Deconstruction of the original Champlain bridge

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Paper prepared for the Structures Session
2024 Transportation Association of Canada (TAC) Conference & Exhibition
Vancouver, British Columbia

Acknowledgements

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Nouvel Horizon St-Laurent (NHSL)
TYLin International

Abstract

Built in 1962, the original Champlain Bridge was a vital economic link for Canada-US trade, and one of Canada's busiest bridges with approximately 50 million vehicle crossings per year. This bridge, spanning a total length of 3.4 km, comprised prestressed concrete girders and decks at the approach spans and steel trusses over the seaway. The extensive use of de-icing salts combined with a sharp increase in traffic volume accelerated the degradation of the bridge over time and led to the end of its service life in 2019. In that same year, Jacques Cartier and Champlain Bridges Incorporated (JCCBI) proceeded with the deconstruction of the bridge and awarded the project to the Nouvel Horizon St-Laurent (NHSL) Consortium, of which AtkinsRéalis and TYLin were responsible for the engineering component. The project had a $400-million budget and the deconstruction of the bridge started in 2020 and was successfully completed in 2023.

The deconstruction of the original Champlain bridge was a high-profile project that is located in a densely urbanized area and crosses a very sensitive ecosystem. Consequently, a sustainability approach was fully integrated into the project with many constraints. There were substantial risks with the deconstruction works due to the deteriorated condition of the bridge and the substantial amount of rehabilitation works that were performed on the structure over the years.

All of these aspects were considered in the design of the deconstruction by using an innovative approach in which the different components of the bridge were carefully dismantled to minimize the impact on the environment and promote the reuse of the materials. Comprehensive work methods were developed and were as follows:

- Deck jacking from a catamaran barge: the deck was jacked up on lifting towers that were installed on a barge and transported to land for dismantlement;
- Controlled girder drop on the jetty: each girder was demolished at a specific predetermined location until it broke and then fell off;
- Lowering of the suspended span sections on a barge using strand jacks: the suspended span was cut and lowered to a barge by strand jacks;
- Reverse construction of the steel spans: the steel spans were dismantled piece by piece with a crane.

As a result, 250,000 tonnes of concrete and 25,000 tonnes of steel were revalorized, the impact of the project on the surrounding environment was significantly minimized, and no issues relating to structural integrity were encountered throughout the entire deconstruction phase.

Introduction and background

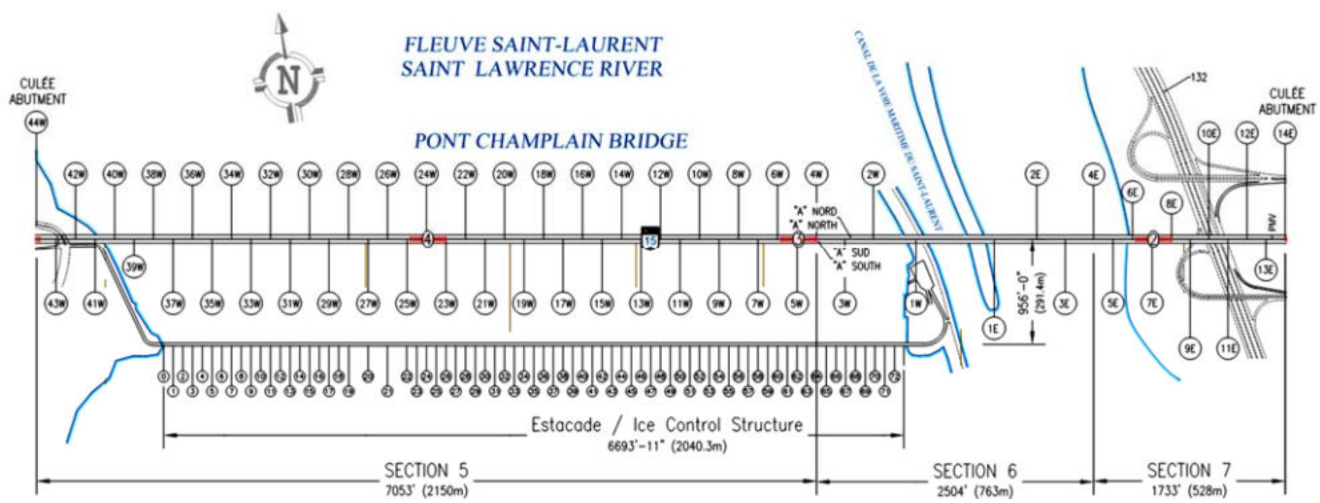
Description of the Existing Bridge Structure

