4D JOURNAL

STEEL PLATE GIRDER DESIGN MODULE

ARBOUR STONE BRIDGE

by Infinity Engineering

LARSA 4D BRIDGE pLT

A LARSA Publication | March 2012

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ANNOUNCEMENTS

Officially released for 2012, Version 7.5 is available for download on our website with extended release notes. This official release version includes major new features such as the full integration of LARSA's Steel Plate Girder Design Module, improved geometric nonlinearity for staged construction, a new influence load positioning algorithm, and much more.

VISIT US

LARSA, Inc. will be exhibiting at the following upcoming conferences:

Structures Congress
March 28 - 30, 2012 | Chicago, Illinois

NASCC World Steel Symposium
April 18 - 20, 2012 | Dallas, Texas

International Bridge Conference
June 10 - 13, 2012 | Pittsburgh, Pennsylvania

PCI Convention & National Bridge Conference
September 29 - October 02, 2012 | Nashville, Tennessee

ASBI Annual Convention
October 29 - 30, 2012 | Miami, Florida

FHWA Bridge Engineering Conference
TBA | TBA

LARSA 4D BRIDGE pLT

New to the LARSA 4D BRIDGE Suite, 4D BRIDGE pLT is the cost-effective solution for steel plate and box girder bridges when migrating from 2D grillage, to a more refined 3D finite element based analysis and design. LARSA 4D's Steel Plate Girder Design Module, built into 4D BRIDGE pLT, takes the complexity out of modeling while creating an FE model for staged construction analysis and code-checking based on the AASHTO LRFD code.

4D BRIDGE pLT includes Section Composer and linear static, nonlinear static, eigenvalue, response spectra, and staged construction analysis along with bridge specific features such as bridge path coordinate systems and influence surface based live load analysis.

STEEL PLATE GIRDER DESIGN MODULE

LARSA 4D's Steel Plate Girder Design Module has a new update for the 2012 release. Its model generation capabilities are for bridges with very complex geometry, new algorithms for influence surface based live load analysis improve accuracy and speed, and the module is updated to check for the current AASHTO LRFD code.

The ability to create a 3D finite element model for code check is vital for bridges that do not follow a simple template. The Steel Plate Girder Design Module will create models with a variety of special conditions, such as bridges with girder lines that are not parallel or not following the bridge alignment, with girders terminating at different stations, and bridges with decks that widen or narrow. With a wizard-like interface within the LARSA 4D environment, the module generates a complete staged analysis bridge model ready to be analyzed and code checked by LARSA 4D's nonlinear staged analysis engine.

This method moves beyond a 2D grillage analysis commonly used for steel plate girder bridges. The 2D grillage method of analysis has the advantage of being simple, quick, and effective for bridges that are horizontally straight (or almost straight) with relatively small skew. There are a number of programs commonly used in the industry to perform an analysis based on the grillage method, but there are common limitations. Live load analysis in these programs is often performed using an influence line where load distributions across multiple girders are not based on a stiffness analysis, and the substructure often cannot be included.

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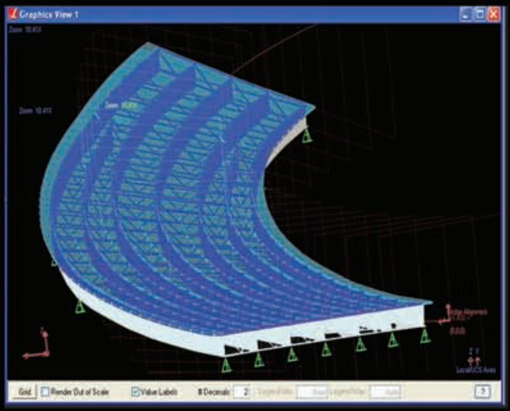


Grillage models do not take into consideration warping of the girder or the shear lag effect. And as the horizontal curvature of the bridge grows and/or larger skew angle is required, grillage analysis becomes insufficient.

