of stiffeners was used. As the bridge is launched, its support conditions vary along the total length. There is a loading condition where each cross-section will experience both positive and negative moments. In addition, the tolerances in

Figure 5

the erection process will result in some lateral movement, which again gives uncertainty in the loading pattern. Therefore a pattern of stiffeners was developed which would attempt to resist all cases.

Knowing the support conditions during launching is essential, and therefore the designer also participated in the development of the Teflon sliding bearings. From a detailed FEM study, it was found that local reactions which slightly strayed off of the box-girder webs and put pressure on the bottom flange would result in unstable loading conditions. A sliding bearing was developed that had a contact length of 1200mm and 250mm wide. To match this, a web stiffener was added every 750mm and projected out to the width of the temporary bearing and down to the bottom flange. Each stiffener was developed as an equivalent column that could carry the maximum loading, including a factor for impact. At this spacing at least 2 stiffeners would be well within the contact surface and provide a redundant load carrying system. Also to account for differing angles at which the superstructure would make contact during launching, the bearings included a curved bottom surface in order to allow it to rotate to the particular geometry. A center pin was used for longitudinal restraint.

In addition to the web stiffeners, a series of 5 bottom flange stiffener plates were used in the longitudinal direction, and intermediate transverse stiffeners were provided every 3.75m. The traditional AASHTO design promotes a single, robust stiffener for the bottom flange, but in this case it would be located far away from the critical local construction loading. Therefore a grillage or a "stiffened skin" approach was adopted such that the bottom flange would have alternate load paths available for unexpected loading conditions.

Figure 6

With this explanation of the box-girder details, it can be observed how the design considerations required a marriage of the construction and service life conditions of the bridge. In many cases, the construction staging was more critical, and the design-build approach was very beneficial where the designer had access to both sides of the process. This way, the construction considerations were not an add-on to the existing design, and efficiencies could be realized by implementing a unified approach to the final details.

Substructure Design Concept and Details

Type Selection

For the Hunt's Bay Bridge substructure, the superstructure layout provided a functional guidance to the substructure selection. The four box-girders were each supported by a single 1.5m diameter pier and enlarged piercap to support the pot-bearings. Compared to the original concept, this replaced a multi-column bent with numerous piles and a large crossbeam, and again cost savings were realized with the alternate design. For the locally available construction equipment, a 1.5m pile and relevant capacity were determined to be an upper-bound size. Therefore a continuous 1.5m single pile and column were provided per box-girder. A transverse cap, 2.0m by 2.0m, was provided just above water line to take ship impact and provide lateral stiffness.

Figure 7

The conditions for the abutment allowed for a traditional seat type abutment supported on 6, 1.5m piles. However under seismic loading it was designed to engage the soil under longitudinal actions, which is described in greater detail below.

Design Loads

The seismicity around Jamaica and the city of Kingston is quite high and governed the design of the bridge substructure. However at the time of design, the seismic loading was not well defined, and a procedure was independently developed to evaluate the bridge. The contractual documents specified using an equivalent static method, assuming a base seismic coefficient of 0.3g. Corresponding with AASHTO, this would qualify as a high seismic location, and should be detailed accordingly where a high level of analysis is warranted.

Where the exact seismic loading is unknown, the capacity design approach provides an excellent tool for designing the bridge. The first step was to use AASHTO LFD, Division I-A Seismic Design provisions, which can estimate the lateral response of the bridge using response spectrum loading. When including the amplification of the soil, the governing lateral load was above 0.4g. Under this level of loading ductile behavior of the piers is assumed, and the code gives guidance to proportioning the reinforcement and providing proper seismic detailing. However the actual capacity of the bridge is not explicitly known, and therefore a pushover analysis was performed in accordance with the California Department of Transportation (CALTRANS) guidelines. Form this, it was determined that the bridge piers could accept displacement demands well above what could be reasonable expected, giving an added layer of assurance to the design of the bridge under uncertain seismic criteria.

Substructure Details

The general soil conditions consisted of medium dense clay which dictated the use of steel friction pipe piles. The mudline is encountered at a depth of about 5m below the water, however the upper soil layers are loose and subject to liquefaction under seismic loading. Because of this, a design condition was considered which ignored the upper 10m of soil resistance. This resulted in driving the piles to a depth of approximately 40m below the water line. In addition, the long unsupported length of the piles required the use of infill reinforced concrete for added stiffness down to a point where the piles experience relative fixity. For seismic reasons, shear rings were added within the upper portion of the pile to ensure composite action and adequate load sharing between the steel shell and concrete core.

By most accounts the substructure is fairly conventional, except for its performance under longitudinal earthquake. Using a method common in California, the Hunt's Bay Bridge is designed to engage the abutments under longitudinal earthquake to help resist the seismic loading. The implementation of this feature was very beneficial for the design of the bridge. The 4 bents in the water are stiff transversely due to the pile orientation, but very flexible longitudinally due to very poor soil conditions. Under traditional lateral restraint systems these bents would be the primary load carrying members, but would not have worked in this case resulting in a significant increase in piles. But by utilizing the abutments, which are there regardless, and including some simple detailing accommodations, mobilizing the soil resistance is a very effective way to resist these forces.

For the abutments to perform this action, the bearings at one abutment are pinned and designed to carry the seismic loads. However the other end required an expansion joint, and therefore the backwall is designed to accept the impact from the bridge deck and transfer the load in a stable manner. This is accomplished by longitudinally extending the top slab to create an overhang from the steel box-girder within the gap at the expansion joint. This essentially serves in making the top slab a battering ram and avoids putting large compression loads directly into the box-girder. The backwall of the abutment is then stiffened with local concrete ribs in order to resist these loads and work in conjunction with the soil backfill to provide longitudinal resistance.

By utilizing this behavior, significant cost savings were realized in the pile bents. The bents are very flexible longitudinally, and under free movement due to seismic forces the displacement and design loads they would have been significantly overstressed. However by engaging the abutments, the longitudinal action of the pile bents is restrained by compatibility, and their design is governed by loading in the transverse direction where they are much more effective.

Summary Remarks

The design of the Hunt's Bay Bridge blended many unique features, and required a fully integrated concept to resist construction, service, and heavy seismic loadings. In particular, the variables associated with the incremental launching design issues proved most challenging, and it is essential that the designer be involved in all aspects of the temporary works and construction methodology such that the final product serves the needs of all demands.