# 2014 CANADIAN CONSULTING ENGINEERING AWARDS

## SUSTAINABLE REHABILITATION OF THE PRINCESS MARGARET BRIDGE

Fredericton, New-Brunswick

## CATEGORY "TRANSPORTATION"

**01 | 05 | 2014**

PROJECT ENTRY



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# SUSTAINABLE REHABILITATION OF THE PRINCESS MARGARET BRIDGE

## Project Summary

In 2012, SNC-Lavalin (the Firm) completed the rehabilitation of the Princess Margaret Bridge in Fredericton, New-Brunswick.

Our innovative solution aimed at extending the service life of the bridge while meeting the challenges of sustainability. The design team developed a system of precast deck panels and introduced a composite action with a steel structure composed of existing trusses: a world first. Other major breakthroughs are the innovative construction method and the use of custom-made transportation, lifting and installation equipment that is currently under a patent application. The use of high-performance materials and innovative design translated into less construction time and energy spent on future maintenance, with minimal environmental impact.

The method of selection and construction, the design team's expertise as well as the originality and functionality of the solution are some of the aspects that led to the success of this project. The Firm is proud to have delivered a project with a positive impact on the residents and users of the bridge in the Fredericton area while integrating the principles of sustainable development. The Firm accomplished the required tasks in accordance with the highest standards of ethics, professional practice and integrity.

Figure 1 shows a general view of the bridge spanning approximately 1.0 km across the St. John River.

Figure 1 – General view of the Princess Margaret Bridge

## Project Structure and Procurement

New bridge options were rejected at the time due to the exorbitant capital requirements, as well as the excessive delay inherent in that option for the users to have the truck loading reinstated. These excessive delays were estimated to add several years to the schedule for the completion of the necessary environmental review processes and the construction effort. The New Brunswick Department of Transportation & Infrastructure (the Client) chose a Design-Build model over traditional build and design procurements primarily for the purpose of schedule acceleration.

The project delivery method was structured as a 2 years design-build project with a two-stage tendering process. The first stage consisted of a public invitation for prequalification in which several consortiums, uniting designers, constructors, project management teams and precasters submitted prequalification application.

## Integrating Innovation

The Firm undertook the sustainable rehabilitation of the Princess Margaret Bridge, a 50-year old structure considered as one of Canada's most important bridges. The 80-million-dollar project aimed to extend the service life of the structure crossing the St. John River in Fredericton, New Brunswick.

After more than 50 years in operation, the combined effects of age, an increase in the weight and number of trucks, and the extensive use of deicing salts to keep the bridge operational during Canada's harsh winters had taken its toll on the bridge. The deck had deteriorated beyond repair. The steel members of the trusses were deficient. There were also indications of leaking expansion joints, frozen and non-functioning bearing systems, collision damage to the railings and corrosion to the supporting steelwork. The concrete piers had suffered severe damage.

The bridge had to be repaired with the least amount of closure time. To deal with the aging structure, the Firm developed a creative and innovative solution: precast deck panels that are made composite with the existing trusses. This project marked the first time that trusses were made composite with a precast concrete deck. Not only did this solution speed up construction, but it also improved the capacity of the existing truss members. The Firm achieved significant savings in the strengthening of the structural steel in trusses and considerably reduced the execution time.

The innovative composite action was accomplished in:

1. The Deck Truss area between the top chord and the deck panels – the first time implemented worldwide to the Firm's knowledge.
2. The Plate Girder area between the top flange and the deck panels;
3. The Through Truss area between deck panels and the floor beams.

Figure 2 describes the different span configuration of the Princess Margaret Bridge.

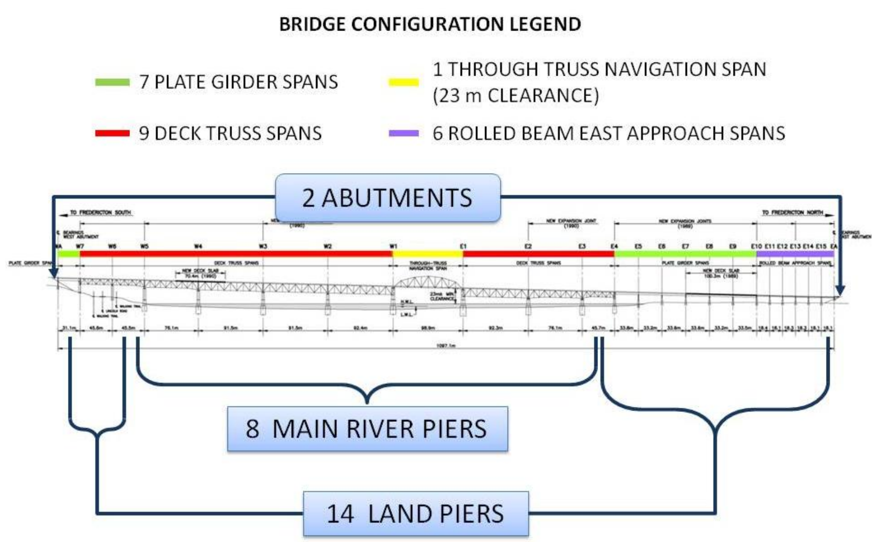



Figure 2 – Bridge span configuration

## Deck Reconstruction: Deck Trusses and Plate Girders

The deck design at the Deck Trusses and Plate Girders consist of precast double tee panels with the pre-tensioned ribs oriented transversely to the direction of traffic. The deck panel geometry is shown in Figure 3. The typical double tee width is 4.5 m and length is 9.66 m. The ribs were orientated in the transverse directions to comprise the floor beams and to span between the two main girder lines as shown in Figure 4. A unique system of post-tensioning the double tee slab parallel to the direction of traffic, which eliminated all duct coupling and any possible beams misalignment was implemented. For both deck truss and plate girder spans, a typical pre-tensioned profile and post-tensioning layout are also shown in Figure 4.

