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Deh Cho Bridge

The Northern Link

Infinity Engineering Group

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It was a long adventurous undertaking for the first settlers to arrive in Yellowknife, Northwest Territories, Canada in the early 1930's. At that time there was no road to Yellowknife and people travelled either by horses in summer, or dogsleds in winter. As the population increased, the need for improved access became evident. In 1967 the Yellowknife Highway was built which connected the region to the lower highway system of Canada. Travel times were reduced significantly but one major obstacle remained: the Mackenzie River. The River is either crossed by ferry in summer or an ice-bridge in winter. Ice bridges are susceptible to collapse, endangering human life, incurring significant financial loss, and causing environmental harm. Additionally, the link is disconnected during the transition seasons as the ice breaks up and neither ferries nor ice bridges can be used as a crossing option.

In 2007, the Government of Northwest Territories (GNWT) entered into a public-private partnership with the Deh Cho Bridge Corporation (DCBC) for the design and construction of a bridge across the Mackenzie River. An independent review by TY Lin International (TYLin) on behalf of the GNWT of the superstructure design identified deficiencies in the original design. Infinity Engineering Group Ltd. (Infinity) was retained to propose conceptual solutions to eliminate the inadequacies with the original design. Infinity developed a redesign option and conducted a value engineering exercise that showed significant savings in cost and schedule while simultaneously improving safety, durability, and constructability. Currently, Infinity is in the process of a detailed redesign of the Deh Cho Bridge superstructure. This article presents the global and construction staging analysis that is being undertaken for the redesign of the bridge superstructure.

Bridge Description

The superstructure is a two lane, nine-span composite steel truss bridge with a cable assisted main span of 190m. The approach spans are symmetrical about the centre of the bridge and have successive lengths of 90m, 112.5m, 112.5m and 112.5m. The total length of the bridge is 1,045m. The superstructure consists of two 4.5m deep Warren trusses with a transverse spacing of 7.32m and a 235mm thick precast composite deck. The truss members are built up I-sections. Two A-pylons, located at Pier IV South and Pier IV North, each support two cable planes. Each cable plane consists of six cables that are connected to the main truss through an outrigger system. Figure 1 shows the bridge layout.

Special Features

The Deh Cho Bridge is a truss bridge with a cable assisted main span. The structural system can be classified as a composite bridge with hybrid extradosed-cable stayed

Deh-Cho Bridge

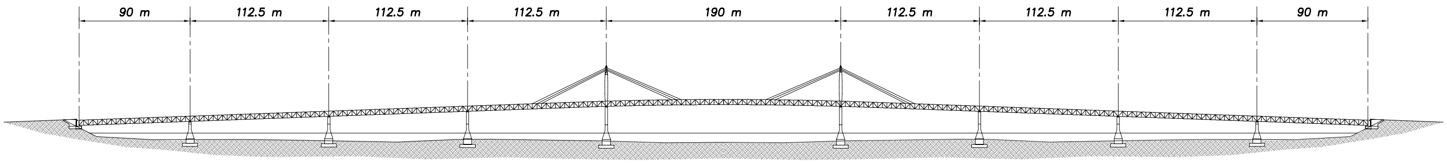

Figure 1: General Arrangement

features. Comparable to a cable stayed system, the primary purpose of the cables is to support the truss in spanning the 190 m navigation channel. However, contrary to a cable stayed system the backstays are not anchored at a pier location. The backstays function by activating the bending stiffness of the truss similar to an extradosed system.

The value engineering provided by Infinity led to the following features. The articulation scheme chosen allows a continuous and jointless deck for length of the entire superstructure over 1 km. The deck is built from precast concrete panels with cast in place infills. A combination of a waterproofing membrane with two layers of asphalt is applied to the surface for sealing purposes. Compact lock coiled cables have been used for the stay system. They have simplified anchorages that can be easily inspected and maintained.

Design Philosophy

The design philosophy adopted for the Deh Cho Bridge consists of the Big Picture Approach, the Failure Mechanism Concept, and the Redundancy & Integrity Rule.

A Big Picture Approach was adopted for the design of the Deh Cho Bridge. Special consideration was given to the following aspects: functionality, safety, durability, constructability, cost, maintenance and aesthetics. Member profiles and materials were selected for their efficiency in resisting the primary force effects they experience. As an example, the bottom chord is an optimized I-profile resisting axial demands during service and in addition bending during launching. The dead load to payload ratio is minimized through the principles of lightweight design. The primary structural objective was to tune the system to be flexible for temperature effects while at the same time being stiff for live and wind loads.

