



ASSOCIATION OF CONSULTING  
ENGINEERING COMPANIES | CANADA



Klohn Crippen Berger

# Knight Street Bridge Geotechnical Seismic Retrofit

ASSOCIATION OF CONSULTING ENGINEERING COMPANIES – CANADA  
2013 AWARDS SUBMISSION







## NAME OF MEMBER FIRM SUBMITTING

Klohn Crippen Berger Ltd.

## ADDRESS OF FIRM

500–2955 Virtual Way, Vancouver BC V5M 4X6

TEL FAX EMAIL

604.669.3800 604.669.3835 asy@klohn.com

## CONTACT NAME

Alex Sy, Ph.D., P.Eng.

## PROJECT TITLE

Knight Street Bridge Geotechnical Seismic Retrofit

## LOCATION OF PROJECT

Vancouver, BC, Canada

## CATEGORY OF ENTRY

Transportation

## PROJECT CLIENT

Associated Engineering (BC) Ltd

## PROJECT OWNER

TransLink



**SEISMIC UPGRADE OF THE KNIGHT STREET BRIDGE WAS A KEY PROJECT TO TRANSLINK TO ASSURE COMMUNITIES THAT IT IS PREPARED FOR THE NEXT EARTHQUAKE.**

## PROJECT SUMMARY

The seismic upgrade of the Knight Street Bridge was a key project to TransLink to protect this critical transit route. Klohn Crippen Berger designed a multifaceted retrofit solution to respond to the unique site constraints and varied ground conditions along the 1.5 km span. An unconventional tender strategy removed much of the risks of ground improvement from the contractors and resulted in cost savings to the owner. Construction to this lifeline bridge was successfully completed.

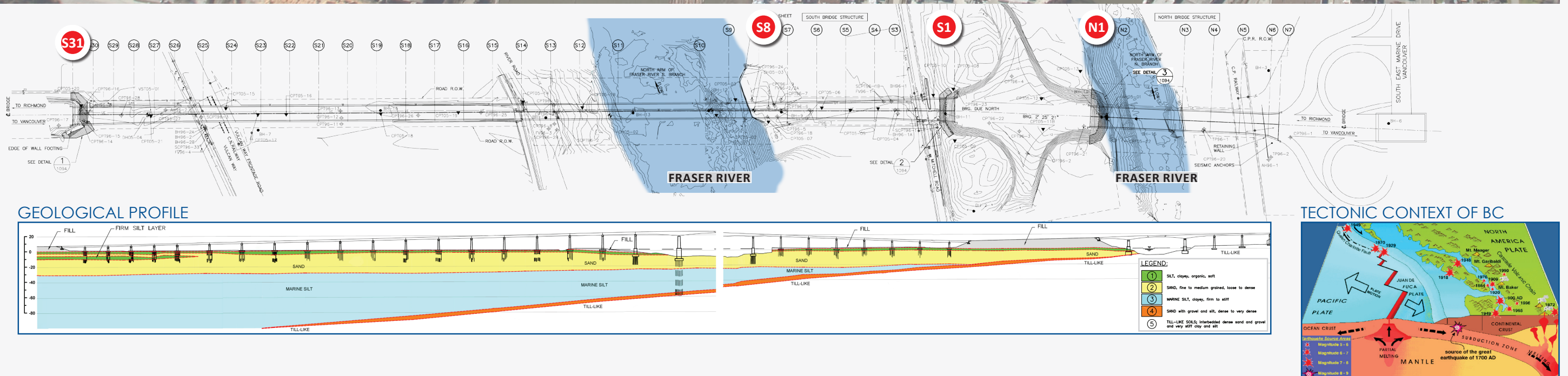
## INNOVATION

The 1.5 km long Knight Street Bridge, which was built in 1974 over two arms of the Fraser River, connects City of Vancouver and City of Richmond, with access to Mitchell Island in between. The bridge carries approximately 100,000 vehicles per day. As part of TransLink's Major Road Network, the "lifeline" bridge needed to be brought up to modern seismic standards. The Lower Mainland of British Columbia is situated in one of the most seismically active regions in Canada. Klohn Crippen Berger (KCB), as subconsultant to Associated Engineering, carried out the geotechnical assessment and ground improvement design for seismic upgrade to the bridge.

The bridge is supported on 38 piers or abutment footings, most of which are located in Richmond and Mitchell Island, underlain by deep deltaic sediments of the Fraser River. During design earthquakes, widespread liquefaction is expected that will cause significant movements of the existing bridge foundations and possibly bridge collapse. Assessments showed that superstructure retrofit alone will not save the bridge, and foundation improvements are necessary. Conventional analyses would require extensive ground improvements, both around the piers on land and in the water; the costs for such ground improvements were excessive. Consequently, detailed modelling by KCB using dynamic soil-structure interaction analysis resulted in reducing geotechnical retrofit requirements to only four on-land piers or abutments, at N1, S1, S8 and S31. The other pier foundations are expected to perform satisfactorily during design earthquakes.