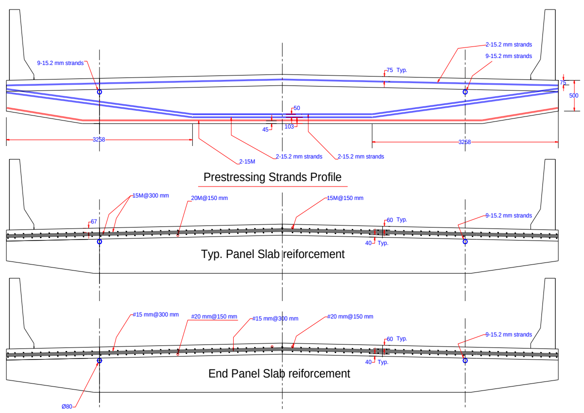



Figure 3 – Prefabricated concrete panels

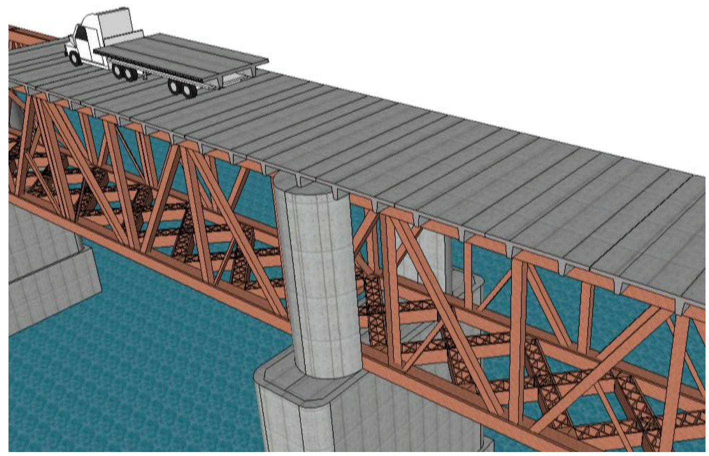


Figure 4 – 3D rendering of the superstructure with installed concrete panels

## Deck Reconstruction: Through truss

The Through Truss measures 98.90 m in length and is shown in Figure 5.

The floor beams in the Through Truss were in a fairly good shape and spaced at 9.60 m. The panel steel forms used for the Deck Truss and Plate Girder panels were utilized to form the Through Truss deck panels. In total, twenty deck panels were used.

The deck panels' ribs in the Through Truss were oriented to span between the floor beams. A second stage cast were added to the though truss panels to facilitate the panel installations as well to form the connecting beam above the floor beams.

Figure 5 – General view of the through truss

## Innovation through Composite Action

Deck Truss panels were pre-tensioned transversally and post-tensioned longitudinally. The composite action to the steel members was achieved as follows: for both deck truss and plate girder, a spine beam was detailed to connect either the Plate Girder top flange or the Deck Truss top chord to the deck panels after the post-tensioning operations (see Figure 6).

For Through Truss, the composite action was created through a shear key between the panels in which shear studs are welded to the floor beams, as shown in Figure 7.

Figure 6 – Spine beam for Plate Girder and Deck Truss spans

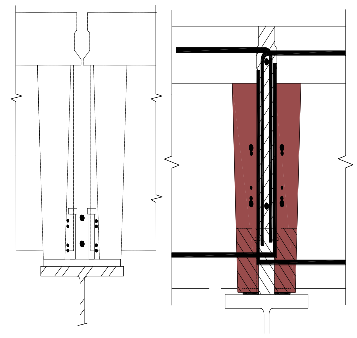


Figure 7 – Spine beam for the Though Truss span

## Deck Panels Fabrication and Construction

The fabrication of the Deck panels was planned in a very efficient way. All the deck panels are double tees. Approximately, a total number of 200 panels were fabricated.

The forms of the deck panels can be divided into two groups. The first group contains the majority of panels, 173 panels. Of those, 153 panels were intended for the deck truss and the plate girders. The remaining 20 panels were intended for the Through Truss.

All 173 panels have the same rib spacing of 2.25 m, and cross-section. The panel foot print is 4.50m x 9.66 m. Only one steel form geometry was used for these 173 panels.

The 153 Deck Truss and Plate Girder panels had a 2% crown. The ribs and the slab at the mid-length of the rib had a crown to match the bridge cross-section. Only one form geometry was designed to form the typical panel, the variable width panel and the span end panel. A concrete blockout used in the panel to contain the drains.

A storage yard was provided near the bridge site to stockpile the precast panels, as shown in Figure 8.

Figure 8 – Stockpiling of concrete panels

## Piers and abutments repair

Most of the bridge substructure components were showing signs of severe deterioration, which take the form of scaling, map cracking, spalling, and delamination of the concrete surface, and corrosion of the embedded steel reinforcement. The deterioration was the result of the combined action of alkali-silica reaction (ASR), cyclic freezing and thawing, and the chloride-induced corrosion of steel. The encapsulation method was chosen to repair the piers and abutments. This method entails the installation of reinforced concrete jacket around and over the structure. This encapsulation tasks included the following:

- Remove concrete to a minimum of 250 mm from the original profile of pier, with all reinforcement, as shown in Figure 9.
- Install a reinforced concrete jacket around and over the pier to completely encapsulate the exposed surface, and using stainless steel for corrosion-resistant steel, as shown in Figure 10.


Figure 9 – Concrete removal

Figure 10 – Installation of stainless steel reinforcement

## Innovative Custom-Made Lifting Equipment

The Firm faced an interesting challenge: the existing bridge trusses could not support the conventional cranes used to remove the old deck and install the new one. To overcome this challenge, the Firm designed a unique, lightweight, electronically controlled machine to install the panels much faster and without the cost of strengthening the top chord to carry temporary crane loads (see Figure 11). The custom-made lifting equipment was essential in providing an effective and time-saving construction procedure.

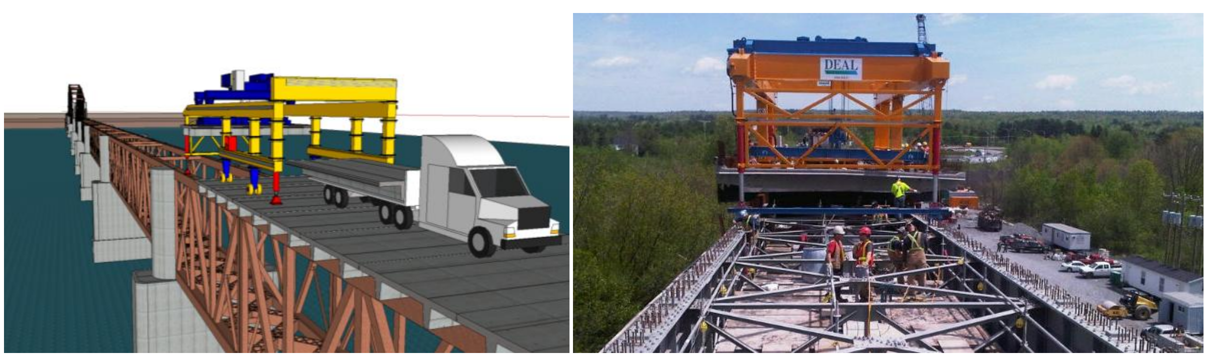



Figure 11 - Light weight lifting equipment

## Complexity

The design-build project and all construction works were completed to ensure that the bridge achieved the required live load carrying capacity and service life objectives.