Built in 1962, the 3.4 km Champlain Bridge was a steel truss cantilever bridge with two concrete approach spans consisting of precast prestressed concrete girders that supported a transversely prestressed concrete deck. The structure comprised 56 piers. Prior to its closure in 2019, the bridge connected the city of Montreal to the South Shore crossing the Saint Lawrence River and was one of the busiest bridges in Canada with 50 million vehicles passing annually and allowed for $20-billion worth of trade per year between Canada and the US.

The bridge had a length of 3441 m from one abutment to the other. The bridge was divided into 3 sections as illustrated in Figure 1:

- Section 5: Between the axes 44W and 4W (40 spans)
- Section 6: Between the axes 4W and 4E (7 spans)
- Section 7: Between the axes 4E and 14E (10 spans)

Figure 1. Original Champlain Bridge sections

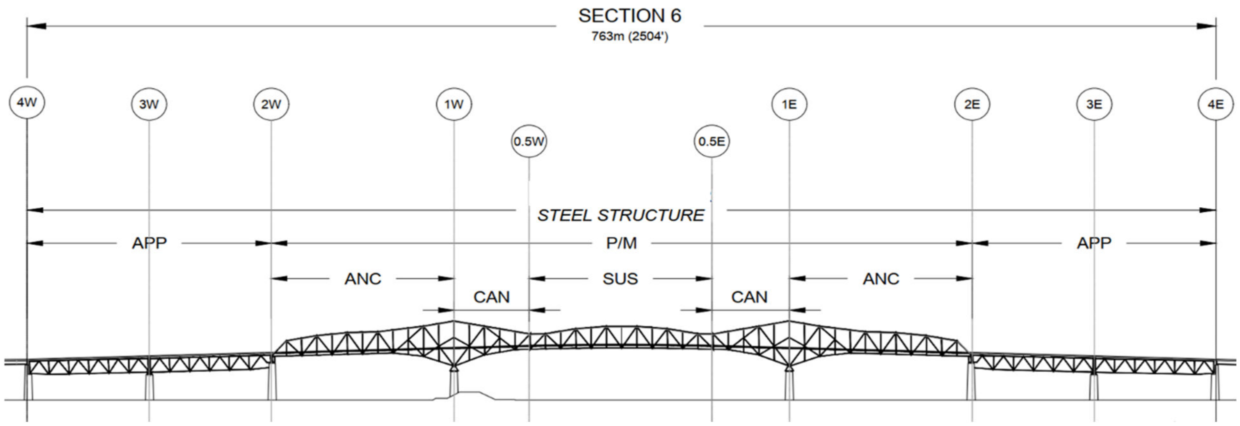


Source: The Jacques Cartier and Champlain Bridges Incorporated (JCCBI)[1]

The superstructure in Sections 5 and 7 consisted of prestressed concrete girders with slab segments between them. The substructure was composed of hammerhead piers sitting on single columns. The columns were based on footings that were supported on bedrock.

Section 6 consisted of three types of steel superstructures: two approaches and one main span consisting of anchor spans and a suspended center span. The steel superstructure rested on reinforced concrete piers. Section 6 of the bridge is shown in Figure 2.

