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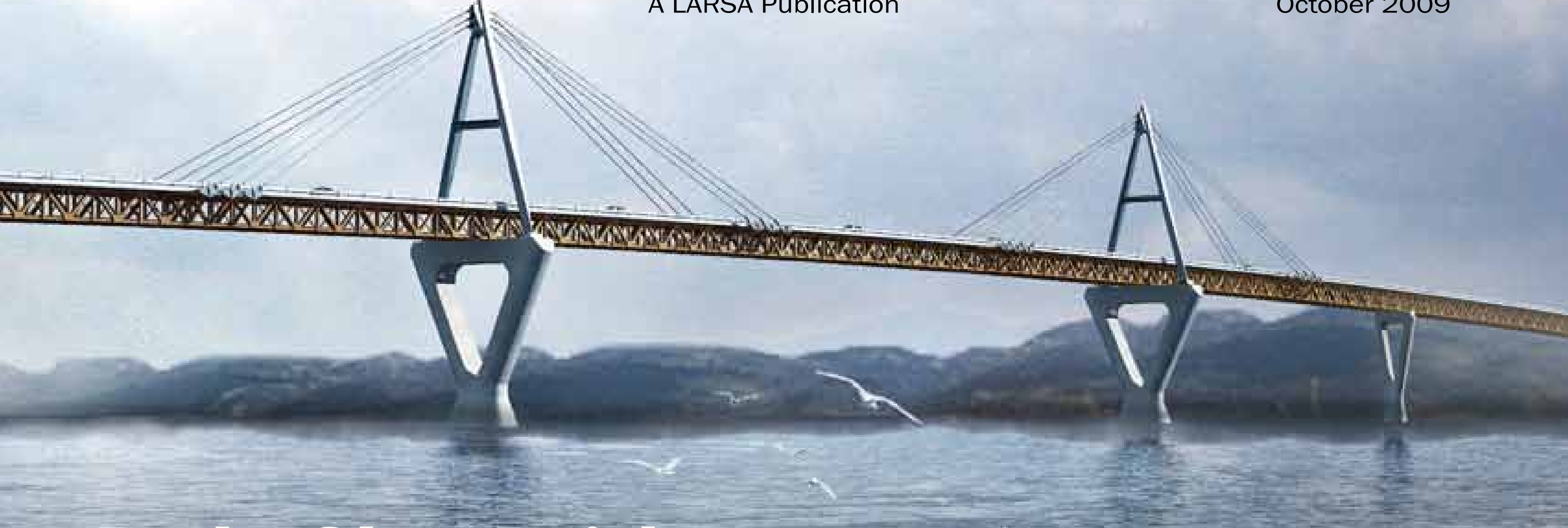

Deh Cho Bridge

The Northern Link

Infinity Engineering Group
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Sebastian Oppel, Designer

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

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Welcome to the 4th Dimension

This year has been an exciting year for the LARSA 4D team. We have delivered a very impressive list of features to our users in the new versions of LARSA 4D, and we saw a significant increase in the use of 4D analysis beyond segmental and cable-stay bridge structures.

As our clients find LARSA 4D well-suited to the complexities of modern bridge design of the 21st century, it is very exciting to see more users have started serious development of their own macros taking advantage of LARSA 4D's unique macro environment to improve their performance on their projects.

We have a long list to deliver on in 2010 including time-dependent composite construction based on a layered approach with no practical set limit for the number of layers. Our world-class team shall continue working to support our clients with the same forward-thinking technology that has made LARSA 4D so unique.

Best of Luck,

Ali D. Karakaplan, Eng. Sc.D
President, LARSA, Inc.

Visit Us

Come visit us at our booth at the following upcoming conferences:

21st Annual ASBI Symposium
October 25-27, 2009
Hilton Hotel
Minneapolis, MN
World Steel Bridge Symposium
November 17-20, 2009
Henry B. Gonzalez Convention Center
San Antonio, TX
International Bridge Conference
June 6-9, 2010
David L. Lawrence Convention Center
Pittsburgh, PA

Meet the 4D Team

Anita Sarrafian is LARSA, Inc's Marketing and Design Associate. She is a graduate of Stony Brook University and has used her knowledge of art and design to transform LARSA's brand. Her responsibilities include the creation of all of LARSA's print media, including this journal as well as the maintenance and development of the LARSA image.