# INNOVATIVE FOUNDATION SOLUTIONS TO RETROFIT BRIDGE





## Innovative Foundation Solutions to Retrofit Bridge

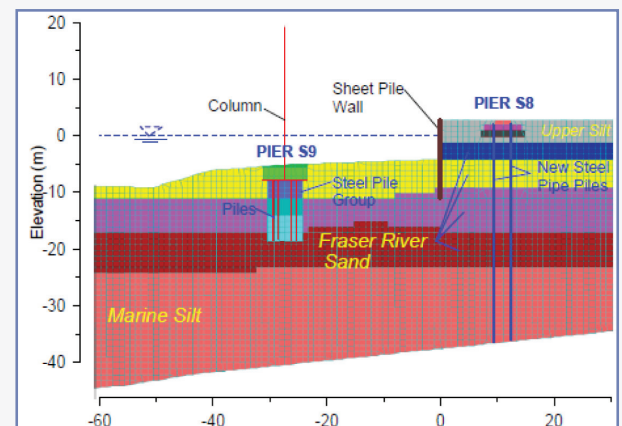
Innovative ground improvement or retrofit methods were designed to suit the ground conditions and site constraints at the four pier locations. The solutions had to avoid any bridge closure during construction, and had to consider existing nearby buried utilities and minimize environmental impacts or damage to fish habitat.

## Unconventional Contracting Strategy for construction

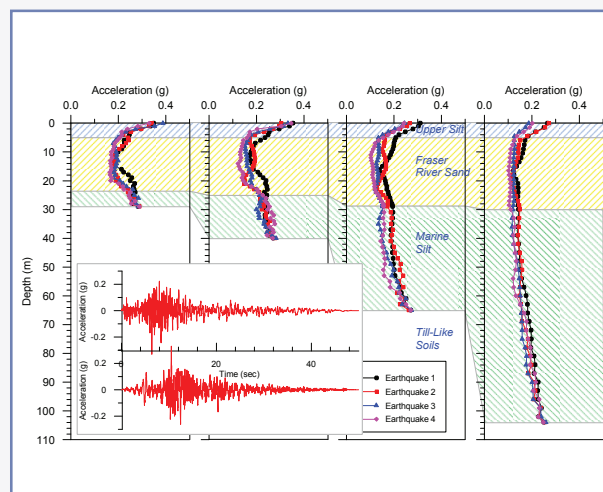
Initial contractors' bids to the ground improvement tender for all sites based on conventional performance-based specifications and where risks of damage to buried utilities were put onto contractors, resulted in prices significantly exceeding the owner's budget. Consequently, an unconventional strategy was adopted for retender, in which contracts were separated according to construction techniques, and method-based specifications were used that transferred performance and utilities risks to the owner. The transfer of risks was prudent because of a number of measures undertaken by KCB, including a pre-construction compaction test pile program, and pre-construction survey and monitoring program for utilities. The construction was completed successfully without delay or damage to utilities, and resulted in significant cost savings to the owner.

## COMPLEXITY

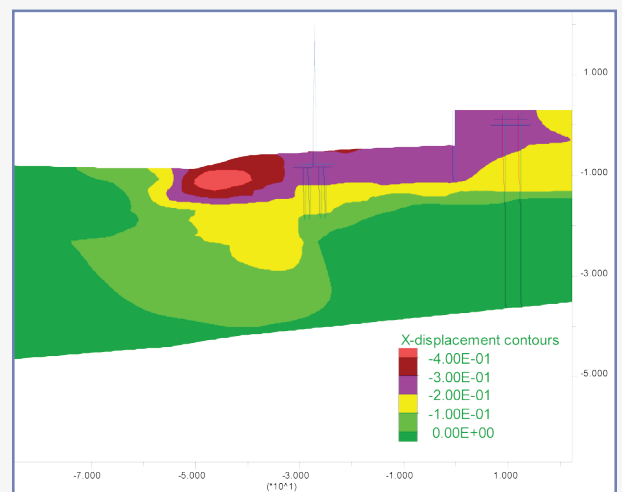
Seismic liquefaction is a well-known phenomenon, and its prediction through conventional site investigation techniques is well-established in practice. Traditional ground improvement methods to prevent liquefaction are also well-established for new site developments. However, for existing structures, predicting liquefaction induced ground displacements, which are the indicator of damage to existing foundations, is much more difficult because of the complexity of soil-foundation-superstructure interaction problem, particularly on highly variable



MODEL  
S8 MODEL ANALYSIS WITH NEW STEEL PIPE PILES



MODEL  
EARTHQUAKE RESPONSE OF GROUND AT BRIDGE PIERS



MODEL  
DISPLACEMENT CONTOURS FROM SEISMIC ANALYSIS OF PIER S8





UTILITIES AND UNDERGROUND SERVICES PROTECTED DURING GROUND IMPROVEMENT



EXISTING EMBANKMENT AT ABUTMENT N1 PROTECTED

soil conditions along the 1.5 km bridge alignment. To optimize retrofit design, KCB employed advanced dynamic soil-structure interaction analyses using state-of-the-art computer models. The analyses resulted in geotechnical retrofit requirements at only 4 of the 38 bridge piers and only on land, which resulted in significant ground improvement costs to the project.