Figure 2. Section 6 of the original Champlain Bridge



Source: JCCBI[1]

Legend:

- APP: Approach spans (4W-2W & 2E-4E)
- P/M: Main span (2W-2E)
- ANC: Anchor spans (2W-1W & 1E-2E)
- CAN: Cantilever spans (1W-0.5W & 0.5E-1E)
- SUS: Suspended spans (0.5W-0.5E)

Background of the project

Montreal's climate is cold and windy in the winter leading to ice buildup on roads, necessitating the use of de-icing salt on bridges to ensure user safety. The bridge was salted for many years to prevent the accumulation of ice on the roadway. In contrast, Montreal's summer is hot and warm which markedly differs from its winter conditions. This notable temperature variation exposed the bridge to freeze-thaw cycles, resulting in concrete degradation and the formation of cracks in its elements. These cracks let the water mixed with de-icing salt penetrate inside the concrete and damage the reinforcing rebars and tendons in girders, piers, piles and other parts of the bridge.

Several mitigation measures were deployed by Jacques-Cartier and Champlain Bridges Incorporated (JCCBI) throughout the years:

- 1989: Replacement of the concrete deck with an orthotropic deck for the steel truss portions of the bridge
- 2011: Announcement that the Champlain bridge will be replaced by a new one
- 2013: During an inspection in November 2013, a crack was discovered in a critical part of the superstructure. A temporary external beam of 75 tons was urgently installed to reinforce the structure as shown in Figure 3. In June 2014, the beam was replaced by a modular truss.

Figure 3. Installation of the temporary external beam reinforcement in 2013

Source: The Jacques Cartier and Champlain Bridges Incorporated (JCCBI)[1]

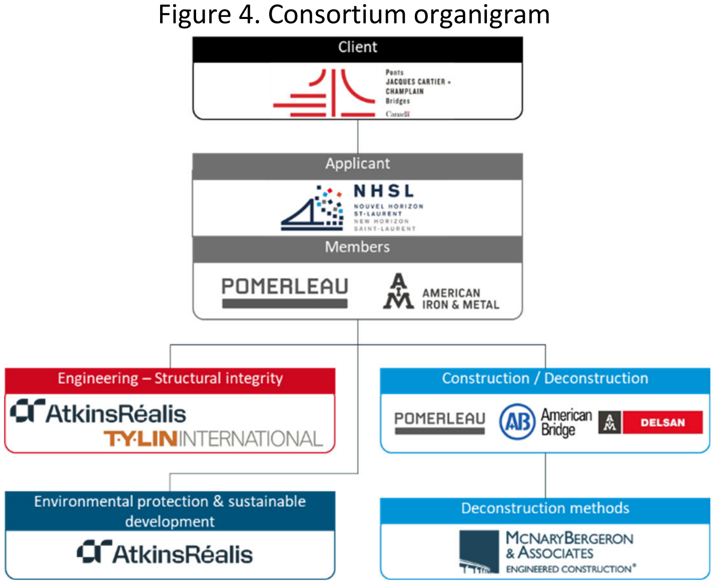
- 2014 to 2018: The modular truss reinforcement was applied to all 100 prestressed concrete edge girders.
- 2019: The traffic was transferred to the new Samuel-de-Champlain Bridge and the Champlain Bridge Deconstruction project was launched.

Project scope

The deconstruction of the original Champlain Bridge was awarded to the Nouvel Horizon Saint-Laurent (NHSL) consortium which consisted of Pomerleau and Delsan-AIM. The scope of the project consisted of deconstructing of the bridge in accordance with a sustainability approach. The goal of the project was to preserve as many structural elements as possible during the deconstruction of the bridge for JCCBI to reuse and revalorize the materials. The deconstruction work also had to respect the highest standard in terms of impact on the environment and stakeholders. In addition to the bridge deconstruction, NHSL also had the task to extract specific structural elements from the bridge to be used as specimens for research projects.