Announcements

We have posted new and updated documentation on our website (www.larsa4d.com). The documentation includes three new training manuals: a basic LARSA 4D training manual, an introductory training manual for bridge projects, and an advanced training manual for bridge projects. Manuals for LARSA Section Composer and macro development are also available, along with an updated User's Guide and Reference Manual.

In The Works

LARSA's development team is continually working to provide new innovative tools for structural analysis. Here is what we're working on now:

Influence Analysis: We will soon be including an updated influence line and surface analysis that is faster and more accurate. The analysis will also have a new entry for centrifugal force factors and will now support AASHTO LFD for influence surfaces with multiple design lanes. The analysis will also take advantage of the additional computing power of multi-core/ multiple-CPU computers.

Front Cover: Infinity Engineering Group, North Vancouver, Canada

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This journal is distributed as a courtesy to our clients and corporate friends. We welcome feedback and suggestions for future stories to info@LARSA4D.com.

Expanding the Possibilities

Using Macros in LARSA 4D

by Ali Koc (a.k.a. “Koch”)
Director of Research, Development & Support

LARSA 4D is a powerful package containing many built-in features but for those who demand further automation, it also offers a flexible platform allowing users to extend LARSA 4D to do almost anything imaginable. Extending LARSA 4D has the following advantages:

- ability to perform custom and/or complex operations in single steps
- saving time in performing repeated actions
- automating model generations
- batch result extraction and custom formatting
- ability to incorporate custom design checks
- ability to incorporate yet-unforeseen features

As a simple example, to calculate the total weight of a structure, you would need to run static analysis with self weight and add up the reactions manually. This procedure, however, can be added into LARSA 4D as a simple plug-in or automated using a short macro so that no analysis or manual computation is required. This task is implemented by the short VBA macro shown above which can be entered into and run in Microsoft Excel with LARSA 4D running.

```
Weight = 0

For i = 1 To project.Members.Count

      Dim m As Object: Set m = project.Members.itemByIndex(i)

      Weight = Weight + m.Length * m.section(1).sectionArea * m.material.unitWeight

Next

MsgBox “Weight of the structure is ” & Weight
```

The first line of the code above creates a variable, initially set to zero, that will accumulate a running total of weight. The second and third lines of the code create a loop, going over all the member elements in the structure. That means each line between `For` and `Next` is repeated over and over for each member in the model. On the fourth line, the weight of each member is computed by multiplying its length by its cross-sectional area by its density, and that is added into the Weight variable. Finally on the sixth line, the accumulated weight is displayed to user in a pop-up message box.

The main distinction between plug-ins and macros is the way they communicate with LARSA 4D. Using macros, you can implement functionality that accesses (and can modify) all the internal data and functionality of LARSA 4D, but it is written and run externally to LARSA 4D, usually in Microsoft Excel’s VBA macro editor. Since almost all LARSA 4D users are familiar with Microsoft Excel, it is practically a standard choice as the platform for LARSA 4D macro development.

A LARSA 4D plug-in is a step forward from macros in terms of its tight integration with LARSA 4D. They compile into a separate module (a .dll file) and are automatically loaded by LARSA 4D at startup. Each plug-in can have its own menu items within LARSA 4D menus. They have direct integration with graphics windows, explorers and spreadsheets of LARSA 4D. They are also capable of displaying their own user interface windows within the application. This system is used even by our own developers -- in fact, most of the design modules in LARSA 4D are plug-ins.

Though Visual Basic and VBA are the coding languages of choice for almost all macros and plug-ins developed for LARSA 4D, it is possible to use any language or platform supporting Microsoft COM technology. That includes scripting languages such as VBScript, JavaScript or lower level languages such as FORTRAN, C, C++. There are some plug-ins developed even in .NET languages, such as C# and VB.NET.