The following aspects describe the nature, complexity and technical challenges faced throughout the project:

1. The use of a precast pre-stressed high-performance concrete (HPC) integral deck system that is composite with the trusses proved to be a very efficient deck replacement strategy that saved a significant amount on the strengthening.
2. The innovative system of post-tensioning the precast panels parallel to the direction of traffic, using the spine beam concept, eliminated all duct coupling and possible misalignment, as seen in Figure 12.

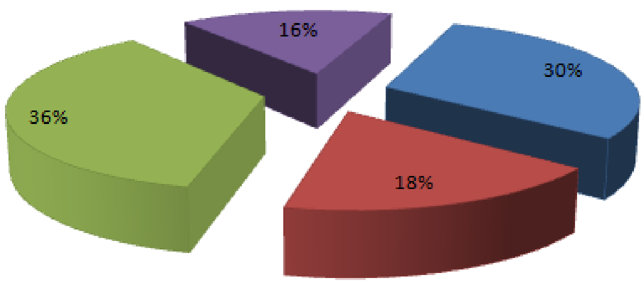
   The post-tensioning in this system is particularly innovative and was unprecedented to the knowledge of the Firm. The pos-tensioning ducts are straight and longitudinally to traffic crossing only the ribs. The top of the ducts was the soffit of the 180 mm slab. This eliminates all the possible duct misalignment and significantly reduces friction losses.
3. Unique light equipment to install the deck panels was instrumental in achieving the required productivity, which allowed the project to be completed within the two-year allotted time frame.
4. The understanding of the structural benefits of a composite action between the new precast concrete deck and the existing supporting elements was paramount to develop a highly durable bridge deck, which will be virtually maintenance-free.
5. The rapid construction and prefabrication drastically reduced traffic congestion, hours and fuel spent in delays, and hours spent working in hazardous construction zones. This assessment is particularly true when considering the conflicting time constraints, traffic management issues, difficulties to access the work site, and unfavorable weather conditions. Figure 13 shows an adaptive construction method to overcome accessibility constraints.

Figure 12 – Post-tensioning system

Figure 13 – “Flying” concrete mixer truck

## Social and Economic Benefits

The Firm assembled and managed experts from several disciplines in the fields of structure, construction, contract management, environmental and traffic management, and promoted effective collaboration between the various stakeholders. The Firm has given certain activities to qualified subcontractors from New-Brunswick to meet the multidisciplinary needs of the project. The Firm is proud to have encouraged the local economy and promoted local partnerships. The 80-million-dollar budget was divided as follows:




| | |
|---|---|
| Deck replacement | 30% |
| Steel strengthening | 18% |
| Rehabilitation of piers and abutments | 36% |
| Painting | 16% |

## Stimulating Local Partnerships

Contribution from local firms and subcontractors was instrumental in completing the project on schedule. The percentage of the overall of construction activities are identified as follows:

| CONSTRUCTION ACTIVITIES | | |
|---|---|---|
| **CONSTRUCTION** | **FIRM** | **PARTICIPATION** |
| Strengthening of the steel structure | Structure GB, Rimouski - Quebec | 17% |
| Paving | Local firm in Fredericton – New-Brunswick | 1% |
| Waterproofing of the deck | Groupe Lefebvre - Quebec | 1,8 % |
| Infrastructure repairs | Construction Injection EDM Inc. - Quebec | 40,3 % |
| Reinforcing steel and prestressing steel | Harris Re-Bar - Alberta | 8,1 % |
| Fabrication of the lifting equipment | Deal - Italy | 2,9 % |
| Fabrication of concrete panels | St. John – New Brunswick and Bedford Nova-Scotia | 9,9 % |
| Sand-blasting and painting | Nor-Lag - Quebec | 13% |
| Sand-blasting and painting | Parker Kaefer - St. John, New-Brunswick | 5% |
| Lighting | Fredericton – New-Brunswick | 1% |
| **TOTAL** | | 100% |

## Promoting New Techniques In Bridge Rehabilitation

The rehabilitation of the Princess Margaret Bridge is an exceptional opportunity for specialists and managers in the field of transportation infrastructure to help launch a meaningful process for the maintenance of bridges and simultaneously promote innovation. The Firm believes that it advanced the field of transportation infrastructure through its leadership role and technical innovations demonstrated in this project. The numerous social and economical benefits derived from the project include:

- Promotion of a new engineering technique;
- Structural innovation;
- Integration of sustainability;
- Reduction of environmental impact;
- Judicious use of traditional and high-performance materials;
- Knowledge of the nature of the constituent materials;
- Evaluation of potential risks at early stages;
- Intervention strategy for structures non-compliant with codes and regulations (including earthquake resistance) ;
- Intervention strategy for structures affected by alkali-aggregate reaction (AAR).

Additionally, the major rehabilitation of the Princess Margaret Bridge, the diversity and complexity of the project are, in our opinion, a springboard for the asset management of bridge structures in Canada.

## Reproductibility, an Added Value

The success and added value of the Princess Margaret Bridge rehabilitation are also based on its reproducibility and adaptability for other similar projects. The use of prefabricated panels provides a flexible and elegant design for newly proposed deck geometries.

The application of the post-tensioning and *in-situ* concreting of a spine beam fits smoothly to the upper chord members of any existing truss. Thus, by changing the prefabricated panel formwork and adjusting the post-tensioning jacking forces, this concept becomes easily applicable to rehabilitation projects of comparable truss bridges.

Furthermore, the innovative construction method and equipment are desirable factors when dealing with traffic management. The quick installation of prefabricated panels facilitates coordination with periodic traffic closures and allows for rapid mobilization and demobilization of teams and equipment. This aspect is especially coveted for bridges located in densely populated areas or considered to be strategic crossings.

The Firm is currently working on a similar concept for the rehabilitation of a major bridge crossing the St-Lawrence River, in Montreal, Quebec.