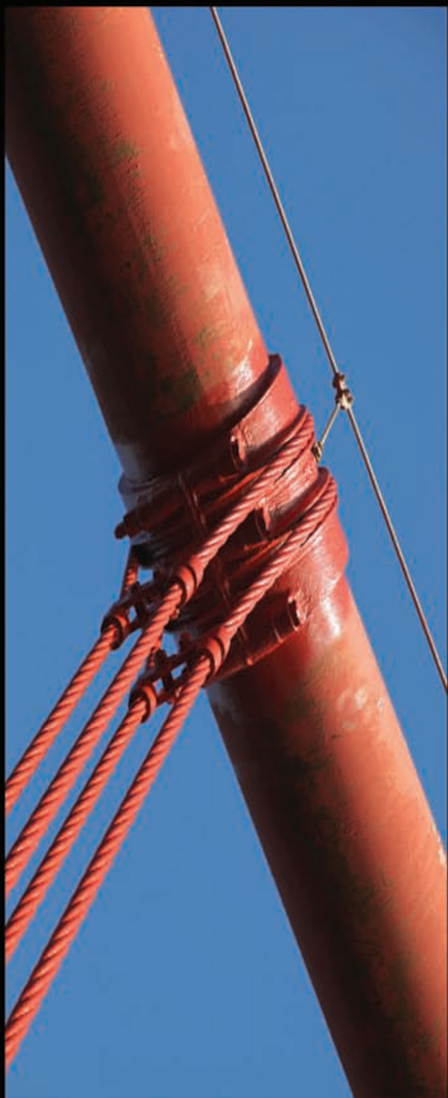
3D finite element analysis is usually required for a more refined and more accurate representation of these bridges. Finite element analysis has been thought of as complex, and model generation for steel girder bridges has been considered difficult, tedious, and computationally expensive, requiring powerful computing programs. General finite element programs often do not include code checking, leaving the end-user to create their own tools to extract results and code check.

The Steel Plate Girder Design Module is a component built in LARSA 4D to take the complexity out of analysis for the analysis and design of steel girder bridges by drawing on the strengths of LARSA 4D. With the help of this module, engineers are able to create a full 3D finite element model of the bridge by providing alignment, span, girder, deck, and cross frame information. LARSA 4D is 3D finite element software for the analysis and design of bridges and structures which require nonlinear, time-dependent, or other advanced analysis. Staged construction analysis, which models the changes to a structure over time including the construction or deconstruction of elements, the application of loading, and time-varying material properties, is the core of LARSA 4D's analysis. The analysis is capable of capturing the 3D behavior that a grillage analysis cannot, including the effect of warping and shear lag, and the behavior of a complex, curved, and/or skewed bridge.

LARSA 4D's full nonlinear staged construction analysis not only takes second order effects into account, but also provides the ability to capture the effects of the construction itself. Simulating the deck pouring sequence and/or screed movement is a good example where the need for staged construction becomes apparent.

Four girder types are now supported by the module: I-girder using beam elements only, I-girder using a combination of beam and plate elements, steel plate box, and steel plate tub. The module can be used to generate the model geometry and roadway lane definitions, load cases for dead, live, and wind loading, staged construction analysis stages and steps, and result combinations and envelopes. The module can also be used to code check an existing model.

While computationally expensive and complex, influence surface based analysis is the most desirable live load analysis capability of today's analysis software for bridge structures. With this method, load distribution across multiple girders is accomplished automatically because the 3D finite element model, with finite elements such as plate and shell elements as the deck, determines how forces are transferred throughout the model. Another advantage of the influence surface method is the ability to apply "two-dimensional" load patterns. The load



patterns are so named because wheels are arranged over a surface, rather than in a line. It is always recommended to use "2D" vehicle load patterns when using influence surfaces. Only 2D load patterns model the width of vehicles, which plays a role in the requirements for vehicle placement within lanes.

The Steel Plate Girder Design Module makes use of LARSA 4D's influence surface analysis method for live load effects. This provides the ability to load the roadway with standard AASHTO trucks, permit trucks, or any other user defined custom load patterns. The influence surface in LARSA 4D covers the complete surface with one or more rows of traffic, not an individual traffic or design lane. LARSA 4D will place as many lanes as will fit on the surface simultaneously maximizing the effect to any multiple presence factors specified.

The new algorithm implemented in 2012 will find the worst-case loading configurations of vehicles and lane load. The improvements include the ability for trucks to be placed at the very edge of design lanes regardless of the transverse grid spacing of the influence surface coefficients, improved accuracy by solving for the best lane and vehicle positions simultaneously, optimization over multiple lane configuration positions simultaneously, improved speed especially on multi-core/multi-processor computers, simultaneous optimization over multiple lane configurations (different truck types and limits on the number of trucks of any type), and the ability to combine the span-by-span requirement of AASHTO LRFD with multiple presence factors. The influence algorithm effectively simulates all of the vehicle configurations that arise from the different number and location of design (traffic) lanes and vehicles placed, the direction of each vehicle (forward or backward), and the length of variable-axle-position load patterns.

Once the 3D finite element is created, loaded, and analyzed, the Steel Plate Girder Design Module can perform code check based on the latest AASHTO LRFD code. The code check report can be viewed in summary mode, where the pass/fail of a particular location on the structure can be investigated, or the results can be viewed in detail mode where step-by-step computation and checks are reported. Users can produce reports simply by specifying the station(s) and girder(s) ID(s) instead of element or joint ID(s). Reports show line-by-line computations that follow the design code, with equation number references to the code. Reports cover the following components of the code: cross-section proportion limits, constructability, service limit state, strength limit state, and stiffeners.