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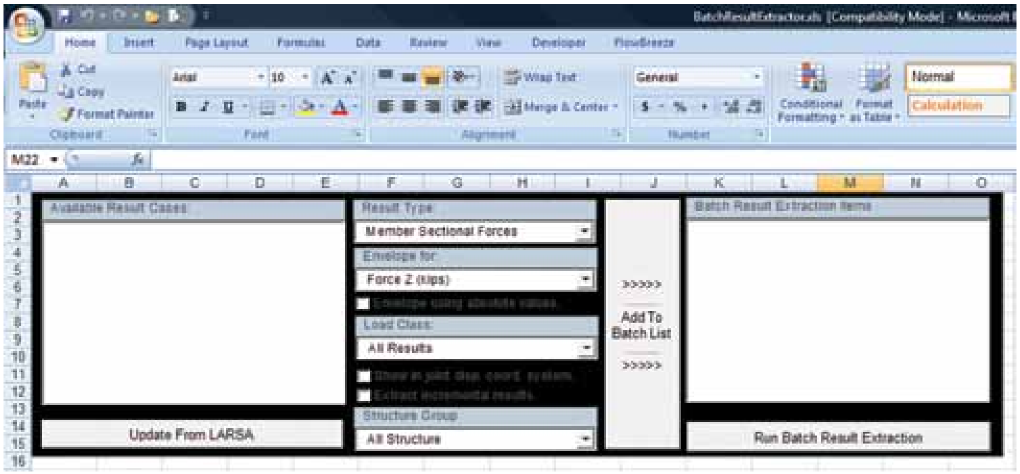
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Envelope for: Force Z (kips)
Load Class: All Results
Structure Group: All Structure

A sample macro screen in Microsoft Excel

Deh-Cho Bridge

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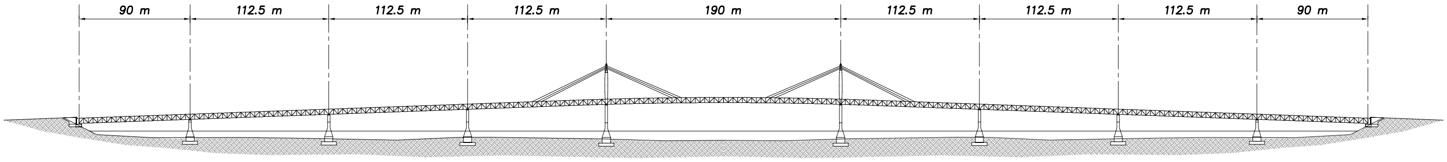

Figure 1: General Arrangement

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
σDL = cable stress under dead load
E = modulus of elasticity of the cable
αT = temperature coefficient for the cable

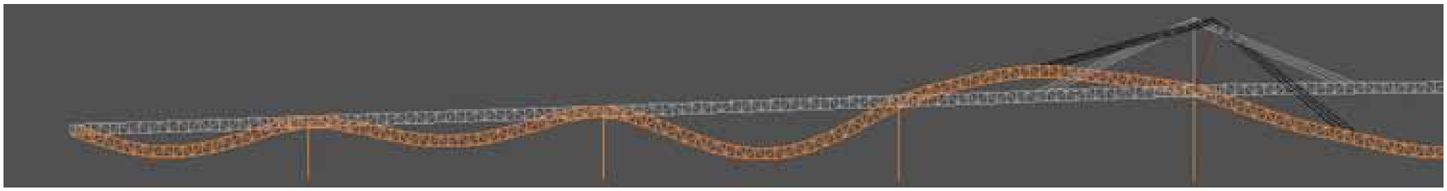

Figure 2: Unbalanced System, Dead Load and Cable Tensioning applied

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.

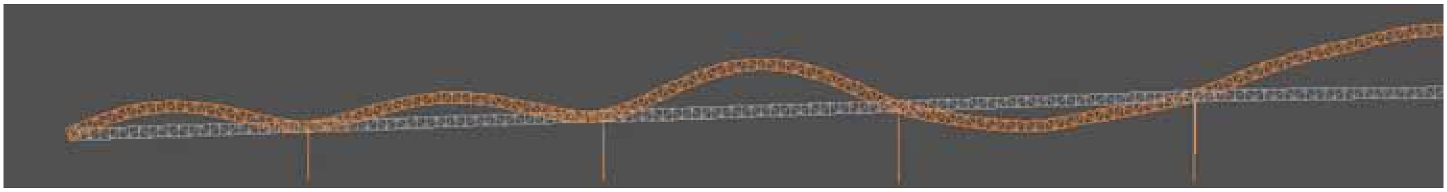

Figure 3: Truss Camber

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.