## Environmental Benefits

The rehabilitation project of the Princess Margaret Bridge is part of a global vision of sustainable development. The principles of sustainability are based on a long-term vision that take into account the inextricable nature of environmental, social and economic dimensions of development.

The project's major highlights of sustainability are:

- A fast-track design-build project;
- An optimal and innovative design;
- A manufacturing process and material selection for reducing environmental impacts.

The fast-track design-build project set the tone by focusing on an optimization approach at every stage. For example, the prefabrication method allowed for significant savings in execution and installation time. This optimization resulted in an accelerated schedule, a significant reduction in traffic congestion, fuel consumption, building materials and *in-situ* interventions.

The innovative composite action of the superstructure significantly reduced the quantities of steel required to upgrade the trusses. This approach reduced the transportation of materials and mobilization of equipment and personnel.

The prefabrication of concrete panels offered benefits, such as better control over the quality of materials and workmanship. Prefabricated panels minimized *in-situ* concrete works and tributary activities (formwork, curing, etc.). A control shelter was used around the structure for sand-blasting and painting procedures and minimized dust, product and noise emissions in the surrounding environmental habitat of the St. John River (see Figures 14 and 15).

The success of the Princess Margaret Bridge project is based on a design and construction method that incorporated with finesse concern for the environment and the well-being and needs of present and future generations. The Firm is also proud to have incorporated a solution with a reduced carbon footprint.


Figure 14 – Temporary work shelter being built

Figure 15 – Thriving wildlife on the St. John River

## Meeting the Client's Needs

The Firm conducted a thorough review of the bridge to develop a solution that properly meets the Client's needs. The study included:

- A review of the existing geometry of the structure, including roadways and sidewalks;
- A study of the structural behaviour of the entire deck;
- A detailed inspection of structural steel with detailed damage reports. The inspection was followed by a finite element analysis that included material deteriorations. The analysis determined the bridge's structural capacity with respect to the S6 code.
- A study of the behaviour of existing piers and their compliance with the S6 code;
- A study of the behaviour to the strength of the superstructure and infrastructure with respect to the lateral wind loads and the response of the bridge to seismic loads.

The condition assessment of the bridge confirmed several structural deficiencies. The bridge was weight-restricted to a maximum of 43,500 kg. Affected trucks were forced to take alternate routes to cross the St. John River while traffic was maintained for other vehicles.

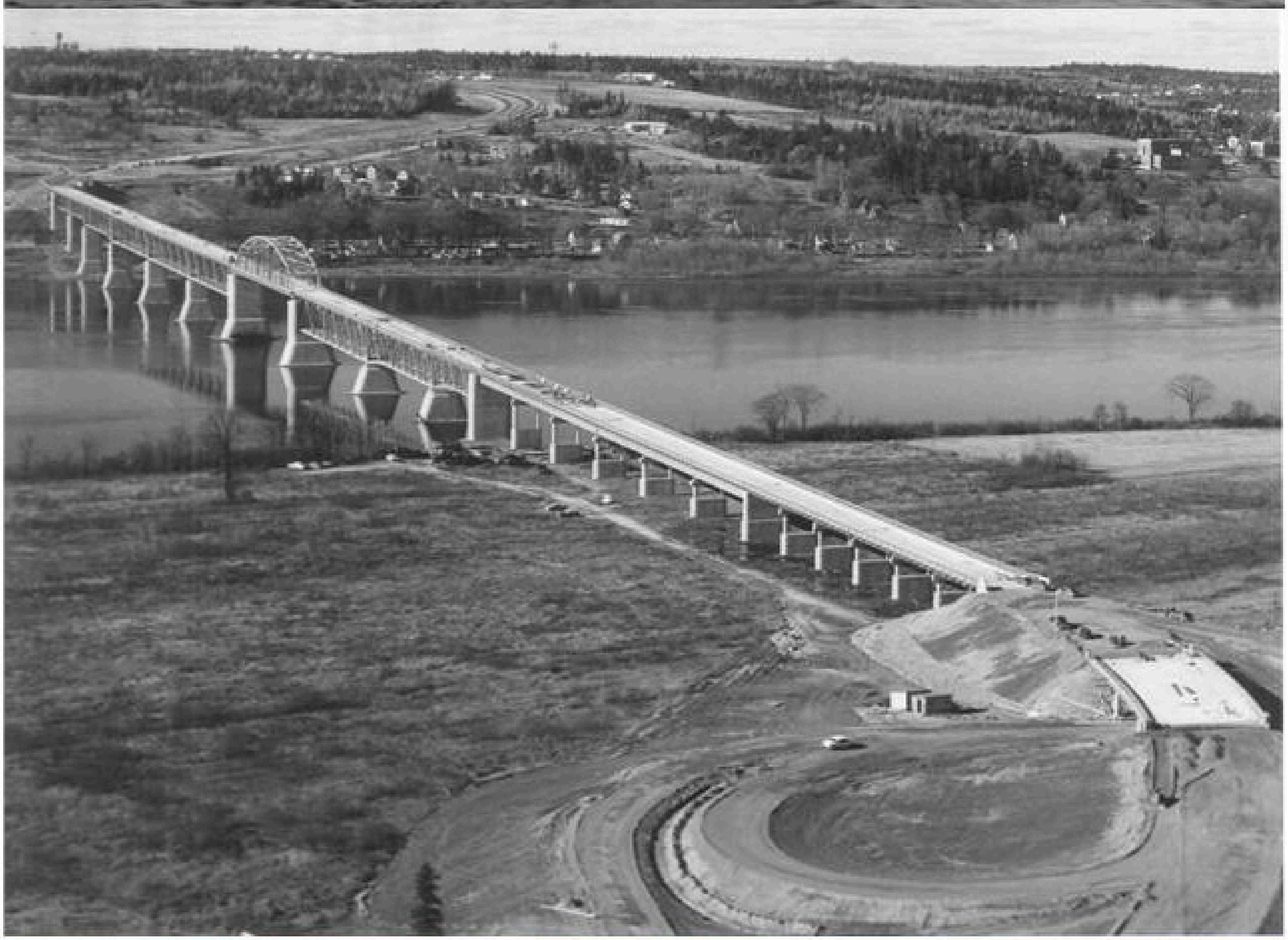
In perspective, the Firm met all the Client's objectives by:

- Developing an innovative concept taking into account the interaction between a new deck and the main structure;
- Minimizing the amount of closure time and respecting the allowed schedule;
- Proposing a solution that did not trigger a time-consuming environmental assessment;
- Restoring the desired truck carrying capacity of the bridge and addressing all structural deficiencies, though rehabilitation or replacement.