Arbour Stone Bridge

An in-depth look at the unique challenges of this twin-arch bridge by Infinity Engineering

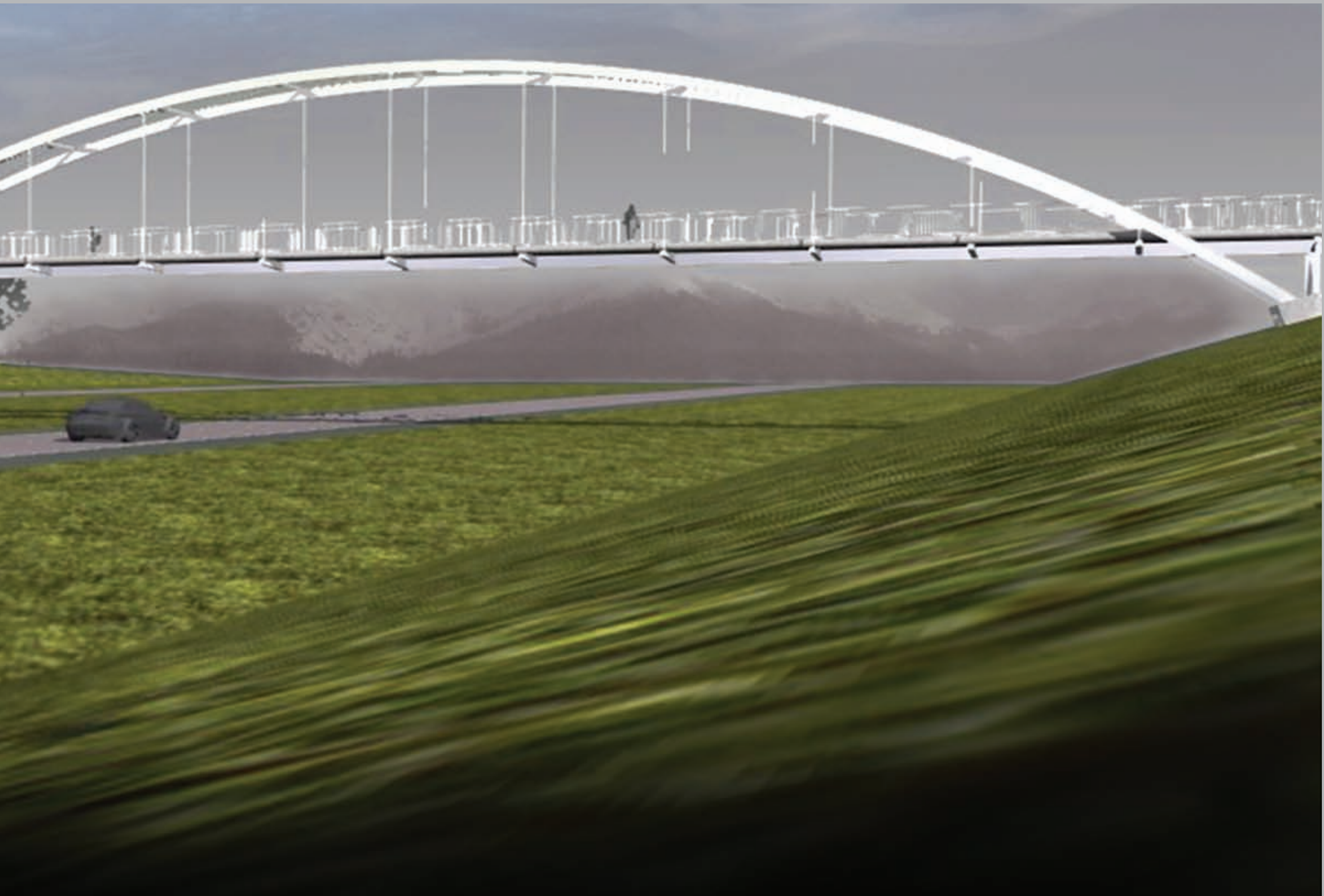
Authored by: Prabhjeet Raj Singh, P, Eng, PE

Dr. Matthias Schuller, P, Eng

IN today's market with aggressive time lines engineers rely heavily on the capability and efficiency of the analysis programs. LARSA 4D has met the expectations of our design team on numerous challenging projects. It proved its utility yet again when the Arbour Stone project hit rough weather.

Construction of a 120-meter twin steel arch pedestrian bridge intended to mimic the clouds during a chinook was completed in the City of Calgary, Alberta, Canada. The pedestrian overpass is located over Stoney Trail at Arbour Stone Rise and provides connectivity between the communities of Arbour Lake and Royal Oak for pedestrians and cyclists. The architectural visual intent behind the design was to use the line of the arch as a natural reference to the "Chinook" weather phenomenon, thus allowing pedestrians and motorists an enhanced experience of this unique meteorological event.

