FEATURE

THE PORT MANN BRIDGE

A demonstration of excellence in reverse erection engineering

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DECONSTRUCTION

IN 2012, THE GOVERNMENT of British Columbia completed the massive upgrade of Highway 1 east of Vancouver, including the construction of the new, 10-lane Port Mann Bridge over the Fraser River. As part of this landmark project, the old Port Mann Bridge—which formerly carried the highway for 50 years— needed to be removed primarily due to maintenance costs and seismic deficiencies.

Most river bridges are simply demolished with explosives when it comes time for decommissioning. However, the presence of lead-based paint and asbestos in the bridge presented a risk to the fish habitats in the Fraser River. Additionally, close proximity to the new bridge (a mere 25 metres away) required that the old bridge be removed in a highly controlled manner.

The BC Ministry of Transportation and Infrastructure contracted with the Connect BC Development Group (CBCDG) for the project. CBCDG's contractor, the Kiewit-Flatiron Joint Venture, needed to execute the deconstruction to a tightly planned schedule to control costs. The McElhanney team was retained as the lead construction engineer in late 2012 for the controlled removal of the old bridge.

Because of the precise control required, the team determined that the best way to remove the bridge was to reverse the erection process followed in 1954, by removing the bridge piece by piece. This involved the use of a cable-stayed system that essentially converted the tied-arch into a cantilever system and allowed for progressive removal. However, several changes, including an expanded railway yard underneath

Photos courtesy of Kiewit-Flatiron

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the south side span, introduced new and significant challenges.

After five decades of fatigue stressing, corrosion, and various modifications on the old bridge, it was difficult to accurately predict what stresses might be released by cutting into the structure. The removal procedures also needed to ensure continued access through the river's shipping channel and the railway tracks below the south side during the entire deconstruction process.

In relative terms, the steel design was easier to remove compared to a concrete structure that would have significantly increased the project cost and duration. The steel pieces that were removed in chunks were also lighter and much easier to cut in mid-air, which meant the components could be removed in longer lengths than concrete pieces, minimizing interference with the environment.

THE BRIDGE AS A HOUSE OF CARDS

During the process to develop the detailed plan for deconstruction, the team held discussions with the designer of the original bridge and studied archived erection plans such as temporary works, construction photos, design plans, and shop drawings. This allowed them to establish that the bridge and its components were configured for high-efficiency and minimal steel usage in the final constructed state of a continuously tied arch. However, the original design considered that prior to attaining full tied-arch action, the partially erected structure and its components would be extremely sensitive to construction stage demands for strength and stability. For example, the deck longitudinal tie-girders were proportioned as a tension tie with only local secondary flexural moments in the final state. This original design aspect presented the biggest engineering challenge in the deconstruction because the girders were subjected to compression forces from the temporary stay cables and to significant global flexural demands. In other words, the bridge in a cantilevered state was to behave akin to a "house of cards" that required precise control to maintain stability.

"This project presented a greater technical challenge than engineering a new cable-stayed bridge," says David Jeakle, PEng, PE, McElhanney's principal engineer on this project who has worked on the design of several cable-supported bridges throughout his career.

CONTROLLING THE HOUSE OF CARDS

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system to the cable-stayed system. Given the sensitive nature of the structure and the number of re-stressing operations that would be required, a relatively extensive stressing system was used to allow for quick and efficient re-tuning of the cables.

One of the most unique innovations on the project was the use of the "crow's nest" control centres on top of the temporary towers. From here the ironworkers could precisely orchestrate the cantilever by stressing or de-stressing the cables in quick order to ensure component stresses remained within allowable limits. The cable jacking forces were determined from a detailed step-by-step construction staging analysis. This analysis, conducted on specialized software, was used to tune the stay cable system. Its results, including cable jacking sequences and pertinent geometric data, were documented in a deconstruction manual.

Falsework bents were erected close to the main piers on each side of the bridge, in order to resist out-of-balance loads and wind forces for the stage when the main span was reduced until the cantilever was at a length approximately equal to the side span. On the north side, where there were no obstacles, the falsework bent consisted of 1.5-metre diameter driven pipe piles supporting a frame system located about

30 metres away from the main pier, similar to the bent used during the construction of the bridge. However, on the south side, the railway yard had expanded since the bridge was built and the proximity of the tracks precluded the use of a similar system. Instead, a frame was put in place straddling the south main pier, using inclined pipes in two directions and supported on the existing footing cap.

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In order for the falsework bents to provide the necessary longitudinal overturning stability to the partially deconstructed bridge, diagonal bracing pipes were installed between the falsework bents and the main pier, enabling it to behave locally as a truss system. While similar diagonal braces had been used during the original construction, the connection gusset plates had been severed and removed on completion. A significant effort was needed to re-establish the connection points on the existing members to allow installation of the new braces.

STRESSFUL CUTS

The first major step in the deconstruction process was to remove the axial compression in the arch rib at mid-span, prior to making the first relief cut in the arch. After stressing the initial configuration of stay cables, one-metre square "windows" were cut from the arch rib web plates so steel brackets and hydraulic jacks could be installed and pressurized to virtually eliminate the remaining arch rib compression. With the cutting of the rib, any residual forces were transferred to the jacks, which, when de-stressed, allowed for a gradual release of the residual forces and caused the arch rib tips to move inward by approximately 250 millimetres.

Despite completing the arch relief cut and reducing the arch rib force to zero at midspan, the tie-girder at mid-span was still resisting large axial tension forces, local flexural moments, and potentially shear forces. To address this, strongback beams that straddled the mid-span cut location were welded directly to the tie-girder and had stressed post-tensioning bars to partially offset the anticipated internal forces. As the tie-girder was sequentially cut, residual forces were transferred to the post-tensioning bars which, upon completion of the cut, were de-stressed to allow the cut gap to grow by approximately 225 millimetres. After the release of the bars, the bridge was transformed from a continuous tied-arch to a cable-stayed cantilever system.

REMOVAL WORKS

With the main span arch rib and tie-girder relief cuts made, the main span could be deconstructed in segments using a barge-mounted crane on the north side and a deck-mounted stiff-leg derrick on the south side. The ribs and edge girders were removed in 15-metre-long sections, while the orthotropic deck panels were removed in sections 20 metres

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wide by 8 metres long. The majority of sections weighed less than 35t; however, some pieces from the knuckle and main pier regions were as heavy as 100t, or about the weight of a Boeing 757-200 aircraft. The main span and some of the side span segments were lowered onto a barge, while the remainder of the south side span segments were lowered onto a truck in the rail yard and transferred to barges for recycling.

In several stages, the suspended cantilevered structure was very flexible with natural periods of vibration up to three seconds and prone to oscillations in severe winds. In collaboration with an expert wind laboratory, McElhanney assessed the potential for dangerous oscillations in severe wind and designed systems of temporary support to limit wind effects to acceptable levels in all stages of the deconstruction.

STEEL SENT FOR RECYCLING

As the team managed to successfully remove the old bridge, they cleared the view of the new Port Mann Bridge traversing the Fraser River. In total, 9,000t of steel were sent for recycling rather than to a landfill. Fifty years ago, or in other parts of the world, this bridge might have been demolished instantly with explosives. With British Columbians demanding higher and higher environmental standards, the project team devised a way to safely remove the bridge, without harming the fish-bearing river.

As the most recycled material on the planet with an overall recycle rate of 88 per cent, the steel from the old bridge can be used in cars, buildings, or other infrastructure projects. And because of steel's metallurgical properties, it can be recycled endlessly without any performance degradation. This demonstrates the advantage of steel in meeting the project's environmental, economic, and sustainability goals. AS