The engineering consortium selected by the contractor to evaluate the structural integrity of the Champlain Bridge during deconstruction operations consisted of AtkinsRéalis (formerly SNC-Lavalin) and TYLin International as shown in the organigram on Figure 4. The engineering consortium was also responsible for the structural maintenance of the bridge throughout the deconstruction process.

Figure 4. Consortium organigram



Constraints

Environmental constraints

The project was located within the fragile natural ecosystem of the Saint-Lawrence River, which is the habitat of certain fish species with special status such as the lake sturgeon, the American shad, the American eel and the stripped bass. The original Champlain Bridge was also the habitat of about 400 cliff swallows. Therefore, careful attention to the environmental impact of the deconstruction had to be integrated in the development and verification of the deconstruction methods.

Stakeholders constraints

The project was situated in a critical sector of the metropolitan region of Montreal, where minimizing road closures for surrounding roads and highways was essential.

One of the road traffic constraints arose from certain spans of the Champlain Bridge positioned above the QC-132 highway. The QC-132 highway is a major provincial highway that is very important for the south shore of Montreal. The deconstruction methods had to include special measures to prevent any prolonged closure.

The seaway is a very important link for the economy, facilitating the transit of a significant volume of merchandise through the port of Montreal. Therefore, it was essential to ensure that the deconstruction methods did not disrupt maritime traffic in the seaway.

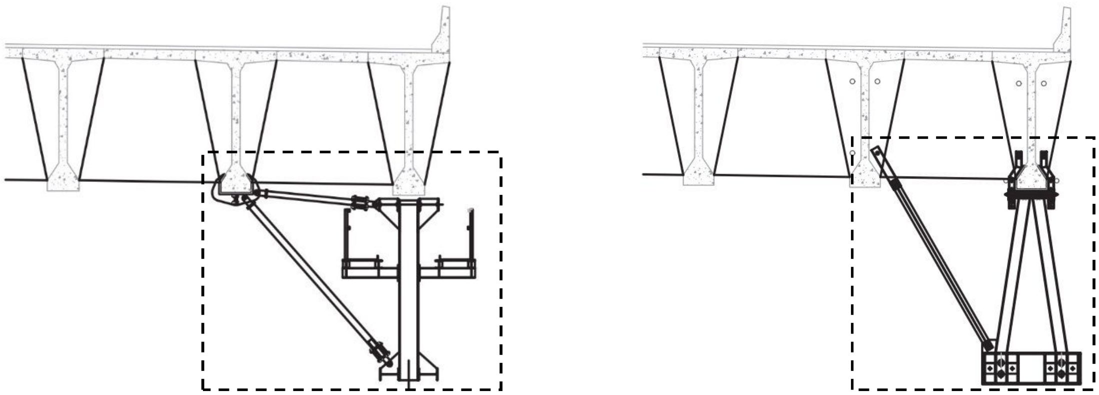
Existing condition of the bridge constraints

As mentioned previously, the original Champlain Bridge was in a deteriorated state when the deconstruction started. Many structural elements of the bridge had reached the end of their service life due to the use of de-icing salt. In order to perform the structural verifications for the structural maintenance plan and different deconstruction methods, it was crucial to determine the residual capacity of each structural element. This presented a complex challenge for elements that were hidden, as they could not be easily inspected to evaluate their level of deterioration. Certain elements such as prestressing tendons in the girders and the slab required destructive testing methods to assess their condition.

Another constraint in the project, related to the existing condition of the bridge, was the addition of many strengthening structural reinforcements over the years. The various strengthening methods described in the project background section had to be considered in the sequencing of methods and in the structural calculations. This constraint added a layer of complexity to the structural verifications.

External post-tension (PTE) was used to enhance the flexural resistance of the girders. The Queen-Post (QP), the Modular Truss (TM), and the Auxiliary Steel Girder (PA) helped support the girder self-weight and additional loads. The Steel Post Shoring (ETM) was utilized to prevent any sudden or major failure of the girder by reducing the forces caused by those loads. Figure 5 illustrates some of the reinforcement systems implemented on the concrete girders of the bridge at the time.