Infinity Engineering Group Ltd. based out of North Vancouver, Canada is the erection engineer for this bridge. Surespan Construction Ltd. is the erection subcontractor while AECON is the general contractor for the project. The structure and connecting regional pathways are owned and maintained by the City of Calgary. Delcan Corporation provided engineering and architectural services for the design of the pedestrian overpass and landscaping.



The bridge design features slender elements which were optimized for the completed bridge structure and loading. The erection scheme assumed by the designer utilized four temporary towers for the support of arches during construction. Upon award of the subcontract for erection of the structural steel, several options were investigated in search of the most economical method for building the bridge. It was determined that using one temporary tower offered a significant cost saving advantage. During the construction of the bridge an unexpected decision by the general contractor to precast curbs as a part of the deck panels significantly increased erection loading. Also due to a fabrication related issue one of the arches had to be forced transversely at the base to fit at the connection to the abutment. This resulted in locked in residual stresses in the arch. Spontaneous decision making and an ability to conduct staging analysis on short notice were needed to maintain the construction schedule. This article presents the innovative erection scheme that was developed for the bridge with a focus on the detailed construction staging analysis.

BRIDGE DESCRIPTION

The pedestrian overpass consists of a two span, steel arch structure. The bridge has slender twin tapering steel box arches, each 60 meters long. Each arch consists of two box sections braced together. The total length of the pedestrian overpass is 120 meters with a 3.6 meter wide reinforced concrete deck supported on a steel grid. The steel grid consists of a 500 mm deep box girder spine with cantilever floor beams at 5 meter intervals. The steel grid supports the reinforced concrete deck. The deck consists of 100 mm thick precast panels that act as forms for the 150 mm thick cast-in-place topping. The concrete curbs, originally planned to be cast-in-place were precast as a part of the deck panels. The floor beams are supported by steel hangers suspended from the arch. The arches are supported on a concrete pier and two concrete abutments. The pier consists of two columns with sloped and tapered faces connected with bent steel.

DESIGNER'S ERECTION SCHEME

The erection scheme adopted by the designer involved the use of four temporary towers, two for each span to support the arch segments. The towers supported the arches until the completion of the arches and deck construction. It is typically not the designer's role to develop an optimal and cost effective erection scheme. Consequently the construction scheme assumed by the designer is a possible method to build the bridge but not the most economical one. It eliminated stability and had the advantage for the designer of not requiring a closer investigation of each construction stage.

CONSTRUCTION ENGINEER'S ERECTION SCHEME

In order to reduce cost, Infinity's Engineering team and Surespan's construction crew decided to use only one temporary tower for building the bridge. One of the major constraints during construction was the stability of the main pier. Since the arches are not self-anchored, the middle pier is subject to lateral thrust from imbalanced loading on the two spans. It was determined that the pier, without any external support could safely resist the thrust from self weight of a complete arch only, not including the spine beam frame and the concrete deck. Therefore, after the erection of the steel arch in the North span and before the installation of the spine beam grid, the temporary tower was moved to the South span before the addition of further loads.

Step 1. Erect arch in North Span (Figures 2 & 3).

-Set up temporary tower at mid-span of North span.

-Assemble first arch segment and hoist onto abutment and temporary tower.

-Secure arch base to abutment and use jacks at temporary tower for adjustments.

-Assemble second arch segment and hoist onto temporary tower and pier.

-Establish field splice between segments, secure arch base at pier and remove temporary tower.

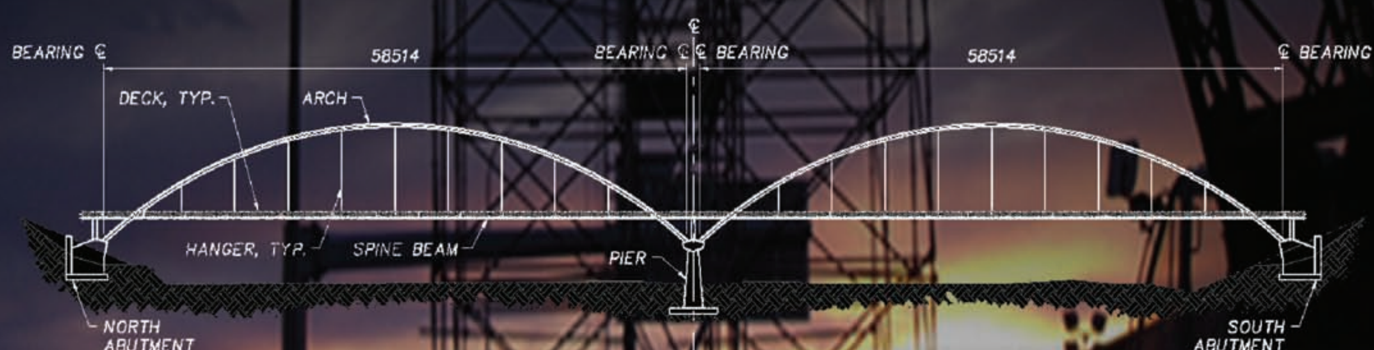
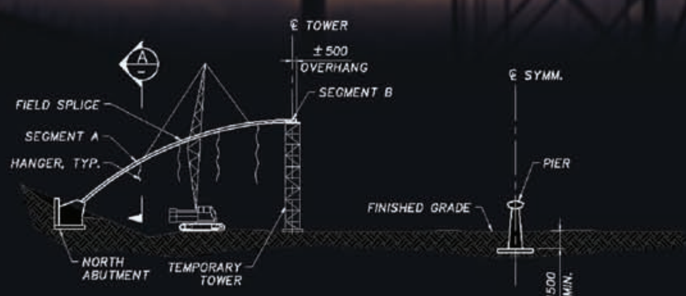


