

The Lions' Gate Bridge Suspended Span Replacement

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## **Abstract**

### **Lions' Gate Bridge Suspended Span Replacement**

The three lane Lions' Gate Suspension Bridge is a landmark structure in Vancouver, British Columbia, Canada. The 472 meter (1550 feet) center span marks the entrance to one of the busiest harbours on the west coast of North America.

Constructed in 1938, the bridge was privately financed, and as such, long term durability was often sacrificed in favor of initial capital cost savings.

In 1997, Buckland & Taylor Ltd. was retained to design the replacement of the entire suspended structure (deck, sidewalks, stiffening trusses, and suspension hangers). Maintaining the traffic (70,000 vehicles per day) on the bridge during the replacement was a critical requirement that influenced every aspect of the design.

After the design was completed in December 1998, the project was tendered. Three bids were received, and the winning Contractor, American Bridge / Surespan A Joint Venture, was selected in April 1999. Between September 2000 and September 2001, the suspended structure of the 60-year old bridge was replaced during 10-hour night time closures plus a few longer closures on weekends. The bridge was open to full traffic at all other times during the reconstruction. The final paving was applied in the summer of 2002.

This project is believed to be the first time an entire suspended structure has been replaced while traffic continued to use the bridge each day. The result is a wider, safer, more durable suspended structure that blends seamlessly with the aesthetics of the remaining original portions of the bridge.

## **Introduction**

The Lions' Gate suspension bridge, located in Vancouver, British Columbia, Canada, has a 472 m center span. Figure 1 shows the elevation view of the bridge. Buckland & Taylor Ltd. (B&T) was retained in 1997 to design the replacement of the suspended structure (deck, sidewalks, stiffening trusses, and hangers) and design a seismic upgrade for the entire bridge. The design was completed in December 1998, and B&T continued to act as Owner's Bridge Engineer during construction.

Three bids for the construction were received in February 1999. The successful Contractor, American Bridge / Surespan A Joint Venture (AB/S), was selected in April 1999 to execute the \$86.5 million contract. The cost of the suspension bridge portion of the project was approximately \$66 million.

Between September 2000 and September 2001, the suspended structure of the bridge was replaced during 10-hour night time closures plus a few longer closures on weekends, and the final paving was applied in the summer of 2002. Both design and construction methods had to accommodate the replacement while maintaining regular traffic (70,000 vehicles per day), except during the short closure periods.

This is believed to be the first and only time a major suspension bridge has had its entire suspended structure replaced while maintaining daytime traffic.

This paper will focus on the Lions' Gate Bridge portion of the project, and in particular, the design and erection of the suspended structure replacement.

## **The Original Bridge**

The Lions' Gate suspension bridge is a landmark structure marking the entrance to Vancouver, one of the busiest harbors on the West Coast of North America. Constructed in 1938 to a brilliantly light design, the bridge was privately financed. As such, long term durability was often sacrificed in favour of initial capital cost savings.

The bridge was initially opened with two traffic lanes, and the only concession the developers made to the future was to design the bridge deck such that three narrow lanes could be squeezed between the curbs. Tolls provided the only source of revenue to pay for the bridge. By 1952, the debt was fully repaid at which time the bridge was sold to the British Columbia Government. In 1954, the lane markings were changed to accommodate three 2.9m lanes, with the middle lane as a free-for-all passing lane. The government continued to collect tolls until 1963, at which time the tolls had serviced the debt incurred by the Government's purchase of the bridge. Traffic volumes on the crossing continued to increase and, in 1965, a reversible counter-flow lane control system was installed, which resulted in three full lanes of traffic, two in one direction and one in the other.

By the early 1970's, the durability of the bridge had become an issue. The concrete deck of the 669m long north approach viaduct to the bridge had deteriorated to the point where the Government was repairing more than 1000 pot holes per year. In addition,

studies had shown that the suspension bridge stiffening truss was deficient for modern live loading. In order to reduce the rate of deterioration and to reduce the loading in the truss, trucks were restricted to 13,600 kg registered GVW in 1974.