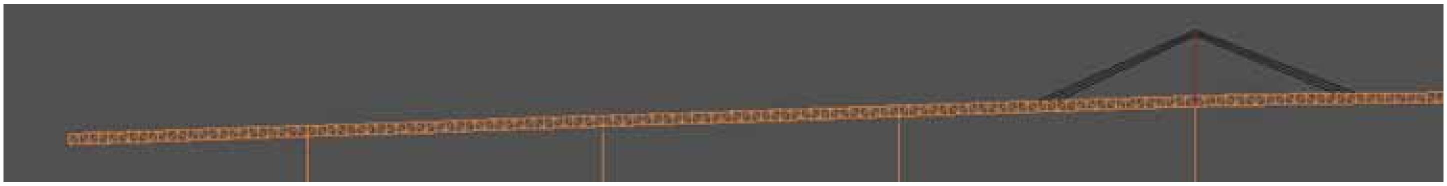

Figure 4: Camber, Shortening Cables and Dead Load applied

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.

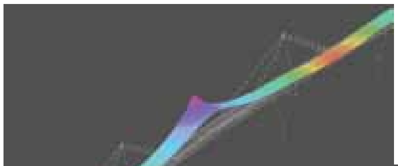

Figure 5: Influence Surface

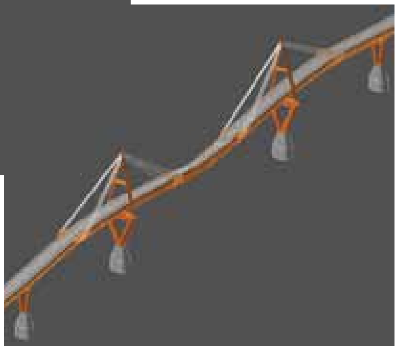

Figure 6: Deformed Bridge

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

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Deh-Cho Bridge *(continued from page 5)*

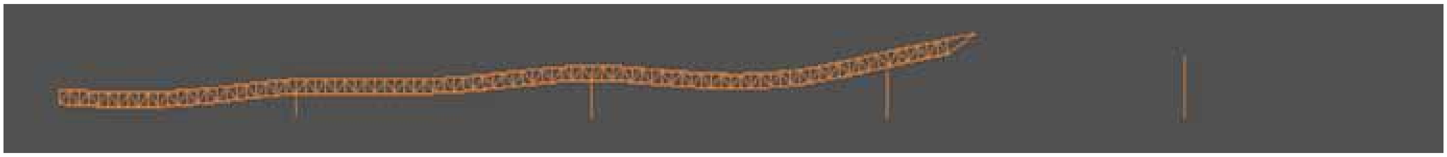

Figure 7: Typical Launch Stage

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.

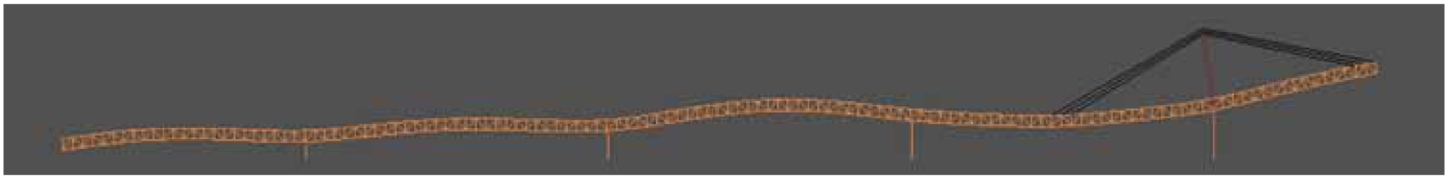

Figure 8: One Step Stressing of Cables

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.*

Using Macros *(continued from page 3)*

Today, developing macros is a routine part of the LARSA 4D technical support process. The complexity of the macros created for technical support solutions ranges from a simple spreadsheet reporting the angle between some deformed members to full blown model generation, analysis extraction, and design checks. For example, there is a macro for the generation, analysis and design of guyed towers in LARSA 4D. We have made tens of macros for generating variety of models such as steel plate girder bridges, segmental bridges and cable stayed bridges.

Some of the macros are for inputting data. These macros, for example, allow users to input tendon geometry in global coordinates, or directly import it from DXF CAD files. Using these macros, user can automatically set up staged construction data, generate loading for nonlinear live load, or setup incremental launching sequence of a segmental bridge. By having direct access to the model, analysis results and the full feature set of LARSA 4D, these macros are capable of performing even more complex tasks, such as iterative shape finding, flexibility matrix generation, and reverse staged construction.