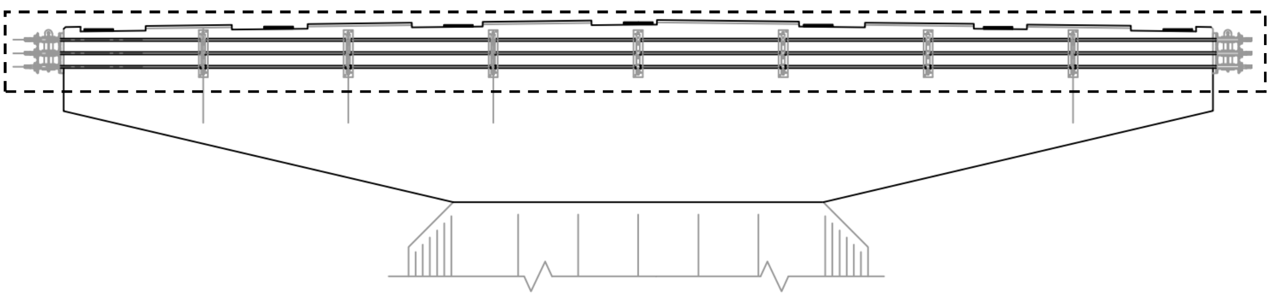
Figure 5. Example of superstructure reinforcement on the original Champlain bridge



Modular Truss (TM) Queen-Post (QP)

Internal and external post-tensioning was used on the piers to improve the flexural resistance of the pier caps and the super-post was used to reduce the demand on the pier cap. The external post-tension reinforcement is shown on Figure 6.

Figure 6. Example of pier-cap external post-tension reinforcement on the original Champlain bridge



Design criteria

The structural integrity of the structure for the deconstruction was verified according to the Canadian Bridge Code (S6-19)[2,3]. Since the Code is adapted for the construction of new bridges, many of the clauses had to be modified to adapt them to the context of the deconstruction. Additionally, other references were used for the project, including AASHTO standard[4], the Canadian Foundation Manual[5], British Standards[6] and the Canadian Building Code[7]. The loads and the load cases differed from the standard due to the presence of heavy equipment circulating on the bridge for operation and maintenance of the bridge during demolition. For example, one of the deconstruction stages required a self-propelled modular transporter (SPMT) to transport a temporary super truss reinforcement for installation. The combined weight of both elements had an important impact on the bridge and its effect was evaluated.

The resistance of the structural elements was determined according to CSA S6-19 and complemented with references from other sources including various Canadian standards (CSA)[8,9,10], AASHTO standards[4], British standards[6] and Federal Highway Association (FHWA) manuals[11,12].

A particular aspect of the project was that structural verifications focused exclusively on the deconstruction operations and maintenance of the bridge during the demolition timeframe. Consequently, there was no need to verify the long-term effects of the loads. For example, no fatigue check was required for the structural elements. Furthermore, since only the short-term resistance of the bridge was assessed, the resistance factors were adjusted as the structure was not required to last the 75 years specified in the Code for new bridges.

Structural maintenance plan

When the project started, the responsibility of the original Champlain Bridge was transferred to NHSL. The consortium was then responsible for the bridge stability during the whole length of the deconstruction. This included the spans being demolished as well as the other spans, including those with significant deficiencies. A structural maintenance plan was developed by the engineering team to ensure the safety of the bridge during the deconstruction.

The structural maintenance plan included three parts:

- A survey program;
- A monitoring program;
- An intervention plan including the impact of the work on the structures and the mitigation measures to these impacts.