In 1972, B&T was hired by the Government to design a replacement deck for the north approach viaduct. A bold replacement option was developed that had never been done before. This option involved replacing the narrow concrete deck with a new, wider orthotropic steel deck during short night closures, while maintaining traffic on the bridge during the day. The replacement deck carries three 3.6m wide traffic lanes and two 1.4m wide sidewalks. The project was a tremendous success and the Government got a new deck with very little disruption to traffic. This method of replacement was so successful, it has since been copied on many bridges throughout North America, including the George Washington Bridge in New York, and the Golden Gate Bridge in San Francisco.

### **The Lions' Gate Project**

By the mid 1990's, the bridge was carrying 70,000 vehicles per day. Due to the heavy traffic, and the economy of the original construction, the suspension bridge deck had deteriorated to the point where maintenance was costing approximately \$3 million per year. At that time, the government decided that the crossing would be rehabilitated and numerous options were considered. By the end of the public process, the solution chosen was to replace the existing suspended structure while maintaining three lanes on the crossing.

The Project included the following major components:

- the entire suspended structure of the suspension bridge (deck, sidewalks, stiffening trusses, and suspension hangers) was replaced with a wider cross section to accommodate three 3.6m traffic lanes and 2m clear width sidewalks;
- the suspension bridge was seismically upgraded;
- the 2km long causeway road through Stanley Park, to the south of the bridge, was widened;
- the north approach viaduct was seismically upgraded
- the sidewalks on the north approach viaduct were widened (the lanes had already been widened in 1975); and
- the electrical, lighting and lane control systems for the crossing were replaced.

## **The Design Team**

In May 1997, the Government initiated the design process of the project.

Buckland & Taylor Ltd. of Vancouver BC, the Owner's Bridge Engineer, prepared the final plans and specifications for the bridge deck replacement and suspension bridge seismic retrofit. N.D. Lea Consultants Ltd. of Vancouver BC (now MMM Group), the Owner's Engineer, prepared the final plans and specifications for the causeway as well as the general contract documents for the Project. As a sub-consultant to N.D. Lea, PBA Engineering Ltd. of Victoria BC prepared the final plans and specifications for the electrical and lane control components of the Project.

## **Suspended Span Replacement Design**

The new suspended structure had to be designed to be replaced with minimal impact to the 70,000 vehicles using the bridge each day. Total closures of the bridge to traffic were to be limited to night closures, from 20:00 to 06:00, and a few weekend closures, from 22:00 Friday to 06:00 Monday. The duration of night closures made the need for planning an order of magnitude more important than for a normal construction project.

Design details were developed that considered the constructibility issues that arose due to the short duration of the bridge closures. The design anticipated 47 new deck sections, typically 20m in length weighing 106 tonnes, progressively erected from north to south. The field splices were located to allow the newly erected deck section to be raised with little interference from the previously erected section. All the splicing of the stiffening trusses and deck troughs used bolted connections rather than field welding, to allow for alignment and quicker completion of the splice.

## **Dead Load**

The design of the original stiffening trusses, floorbeams, stringers, concrete filled tee-grid deck, and steel sidewalks produced a relatively light suspended structure. Though the new deck is approximately 35% wider, with almost 45% more usable width than the original deck, the weight was kept to that of the original bridge. This was important as it meant that the towers, main cables, and main cable anchorages did not need to be upgraded to carry any additional load. Maintaining the same light weight was also critical to allow sequential replacement of the deck in sections without inducing unacceptably large deformations and stresses in the original or new structural components during construction.

B&T's design increased the width of the three traffic lanes from 2.9m to 3.6m, included traffic barriers to separate pedestrians and cyclists from the traffic (the original bridge has no barriers), and increased the width of the sidewalk width from 1.3m to 2.7m (2.0m clear at the hanger locations).

The new longitudinal stiffening trusses are composite with the orthotropic deck, and unlike the original trusses, the new ones are placed under the deck.

See Figures 2 and 3 for a comparison of the old and new cross sections.

### Seismic

Due to the significance of the structure and its location on the West Coast of North America, the response of the structure to an earthquake was crucial in the design. B&T considered two types of seismic events, a moderate magnitude quake close to the site and a major, subduction earthquake located some 200 km away.