The Princess Margaret Bridge now safely serves 20,000 vehicles daily. It remains a strategic bridge across the St. John River in Fredericton.

Figure 16 – The rehabilitated Princess Margaret Bridge is re-opened

# LIST OF PHOTOGRAHS



1 – Construction of the Princess Margaret Bridge

Construction began in 1957 and the bridge was inaugurated in 1959 by Princess Margaret

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2 – General view of the Princess Margaret Bridge

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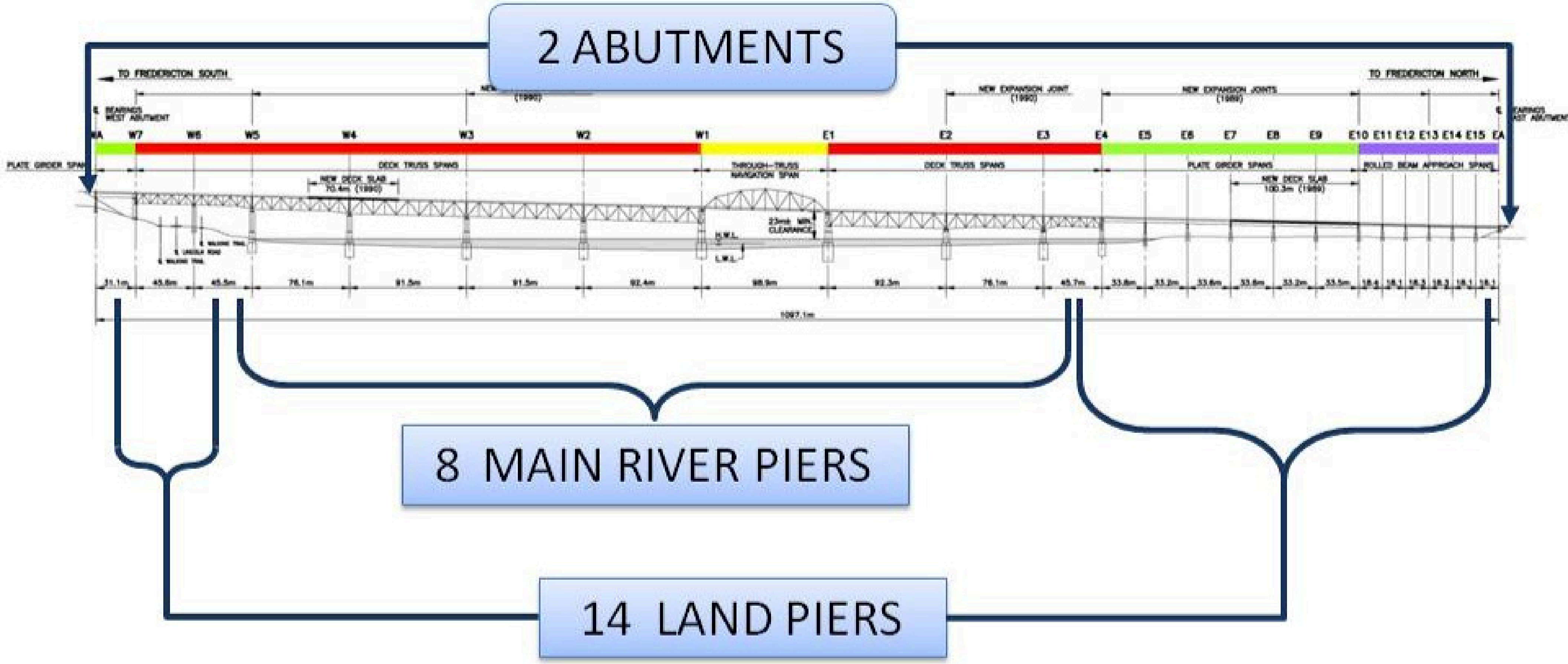
# BRIDGE CONFIGURATION LEGEND

- 7 PLATE GIRDER SPANS
- 1 THROUGH TRUSS NAVIGATION SPAN (23 m CLEARANCE)
- 9 DECK TRUSS SPANS
- 6 ROLLED BEAM EAST APPROACH SPANS



4 – General view of the through truss

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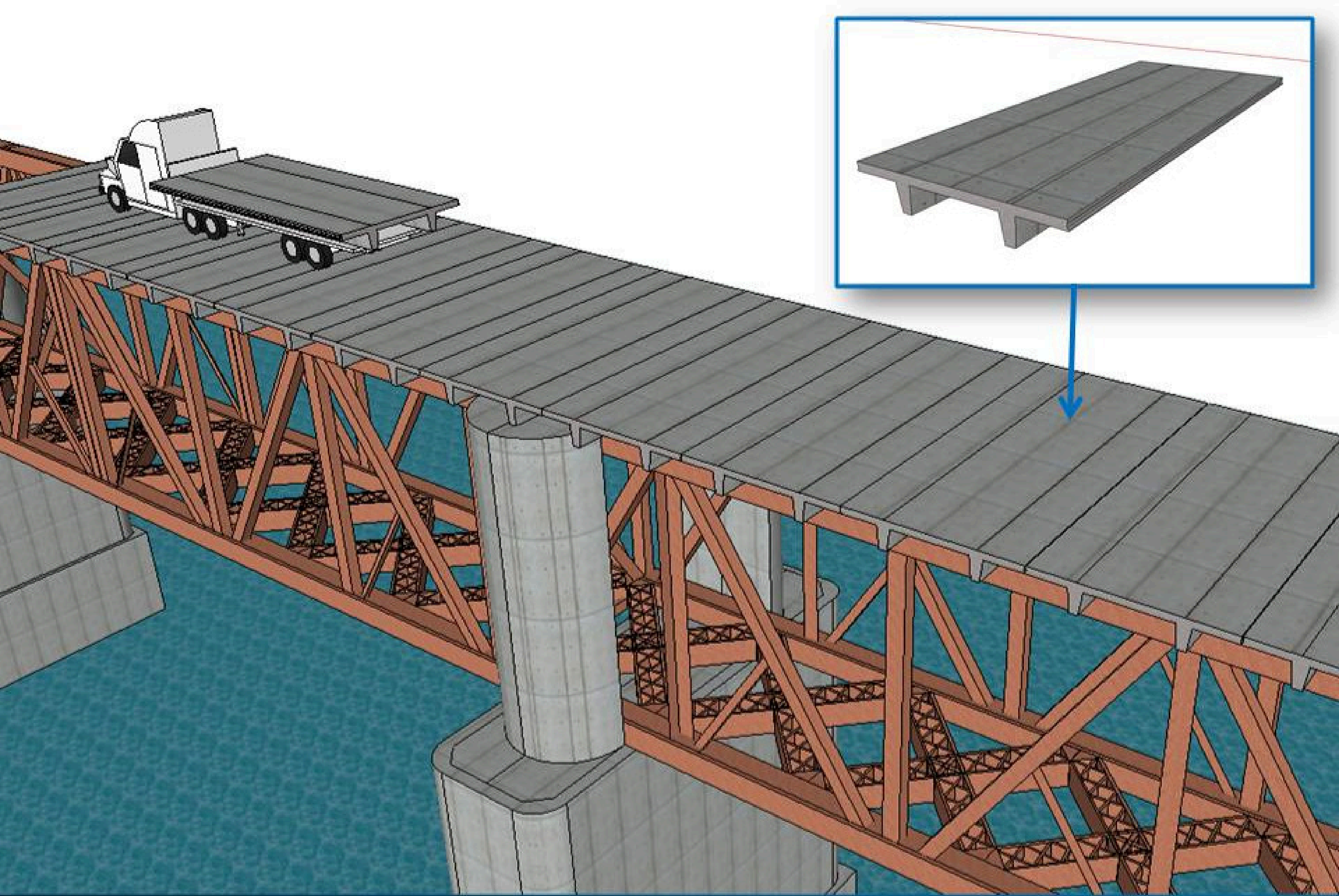