Whatever your need may be, this flexible platform can be utilized to not only carry out the required task, but also perform it in a customized format suitable to your specific work style. •

Cable Tension Optimization

by Josh Tauberer
Director of Software Architecture

A common problem in the analysis of a cable-stayed bridge is the determination of initial cable tension forces that — in combination with other loading, the construction sequence, and time-dependent material effects — gives the structure its desired final geometry and internal forces. LARSA 4D Bridge Plus provides two solutions to this process. The first determines cable tension forces in a model in which the structure is constructed in a single step. The second is based on the unit-load method and is used for models with a construction sequence.

We call these procedures model optimization. Optimization is the term from mathematics of finding a minimum of a function. These procedures are used in LARSA 4D to minimize deflection.

Iteration Using Final Cable Tension

In a nonlinear structure such as one with cables, one cannot solve directly for the set of cable forces at cable installation that is needed to achieve a chosen deformed state once other loading has been applied. If all of the deformation on the structure takes place after the cable is tensioned, and the goal is to have the base of the cable stay at its undeformed location, then one can make use of the fact that the cable jacking force will match exactly with the final tension in the cable. If there is no change in axial force, the cable has not deformed.

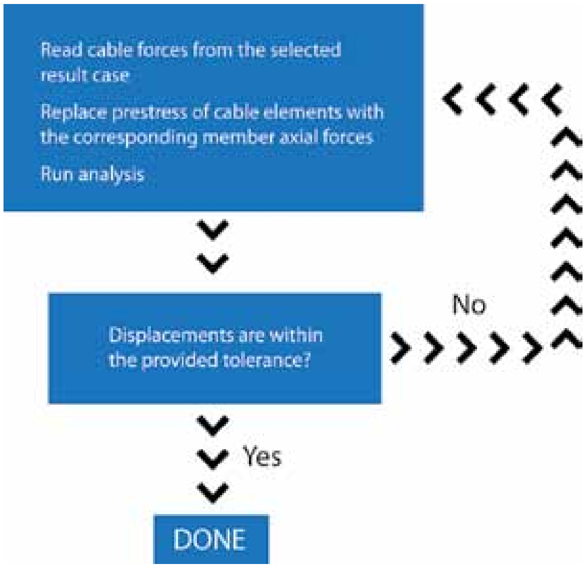

Figure 1. Flow chart of the method to iterate using final cable tension.

A simple procedure that has been carried out by engineers by hand has been to start the cables with minimal jacking force, solve for the axial forces in the cables at the end of construction, take those axial forces and use them as the cable jacking forces the next time around, and then repeat this process until the tensile forces no longer change as a result of other loading on the structure. The procedure is illustrated in Figure 1.

To see why this might work, take the case of a single cable holding up a deck. If the initial cable force is not great enough to hold up the deck, the deck will lower causing the force in the cable to increase. If the cable is jacked too much, the deck will raise and the cable will shorten, causing the cable force to decrease. When the deck is held up in place, the cable does not deform and there is no change in axial force.

We can think of the static analysis as a function $f(x)$, where x is the initial cable force ("pretension" in LARSA 4D) and $f(x)$ is the cable tension after other loading has been applied (the Fx member end force). The goal is to find x such that $f(x) = x$.

If there is more than one cable, we can think of f as a function from a vector of cable jacking forces x to a vector of final cable tension values $f(x)$.

This procedure is automated in LARSA 4D.

In a typical nine-cable cable-stayed bridge model, we have found that the process requires only roughly five iterations to achieve near-zero displacements. A perfect solution may be

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impossible due to other structural elements in the model, and in this case the procedure could be left to adjust pretension values indefinitely. The cable pretension values for the nine cables in a typical model after each iteration are shown in Figure 2. At the first iteration the cables are all set to a common initial prestress force.

Iteration Using Unit Loading and a Flexibility Matrix

In a segmental assembly a cable may be installed after its segment has already deformed due to dead load. The goal here is to achieve zero joint displacement, but because the cable is installed in the middle of the construction sequence the cable is intended to deform as it brings the joint back up to its initial location. Since the cable will deform, the initial cable tension will not match final cable tension, the first procedure is not applicable in this case.

A different method is required in this case. The “unit load method” has been applied in the past to solve this problem. In this method, we apply a unit-tug — i.e. one extra unit of jacking force — to each cable and observe its effect on each of the joints at the bases of the cables (or any other joints on the deck). Then we solve for a factor to apply to the tug to zero-out the displacements at a joint. Take the case of a single cable. At the initial condition, the joint at the base of the cable has displaced by 5 meters. Through a static analysis we determine that adding 1 kN of force to the cable raises the joint by 1 meter. We then conclude that 5 times the 1 kN = 5 kN will raise the joint back to its undeformed location. If the structure has nonlinear behavior 5 kN may not have the effect of 5 times the effect of 1 kN, so the process must be iterated until the displacement comes within tolerable limits.