It turned out that the new structure has a few characteristics that improve its anticipated performance in the design earthquake; the dead load of the suspended structure was kept to a minimum and the primary dynamic periods of the structure are long. These characteristics reduce the impact of a seismic event on the structure, the result being that wind loading was the controlling factor for many of the transverse structural elements, and little retrofit was required for the towers and cables.

### Construction

In April 1999, the BC Government awarded a \$86.5 million contract to upgrade the Lions' Gate crossing, including the approach roads, to American Bridge/Surespan A Joint Venture. The reconstruction cost for the bridge was approximately \$66 million.

The north approach viaduct seismic upgrade was included as a design-build portion of the project, and was designed by Klohn-Crippen Consultants Ltd. of Vancouver BC (now Klohn Crippen Berger Ltd.), and independently checked by Parsons Brinkerhoff Quade & Douglas Inc. of Sacramento CA, both working for the Contractor.

Since the public continued to use the bridge during construction, the Government required that the Contractor both carry out a design, and perform a complete independent check, of the erection procedures for the replacement. Parsons Transportation Group Inc. (formerly Steinman) of New York performed the erection analysis for the bridge deck replacement, and Parsons Brinkerhoff Quade & Douglas Inc. of New York independently checked the erection analysis, both working for the Contractor.

### Construction Equipment

The main components of the Contractor's construction equipment were a "jacking traveler" (see Figure 4), which supported four 60 tonne capacity strand jacks, and a "continuity link" (see Figure 5), which provided the vertical and lateral connection between the new and old deck sections at the erection front. The jacking traveler was a steel frame that weighed approximately 55 tonnes and was the support structure for lifting and lowering deck sections. The jacking traveler was designed to be supported on the original hangers when lowering and lifting sections and to be supported on the deck when the jacking traveler was moved.

The continuity link, which weighed approximately 20 tonnes, was needed whenever traffic was using the bridge. It connected the new and old sections together at the

erection front and, therefore, maintained the continuity of the roadway surface. At the beginning of a night closure, the continuity link was disconnected and moved, on the existing maintenance traveler rails, to the next location. After the deck section was replaced, the continuity link was re-connected prior to allowing traffic to use the bridge.

### Typical Deck Section Replacement Cycle

The replacement of a typical deck section began by positioning the jacking traveler over the section to be removed (this was typically done during the day while traffic was using the bridge). At the start of a night closure, the bridge was closed to traffic and the continuity link was disconnected and moved to the next location. The old truss, old deck and the original hanger lug plates were cut (see Figure 6), thereby releasing a 20m section of the existing deck from the bridge onto the strand jacks. The old section was lowered (see Figure 7) and disconnected from the strand jacks. The new deck section was attached to the strand jacks and raised into place (see Figure 8). The geometry of the new section, in relation to the previously erected new sections, was established and bolts were installed and torqued in the trusses and the orthotropic deck troughs (see Figure 9). Temporary adjustable hanger extensions were installed between the original hangers and the new deck then the continuity link was connected. The strand jacks were disconnected and the adjustable hanger extensions were set to their correct lengths to distribute the loads between hangers to avoid overloading the structure. Temporary deck plates and temporary traffic barriers were installed and the bridge was reopened to traffic.

The non-typical sections at the ends of the spans required a similar process but also included replacement of the bearings, wind guides and expansion joints, and were therefore replaced during a longer weekend closure.

The Contractor elected to replace the south side span in 10m sections. This change in procedure allowed the Contractor to eliminate the need for an elaborate ramp system on the steep slope below the side span that was anticipated during the design. It also resulted in a total of 54 deck sections for the bridge instead of the 47 shown on the design drawings. The jacking traveler was modified to allow the sections to be driven to the erection front on the new deck (i.e. from the north), lifted by the jacking traveler, rotated 90 degrees (see Figure 10), and lowered into place.

The deck erection started at the north end and progressed south. The first deck section was installed in September 2000 and the last one a year later in September 2001. Following installation of the deck sections, the original cable suspenders were replaced. Due to minimum temperature requirements, the final lift of epoxy asphalt was installed in the summer of 2002 (see Figure 11).