Figure 1: General Arrangement



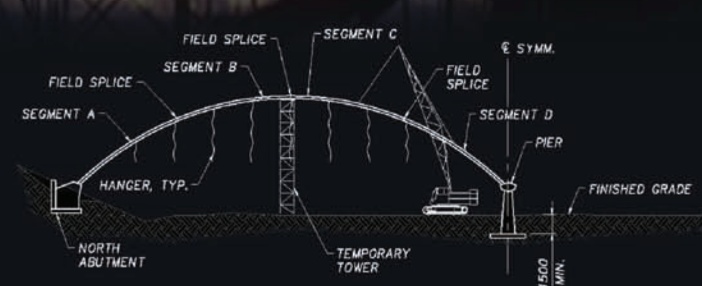


Figure 2: Erection Scheme of 1st Arch Segment in North span

Figure 3: Erection of 2nd Arch Segment in North span

Step 2. Erect arch in South span (Figure 4).
-Repeat steps followed for North span arch erection.

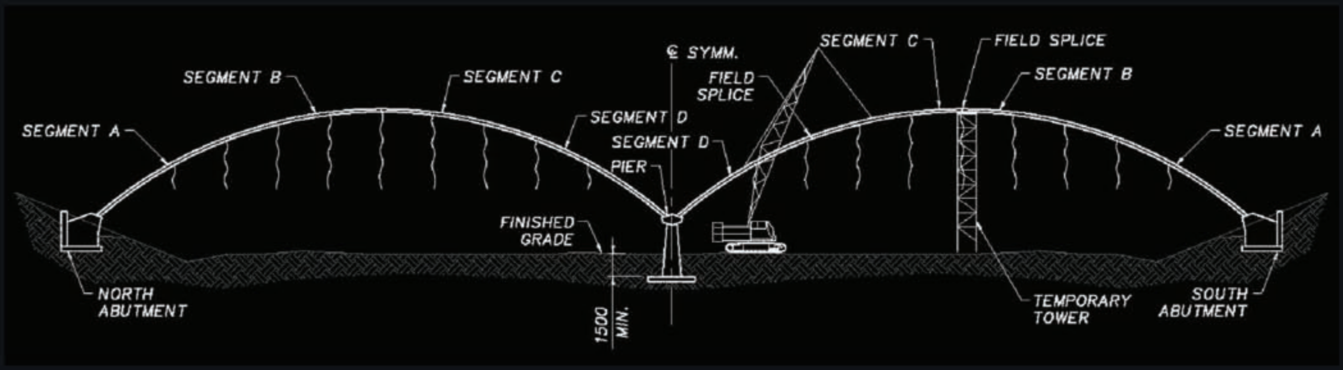


Figure 4: Erection of Arch in South span

Step 3. Erect the steel grid of the entire bridge (Figure 5).