In addition to the variable ground conditions at the four pier locations, the headroom under the bridge at each site was limited, and there were numerous buried utilities at or close to the construction areas, including water mains, sewer mains, and electrical ducts, as well as surface structures, such as existing foundations and an electrical substation. Relocation of these utilities was impractical, as shutting down some of these was not an option with utility owners. Two of the sites were also next to riverbanks. These multiple site constraints eliminated more traditional and cheaper ground improvement techniques, such as vibro-replacement and dynamic compaction, leading to a multifaceted solution employing several methods, and the use of an unconventional tender strategy to minimize ground improvement construction costs.

## SOCIAL AND ECONOMIC BENEFITS

Knight Street Bridge is a major bridge connecting two of the most important cities in BC, and it currently serves more than 100,000 vehicles daily. It is also vital to BC's economy. The original bridge, built in the mid-seventies, did not meet the current seismic standards and would not have survived a major earthquake; however, the people and the businesses that depend on this bridge, require this bridge to survive a large earthquake and to be functional. This retrofitted "lifeline" bridge will provide unimpeded connection between the two cities, and allow emergency personnel and disaster response teams to provide help to people in need after an earthquake. The seismic upgrade of the bridge satisfied these requirements, and the bridge has been made ready for the next big earthquake, when it comes.

The seismic retrofit, carried out using innovative design and unconventional contracting strategy, provided a cost-effective solution to a complex site, while ensuring that the construction itself did not cause any adverse environmental impacts. The construction also did not require closure of the bridge during construction which would have inconvenienced hundreds of thousands of commuters. The economic benefit of a functional bridge after an earthquake is also expected to be significant.



## ENVIRONMENTAL IMPACT

At the design stage, the retrofit strategy required not only a cost-effective but also an environmentally friendly solution. As the bridge crosses two arms of the Fraser River, minimizing impact on the river and its habitat was a key consideration. An innovative design solution for the riverbank Pier S8, which avoided ground densifications around the piers in water and led to a land-based retrofit scheme, prevented impact to the river. The retrofit solution of using compaction piles at the abutment Pier N1, which is located next to the north riverbank, also avoided causing any environmental impact to the river. This technique, unlike more traditional methods, does not use water or produce waste water or silt. The contractors, owner and KCB worked together to ensure best environmental practices were followed during construction. Despite working in the vicinity of the river, no wastewater, oil or silt was introduced into the river. Only two trees were removed for construction, but three were re-planted upon completion. The cleared construction areas and slopes were hydro-seeded. The areas under the bridge deck were protected either with a concrete slab or gravel to prevent erosion and control dust. The drainage lines from the bridge were diverted to designated areas prior to construction and re-established. Surface water control measures were provided in all areas.

## MEETING CLIENT'S NEEDS

Seismic upgrade of the Knight Street Bridge was a key project to TransLink to assure communities that it is prepared for the next earthquake. According to design criteria established for the bridge by the owner, the “lifeline” bridge should be functional after a 500 year return period earthquake, and should not collapse after a 1000 year return period earthquake. The upgraded bridge and the adopted geotechnical retrofit schemes met the design criteria.

The innovative design and contracting strategy provided a cost-effective solution to TransLink, and also reduced the maintenance cost for the bridge structure. At no time was the bridge closed for traffic during ground improvement construction. The owner was concerned about the presence of numerous utilities in the ground improvement areas owned by the client and other organizations. All the utilities were exposed prior to construction, and monitored for movement daily and as frequent as necessary during construction to ensure that there is no damage. Timely monitoring data was provided by KCB to the owner and to the other utility owners. KCB provided full time observation during construction to ensure quality, and to confirm that construction was in compliance with the design, and any issues arising from the construction were promptly addressed. KCB also provided the necessary data to the owner as required for payment to the contractors in a timely manner.



## PHOTOS



TIMBER COMPACTION PILE INSTALLATION AT ABUTMENT N1 ADJACENT TO THE RIVER



TIMBER COMPACTION PILE AND SEISMIC DRAIN INSTALLATION UNDER BRIDGE DECK AT PIER S1



SPlicing STEEL PIPE PILES AT PIER S8



COMPACTION GROUTING UNDER BRIDGE DECK AT PIER S31





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