The first element was the survey program. To confirm the provided information and manage the risk of error or ongoing deterioration, an immediate visual inspection was performed, augmented by destructive testing, starting with all red-flagged girders, and a sampling of the orange-flagged girders. Red-flagging indicated the member was unsafe under its self-weight upon removing part or all of the external reinforcement. Orange-flagging indicated potential unsafety under certain loadings, requiring a condition assessment. Inspection access was facilitated by man lifts from jetties or land, or top of the deck inspection vehicle. Red- and Orange-flagged girder designations were determined through a rating evaluation that was performed based on the existing field inspection reports provided by the owner of the bridge, JCCBI. The rating was performed according to the recommendations from different manuals such as the one from the Ministry of Transportation of Quebec[13] and the one from AASHTO[14].

The second element was the monitoring program which aimed to observe and track the progression of degradation identified in the initial survey program. This was done through different methods depending on the structural element being monitored:

- Prestressed girders: Survey of the vertical deflection at the ends and center of the girders;
- Steel truss: Measurement of the strain in the members using strain gauges;
- Concrete pier caps: Survey of the vertical deflection of pier caps.

The different measures were then correlated with degradation levels and risks for the structure. NHSL's strategy included actions required prior to the critical level of sudden failure. Three levels of damage were developed: alert, action and alarm. Mitigation measures were developed for each structural element and for each level of damage.

The third element was the intervention plan, which included a communication component and an implementation component of the mitigation measures planned and defined according to the monitoring program. The communication protocol and the prescribed attenuation were activated promptly upon reaching any alarm level.

An example of an intervention plan for the concrete is shown on the table below:

Table 1 :Extract from the Intervention plan

	Criteria for evaluation of approach girders		Required Implementation	
	Deflection	Midspan Tendon Strain	Frequency of measurement and analysis of data	Action if level is reached
Initial condition	Deflection > 1/1200 of span		Every three months	
Alert	Deflection > 1/500 of span	25% plastic strain	Monthly	• Perform visual inspections of the full girder to determine damage status. • Increase the frequency of data analysis
Action	Deflection > 1/300 of span	50% plastic strain	Weekly	• Visual Inspections by Structural Eng. and Deconstruction Eng. • Setting up preventive measures to return to acceptable criteria • Review necessary measures (install super-truss) determined jointly by both Structural Eng. and Deconstruction Eng.

Deconstruction methods

The deconstruction methods developed by NHSL had to be adapted depending on the span having to be demolished to accommodate the different constraints and to ensure the safety[15]. The main deconstruction methods used on the project are the following:

- Deconstruction from a platform on a catamaran barge
- Lowering and dismantling of the suspended steel span
- Reverse construction of the steel spans
- Traditional mechanical demolition of the span and piers

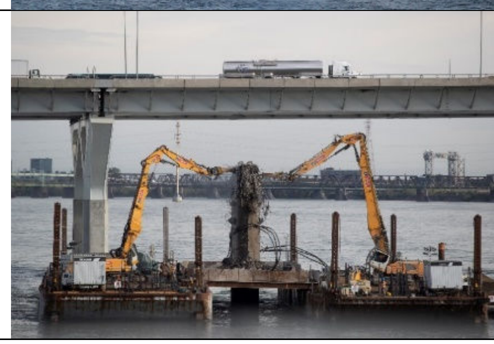
<u>Jacking of the span from a platform on a catamaran barge</u>

The environmental constraints related to the flow of the Saint-Lawrence River did not allow for the construction of a cofferdam spanning from one side of the bridge to the other. Because of this limitation, the deconstruction had to be performed from barges. To minimize the risks associated with deconstruction, facilitate the operations, and limit the potential debris dropped in the river, a particular method was developed to respect all constraints. This method involved the following steps:

- Remove the structural reinforcements on the girders
- Perform jacking of the spans
- Transport the spans away from the piers
- Lower the spans and demolish them directly on barges.