The Failure Mechanism Concept was applied to ensure that the structure does not experience a sudden collapse under any given load scenarios. The primary load paths are designed for a controlled failure mechanism. The load travels through a series of structural components comparable to a structural chain. The weakest link in the chain is determined by the designer and engineered to fail with adequate warning (ductile behavior). For example, the cable anchorage and attachments are designed for the minimum breaking load of the cable, making the cables the crucial component of this particular load path.

Redundancy stands for alternate load paths provided by the designer. The Post-Tensioning Institute (PTI) recommends that the designer considers cable loss scenarios. For those extreme events the designer should ensure that the Integrity of the bridge is not endangered.

Analysis

The analysis undertaken for the project included a global analysis of the entire bridge, an erection staging analysis and local finite element analyses for specific connections and details. The focus of this article is on the global and erection staging analysis. The work is being performed under an accelerated schedule which requires a user friendly and powerful analysis tool supporting the design.

Global Analysis

A three-dimensional model was created that included the entire bridge consisting of foundations, piers & abutments, bearings, truss, pylons, cables and deck. The global analysis was conducted with LARSA 4D.

Tuning

The first step in the global analysis was to tune the dead load sharing in the truss and the cables to obtain a beneficial behavior. An accurate estimate of the cable force was obtained by making all the members infinitely stiff under dead load. The preliminary cable size was determined using the dead load cable force and a contingency for transitory loads. The properties of the cables thus determined were used in the model together with the real stiffness of all other members. The cable elongation under dead load was compensated using a temperature load case using the following formula:

$$\Delta T = - \sigma_{DL} / (E \, \alpha_T)$$

with:
- ΔT = compensating temperature
- σ_{DL} = cable stress under dead load
- E = modulus of elasticity of the cable
- α_T = temperature coefficient for the cable

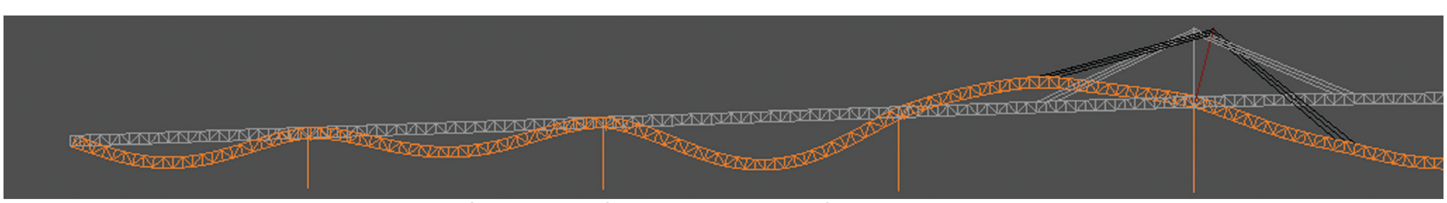

Figure 2: Unbalanced System, Dead Load and Cable Tensioning applied

Truss Camber

The span arrangement of the Deh Cho Bridge requires a truss camber at the cable support locations. The span supported by the back stays is only 112.5 m while the span supported by the front stays is 190 m. This uneven configuration results in unbalanced cable forces in the front and back stays, and thus causes a tower rotation to find equilibrium, see Figure 2. Since the back stays are not connected to a fixed point such as an anchor pier, typical for cable-stayed bridges, truss uplift at the backspan cable support cannot be compensated by cable force manipulation.

Figure 3: Truss Camber

To achieve the given roadway profile the truss needed to be cambered down in the backspan. The truss camber for half the bridge is shown in Figure 3.

The truss camber shown in Figure 3 compensates the permanent load deflections shown in Figure 2 resulting in the desired roadway profile, see Figure 4.

Figure 4: Camber, Shortening Cables and Dead Load applied

Loads

Influence surfaces were used to determine the maximum force effects from moving loads. An influence surface, or 3-D grid of influence coefficients, is created by running a unit load over a predefined load area (typically traffic lanes). An influence surface can be generated for a force effect (i.e. bending, shear, compression etc.) at any cross-section of a component of the structure. The magnitude of the force effect from a vehicle placed anywhere on the load area is determined from the influence coefficients and the vehicle loads. Ultimately, the vehicle is positioned on the influence surface to maximize the force effects under consideration. The influence surface for the bottom chord in the center of hanging span can be seen in Figure 5. The corresponding deformation for a truck positioned in the most unfavorable location is shown in Figure 6.