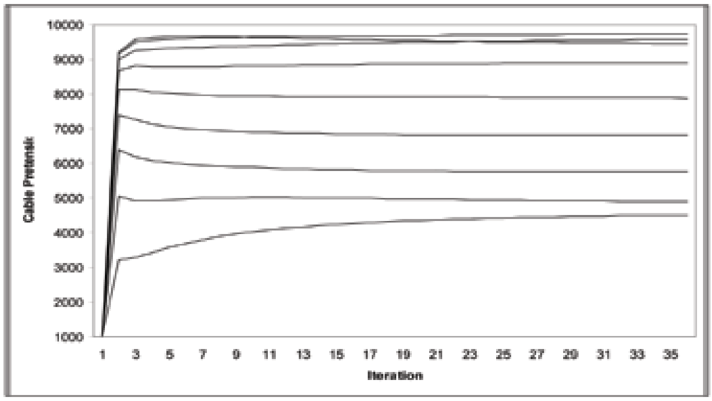

Figure 2. Cable pretension values for nine cables after the first 35 iterations.

This is the application of a procedure used in many other fields of applied mathematics and is a generalization into multiple dimensions of the Newton-Raphson method of finding the solution to $f(x) = 0$. As opposed to the first iterative method described above, $f(x)$ here is a function from a vector of cable pretension forces to a vector of joint deformations in the elevation axis.

The Newton-Raphson method can be summarized as follows: when searching values of x for the one that makes $f(x) = 0$, a good guess is to use the slope of f to predict where the function is going. This is shown in Figure 3, and formally in Equations 1–2, where f' denotes the derivative of f.

eqn 1. $f'(x) \cdot \Delta x = -f(x)$

eqn 2. $\Delta x = \frac{f(x)}{f'(x)}$

When there is more than one cable this process must be generalized to multiple dimensions, and the iterative step is derived as shown in Equations 3–4. The matrix J, called the Jacobian matrix, represents the slope of the function in each dimension. J_{ij} is the change in displacement at joint i due to a one-unit tug on cable j. Δx is the computed additional initial cable tension that is needed and is added in at the end of the current iteration.

eqn 3. $J \cdot \Delta x = -f(x)$

eqn 4. $\Delta x = -J^{-1} f(x)$

J is computed by running a separate static analysis for each column of the matrix. Each analysis applies a one-unit tug u_i to each cable at the time it is installed, within a Staged Construction Analysis already set up by the user that might additionally contain dead load, time-dependent material effects, and other nonlinear behavior. For each analysis we record the displacement of the joints at the bases of the cables at the end of construction (i.e. at the final construction step) and subtract off the corresponding displacements without the unit tug.

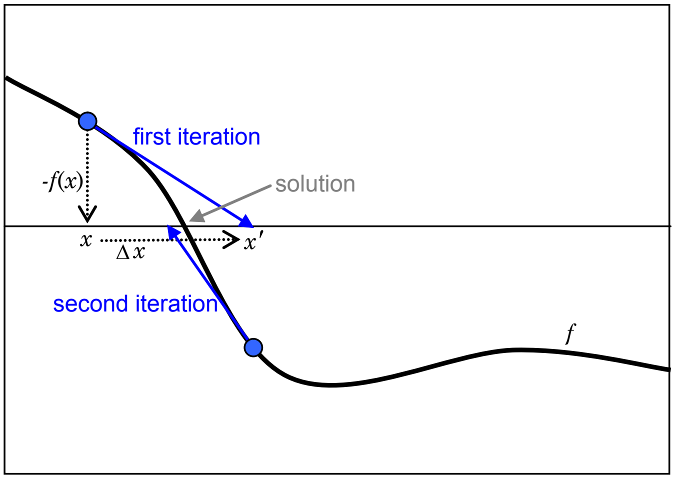

Figure 3. Illustration of Newton-Raphson in one dimension.

The cable jacking forces can be applied at different times, i.e. at different stages during a construction analysis that takes into account time-dependent material properties, temporary loading, other construction activities, and geometric nonlinearity. The algorithm will find whatever pretension force such that the deformations work out at the end.

More details on using these tools can be found in the documentation section of our website http://www.larsa4d.com. •