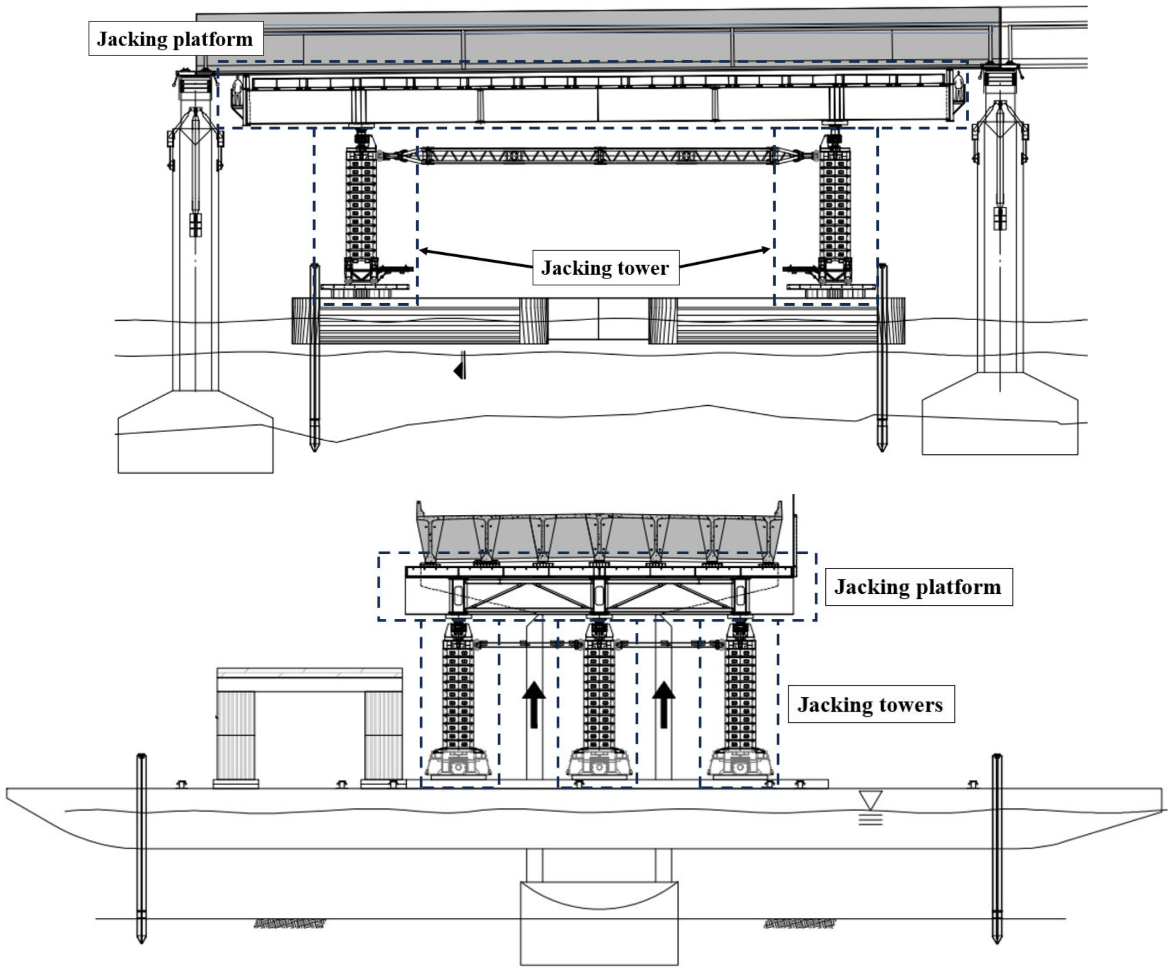
This process allowed for better control of the demolition since it was carried out from a lower height than if it was still sitting on the piers. This method was made possible using a special catamaran barge specifically designed for the project. The piers were then mechanically demolished using excavators installed on barges. The method is shown on Figure 7.

Figure 7. Description of the jacking of the span method of deconstruction

1. Jacking and transportation of the span	
2. Demolition of the span on the barge-catamaran	
3. Demolition of the piers on barges	

Additional structural complexity for this method came from the verification of the resistance of the girders during jacking of the span. Jacking was performed from a platform supported on jacking towers to ensure the stability of the deck during span lowering as shown in Figure 8.