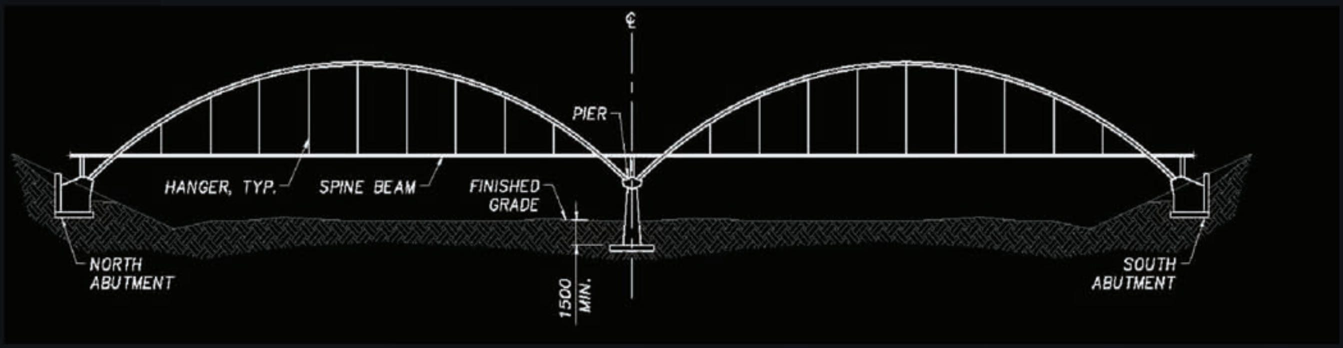


Figure 5: Erection of Spine Beam

Step 4. Place the concrete deck panels starting in the middle of a span and working towards the supports simultaneously in both directions (Figure 6). This was required to load the arch symmetrically. The weight of the original deck panels (without the concrete curbs) was 1.5 metric tons per panel approximately.

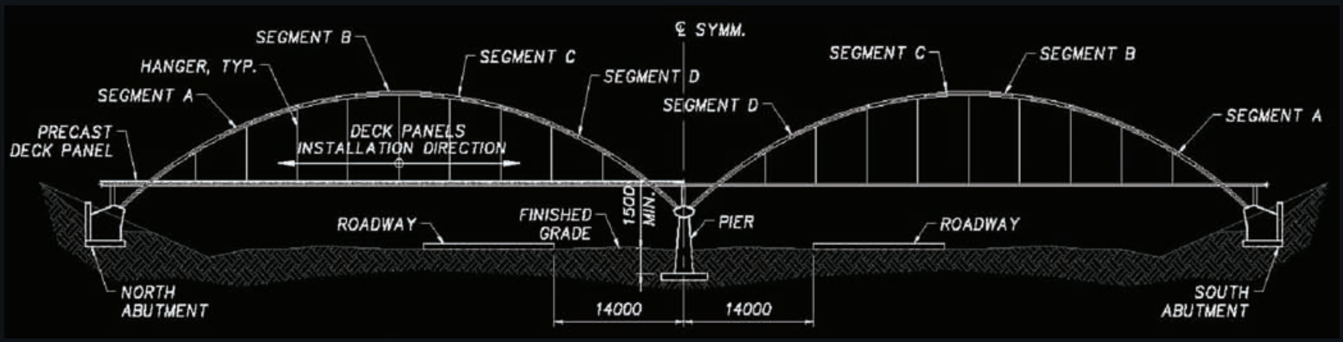


Figure 6: Original Installation Scheme for the Deck Panels

Hand calculations were conducted for the initial erection scheme to determine the force effects and the capacity of members at the various construction stages. As a part of the process at Infinity, a simple 2-dimensional model was developed to verify the hand-calculations. There was good co-relation between the calculations. The maximum stress in the arch section occurred during the placement of the deck panels under a combination of dead load, construction live load, and wind. The effects of geometric non-linearity were included in the analysis.