## **Conclusion**

Between 2000 and 2002, the three lane Lions' Gate Suspension Bridge underwent major reconstruction. The entire suspended structure (stiffening trusses, deck, sidewalks, and hangers) was replaced in 20m or 10m long sections at night, while 70,000 vehicles continued to use the bridge each day. See Figure 12 for an overall picture of the bridge after construction was complete.

It is believed that this was the first of its kind in the world, and at the time of writing this paper, it was a construction and engineering feat that has not been repeated.



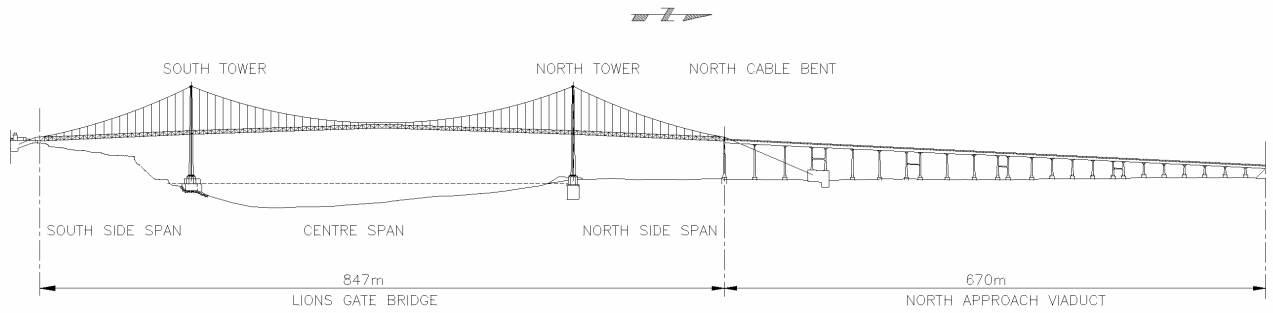


Figure 1: Lions' Gate Bridge Elevation

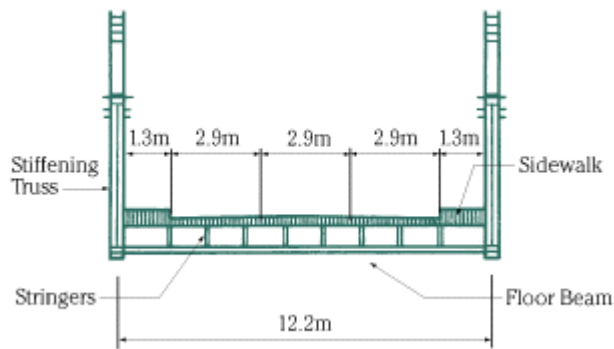


Figure 2: Old Cross Section and Old Sidewalk Photo

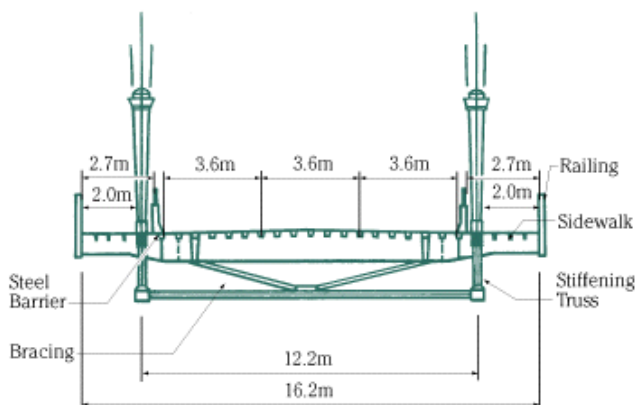


Figure 3: New Cross Section and New Sidewalk Photo



Figure 4: Contractors Jacking Traveler



Figure 5: Contractors Continuity Link (Mates with Section Attached to Old Bridge)





Figure 6: Cutting Old Deck Section Free



Figure 7: Lowering Old Deck Section





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Figure 8: New Deck Section Being Raised



Figure 9: New Section Being Bolted to Previously Erected Section





Figure 10: Modified Jacking Traveler Rotating South Side Span Section



Figure 11: Final Paving Being Applied



Figure 12: Overall Photo After Construction