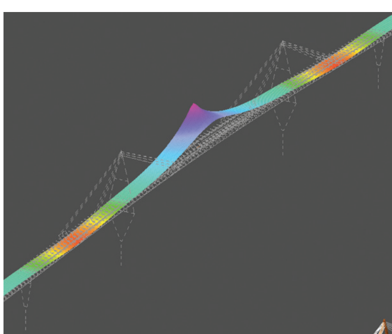

Figure 5: Influence Surface

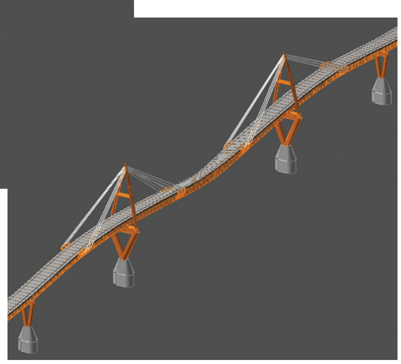

Figure 6: Deformed Bridge

Horizontal Load Effects

Two separate models were created to represent the different articulation scenarios depending on the nature of horizontal load effects. The bridge is fixed transversely at the piers and abutments. The continuous superstructure requires both flexibility for movements and fixity for load sharing of longitudinal loads. This contradiction has been resolved by the use of lock-up-devices (LUDs) that release temperature restraining effects but engage the piers for external load effects such as wind and braking loads.

The master-slave joint feature of the software was used to model the articulation. The use of master-slave joints provides the option to couple or un-couple any of the six degrees of freedom to model various articulation conditions.

Erection Analysis

The designer shall consider at least one feasible construction method in the analysis of complex bridges. For the Deh Cho Bridge the following erection stages have been incorporated into the design:

- Launching 494 m long truss approaches from each abutment
- Installation of A-pylons and cables
- One-step stressing of all cables simultaneously by lowering truss at pier 4
- Deck panel installation up to pier 4
- Installation of 57 m long lifting span
- Deck panel installation in the main span
- Activation of composite action
- Casting curb and installation of railing
- Installation of waterproofing and wearing surface

A staged analysis for the launch was performed. The effect

Figure 7: Typical Launch Stage

of camber was included in the analysis using a temperature load case. This method has the advantage of being able to turn camber off when the truss is moved ahead and connected to the supports in the new location. About 130 launch stages were analyzed and summarized in demand envelopes. A typical stage is shown in Figure 7.

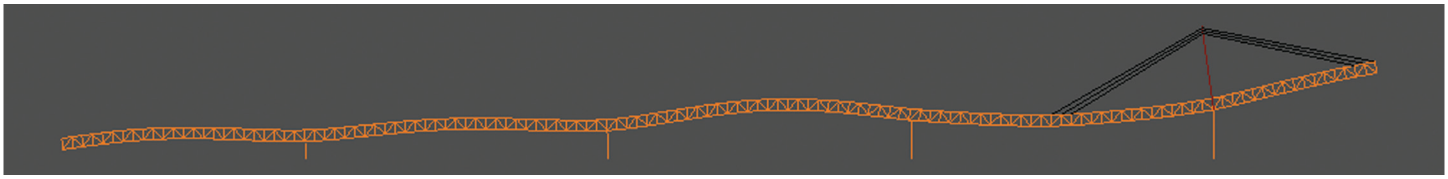

Figure 8: One Step Stressing of Cables

After erection of the A-pylon is completed, the truss is jacked up at pier 4 to facilitate installation of the cables. Thereafter, the truss is lowered to its final position stressing all cables simultaneously, see Figure 8.

Figure 9: Lifting Span Operation

The lifting span splice requires geometric compatibility of the truss ends, see Figure 9. This is achieved by loading the backspan through placing deck panels from the abutment to pier 4. The design takes into account the construction demands including forces, deflections and rotations from the stages before.

Conclusion

The Deh Cho Bridge is a major long span crossing that requires rigorous analysis. LARSA 4D has proven to be an effective tool to support the design in the conceptual and detailed design stages. This article focused on cable tuning and an analysis for camber, live load and other transitory loads. In addition, the analysis for a staged erection concept has been presented. This investigation consisted of truss launching, cable stressing and a lifting span operation.

The overall project success depends decisively on the analysis tools employed. In today's market with aggressive timelines engineers rely heavily on the efficiency of programs and the support provided by the software developer. LARSA 4D delivered both: the tool and the support. •

Infinity Engineering Group *based in North Vancouver, Canada specializes in the design and erection engineering of bridges. The experience of their team has been developed through work on many bridge projects including complex curved and long span cable supported grade separations. Infinity Engineering Group is committed to understanding the client's needs and working within the necessary budgets and schedules.*