5 – 3D rendering showing the position and orientation of prefabricated concrete panels

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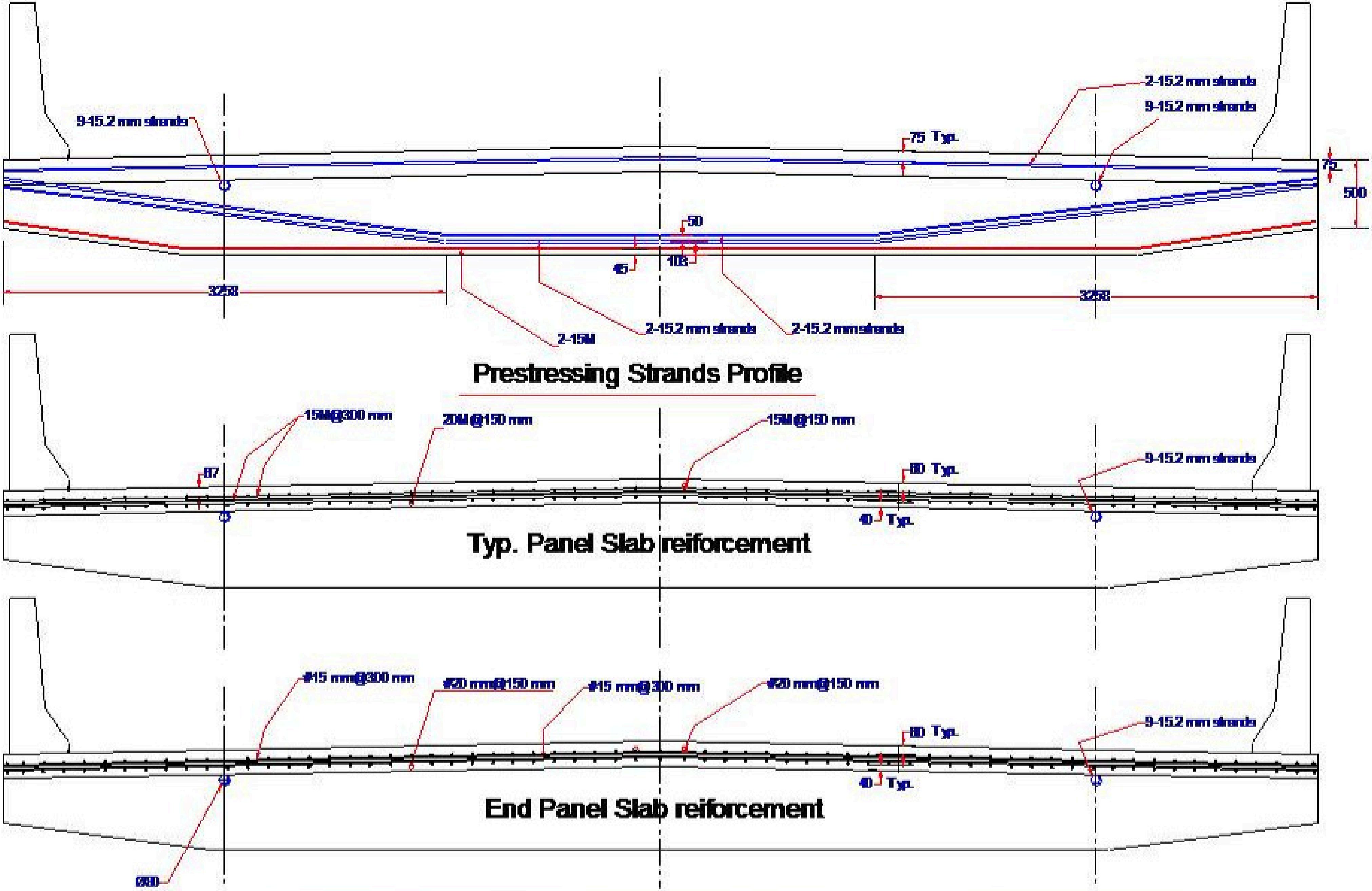


6 – Detailing of prefabricated concrete panels

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7 – Stockpiling of concrete panels