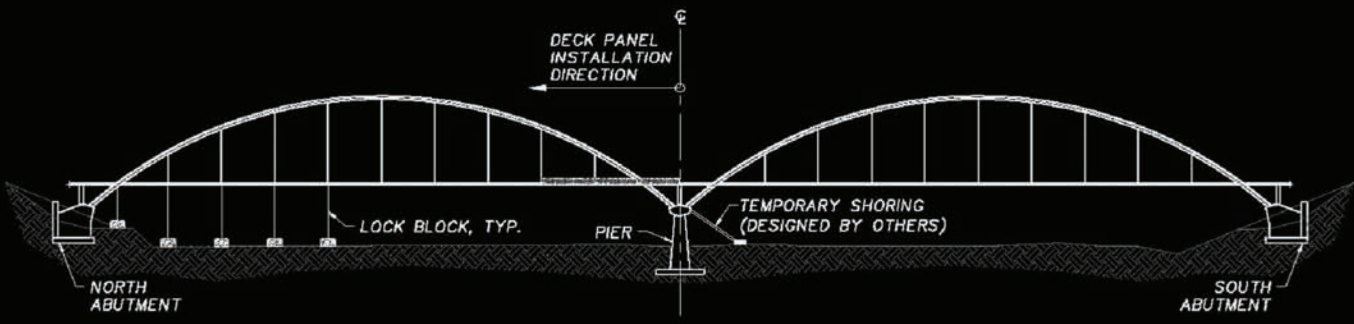


Figure 7: Revised Erection Scheme for Heavier Deck Panels

REVISED ERECTION SCHEME

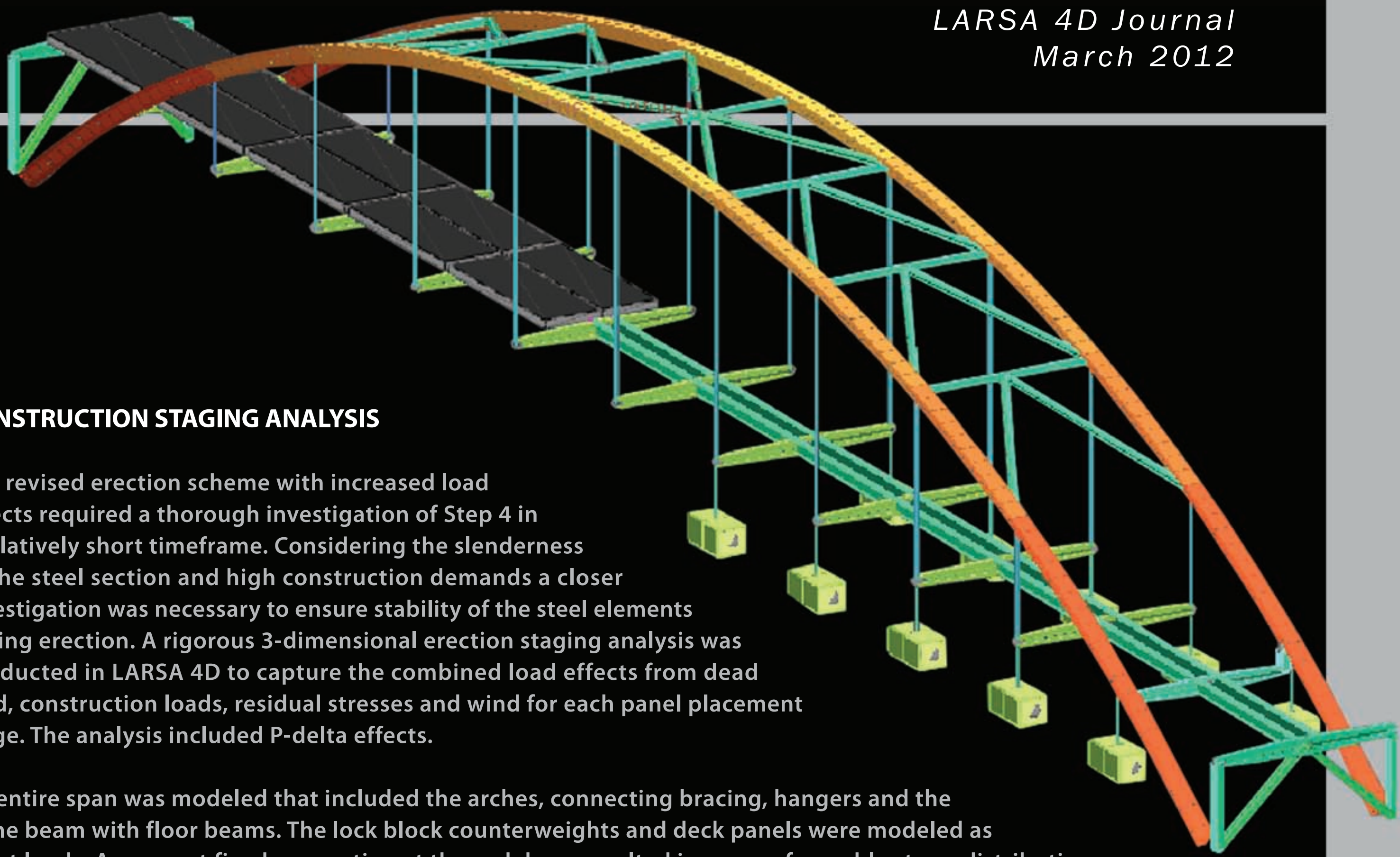
As is common with most construction projects, modifications to the original plan are required as the work progresses to gain an advantage or to remedy problems. In the Arbour Stone project, two changes significantly impacted the initial erection scheme.

The first was related to the deck curbs. The outside bottom edges of concrete curbs have a rounded shape for aesthetic reasons. During the construction of the precast deck panels the general contractor decided to precast the curbs with the panels to avoid having to cast the complex shape unit in situ. The addition of the concrete curbs increased the weight of the concrete deck panels from 1.5 metric tons to 2.7 metric tons per panel.

The second was related to what is believed to be a fabrication problem where the remedy involved pulling the arch legs transversely at the base to fit at the support connection. An analysis was conducted by the designer to determine the locked-in stresses in the arch due to the forced fitting procedure. The results of the analysis were supplied to the erection engineer to include in the staging analysis.