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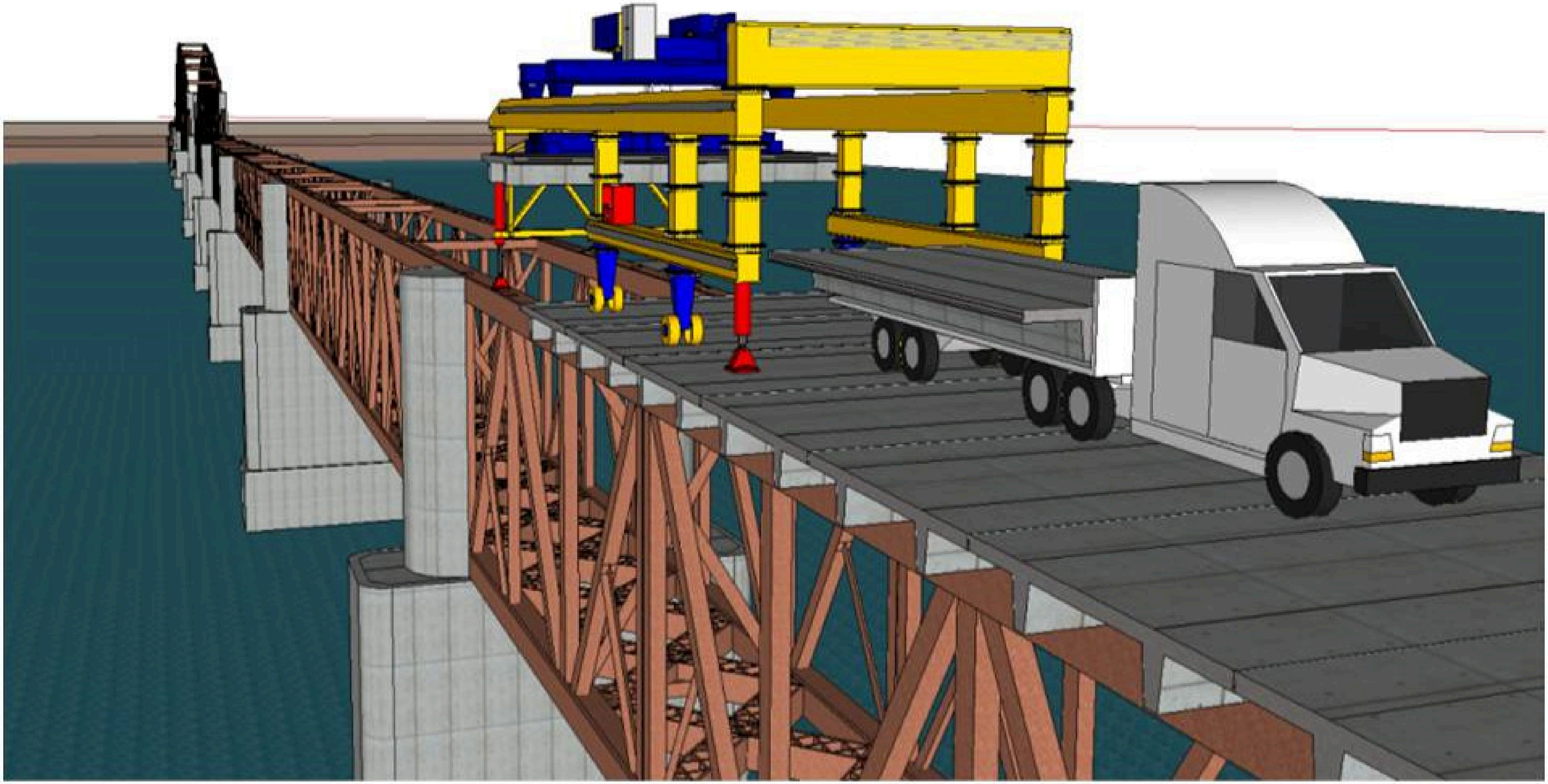
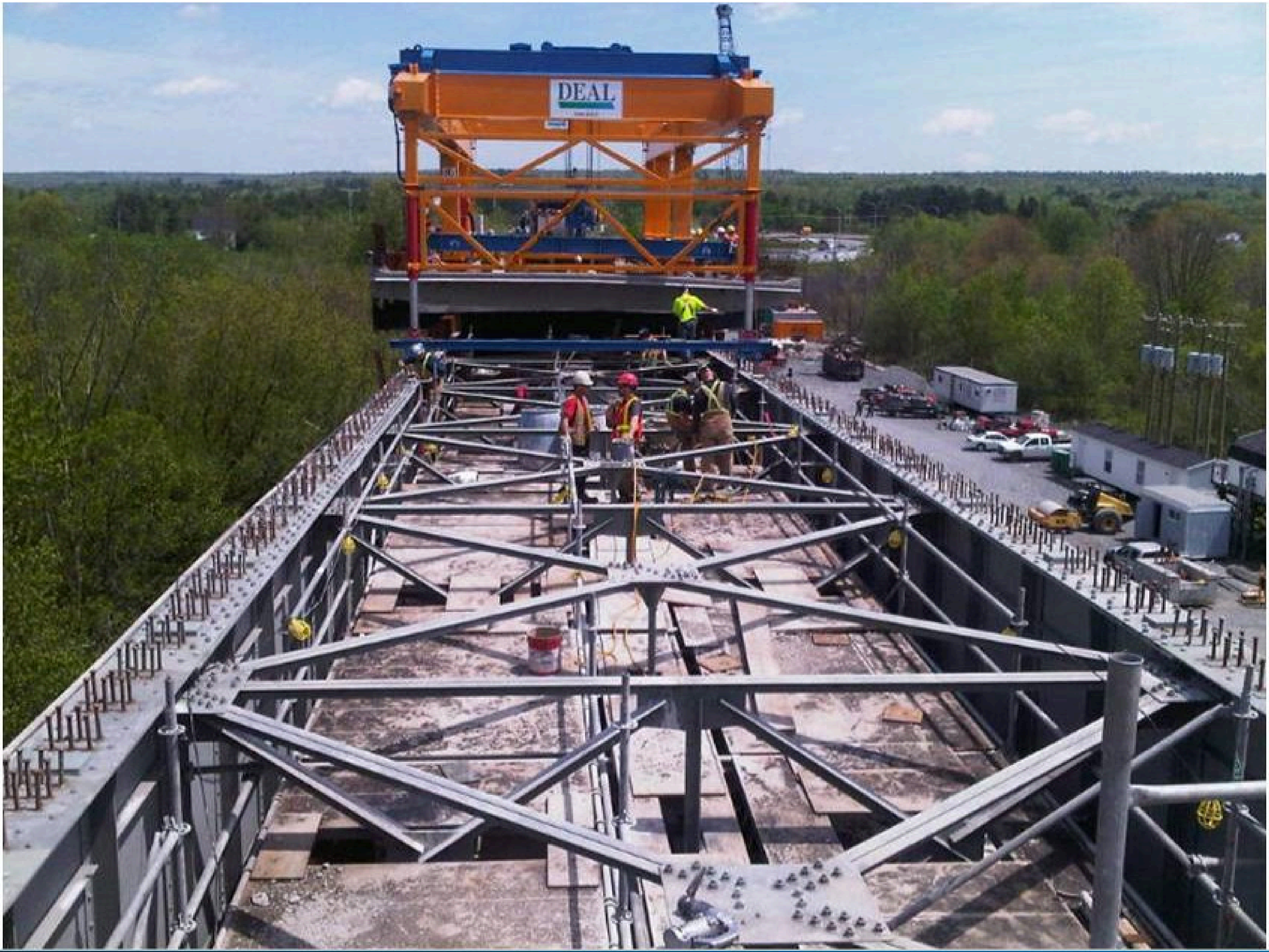


8 – 3D rendering of light-weight lifting equipment




9 – Light-weight lifting equipment

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10 - Installation of panels using light-weight lifting equipment

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11 – Deck panel geometry

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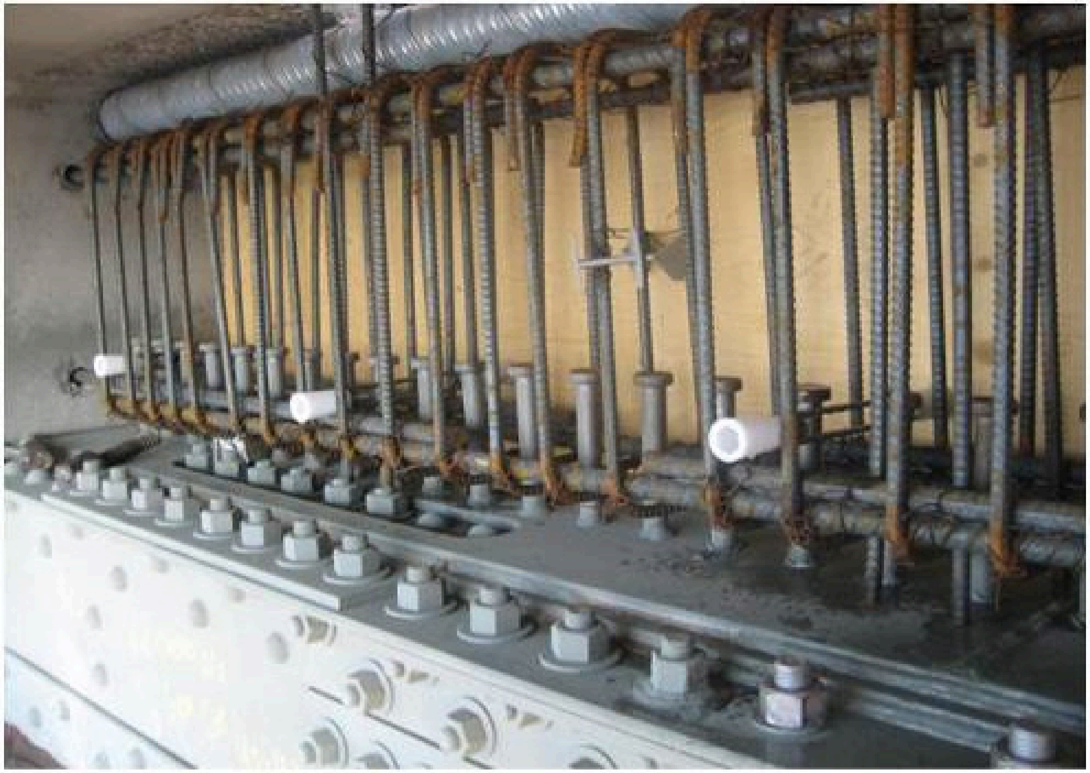

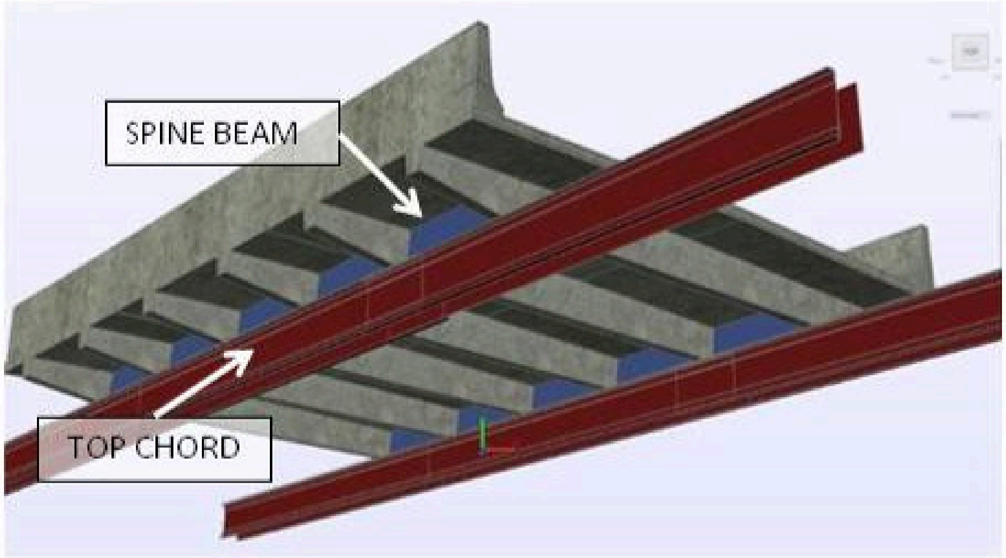


12 – Spine beam details located between the truss top chord and the concrete panels

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13 – Post-tensioning system

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14 – « Flying » concrete mixer truck used to overcome accessibility issues

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15 – Temporary shelter and thriving wildlife on the St. John River

Installation of the shelter limited environmental impact of construction activities

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16 – Prefabrication and installation of bent caps

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17 – Removal of deteriorated concrete at piers

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18 - Installation of stainless steel reinforcement at piers

19 – General view of the Princess Margaret Bridge at re-opening

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20 – General view of the steel trusses at project completion
The walkway and the steel structure were reinforced and repainted

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