The above changes impacted Step 4 of the initial erection sequence, as shown in Figure 7. The increased load of precast deck panels and the residual forces due to the forced fitting overstressed the arch under patch loading in the middle of the span. Patch loading activates the arch section in bending and a relatively small load can lead to significant stresses over a 60 meter span. Also, the placement of the heavier panels in one span would increase the imbalanced thrust on the middle pier and render it unstable for overturning.

It was determined that loading the panels from both ends simultaneously and working towards mid-span would work. However, the contractor was reluctant to have two sets of crews and equipment working simultaneously to place panels. A cost-effective innovative solution was developed to allow loading of the precast deck panels starting from the middle pier end to the abutment end of a span. The solution involved using concrete lock blocks as counterweight to the panel loads. Lock blocks were connected using slings to the underside of the spine beam grid at the floor beams. The slings were tightened using a turnbuckle to remove slack. As the panels were placed at the pier end the arch pulled up at the abutment end and activated the lock block counterweights, thus enabling a symmetrical loading of the span. An external support in the form of a steel pipe struts bearing on lock block footings was provided to support the middle of the pier during placement of the deck panels in the North span.



CONSTRUCTION STAGING ANALYSIS

The revised erection scheme with increased load effects required a thorough investigation of Step 4 in a relatively short timeframe. Considering the slenderness of the steel section and high construction demands a closer investigation was necessary to ensure stability of the steel elements during erection. A rigorous 3-dimensional erection staging analysis was conducted in LARSA 4D to capture the combined load effects from dead load, construction loads, residual stresses and wind for each panel placement stage. The analysis included P-delta effects.

An entire span was modeled that included the arches, connecting bracing, hangers and the spine beam with floor beams. The lock block counterweights and deck panels were modeled as point loads. A moment fixed connection at the arch base resulted in a more favorable stress distribution

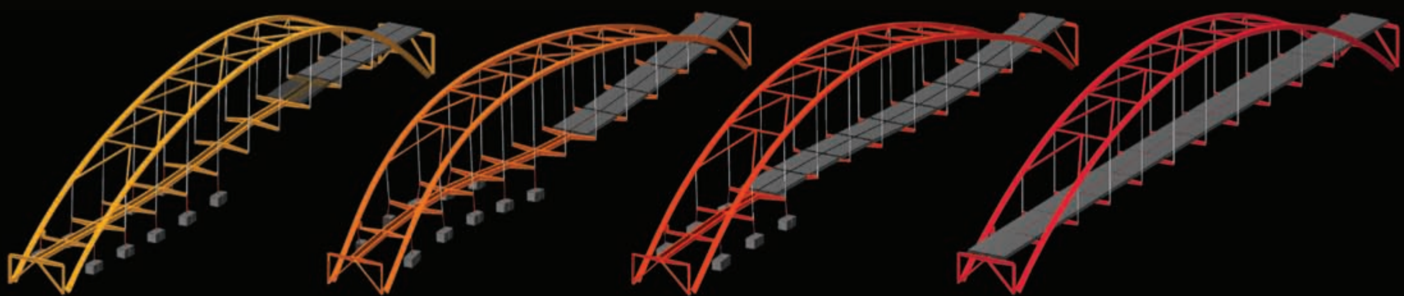


Figure 8: Deformation during successive Step 4 stages

as compared to a hinged connection for Step 4 stages. However, the connection frozen for Step 4 would lead to unfavourable stress distribution in the later stages and during permanent limit states. A hinged connection fixed against translation was used as the articulation at the base. Brackets anchored to concrete and blocked against the base plate of the arch base were designed to provide temporary fixity during Step 4 stages.

The deformation shape of the bridge at each stage of panel installation provided a visual verification of the anticipated structural behavior. The deformation profile bridge during the precast panel placement stages in Step 4 is shown in Figure 8. An overall demand envelope was created for all the analysis erection stages during Step 4.

CONCLUSION

The Arbour Stone twin arch pedestrian bridge is an elegant structure with slender steel elements that are optimized for the permanent static system and loads. While being adequately stable for the permanent loads such slender bridges can be quite challenging to engineer during construction especially for a cost-effective and accelerated construction scheme. Quick decision making from the erection engineering consultant and an ability to conduct rigorous construction staging analysis on a reliable software program is essential to the successful execution of construction.


NEW ADDITIONS TO LARSA 4D FE LIBRARY
HYSTERETIC ELEMENTS
• Friction Pendulum Bearing
• Coupled Viscous Dashpot and Sliding Friction
• Biaxial Flat Sliding Friction Bearing
PLATES AND SHELLS
• Membrane Geometric Nonlinearity
• Material Nonlinearity for Shells
• Drilling Membrane
SOLID ELEMENTS
• 6-Node & 15-Node Wedge
• 8-Node & 20-Node Brick
• Geometric Nonlinearity
• Nonlinear Material