Figure 8. Plan of the platform and jacking towers for the deconstruction



The towers were located at approximately 11 m from the end of the girders. This introduced negative bending moments on the cantilever portions of the girders. This demand was not accounted for in the original design of the girders, as they were supported at their ends during construction and in service. Therefore, a special analysis was performed to evaluate the resistance of the girders for this load effect, to optimize the location of the jacking towers, and to calculate the capacity needed for the jacking towers.

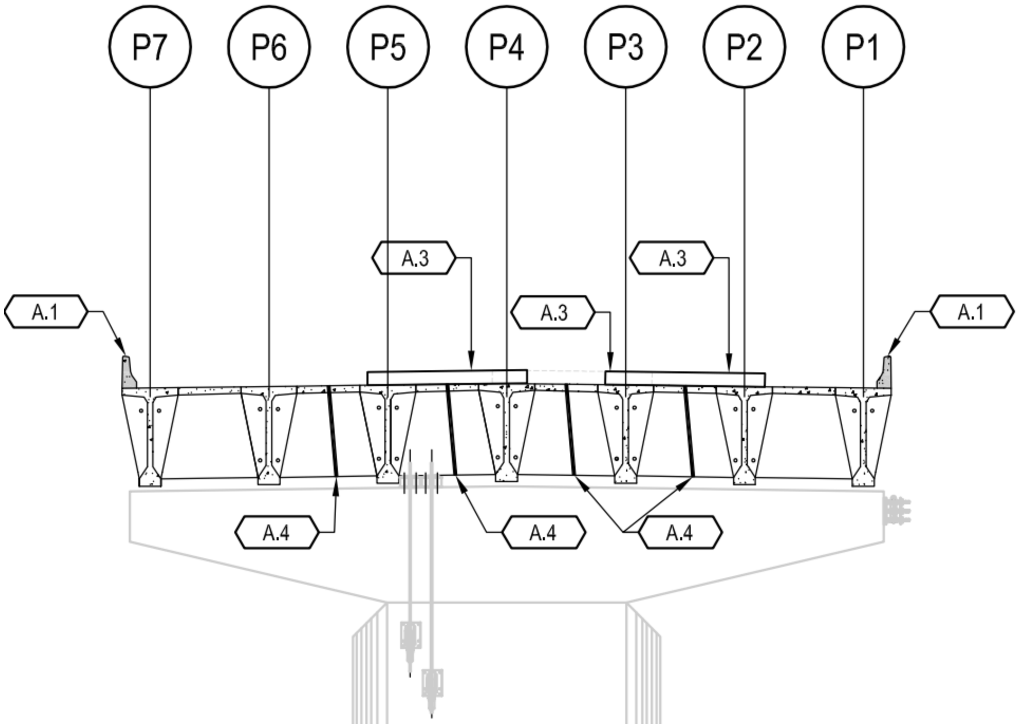
Controlled drop of the deck

This method was applied for the spans over the jetty on the south shore side of the bridge which was the Section 7 of the bridge. Due to the height of the piers which could go up to 24.8 m, a controlled-drop method was chosen for these spans. The method involves the following steps:

1. Remove external reinforcement on the deck
2. Install temporary support for the pier-cap and mechanical demolition of the jerseys
3. Cut the girders at the temporary restraint support locations and install the temporary lateral restraint support.
4. Cut the deck and diaphragms longitudinally between each girder from P3 to P5
5. Perform a controlled drop of P6 and P7 simultaneously and proceed with the cleaning afterwards.
6. Perform a controlled drop of each girder: P5 to P3, and proceed with the cleaning after each controlled drop.
7. Perform a controlled drop of P1 and P2 simultaneously and proceed with the cleaning afterwards.

A summary of the method is shown on Figure 9.

Figure 9. Summary of method D



Legend

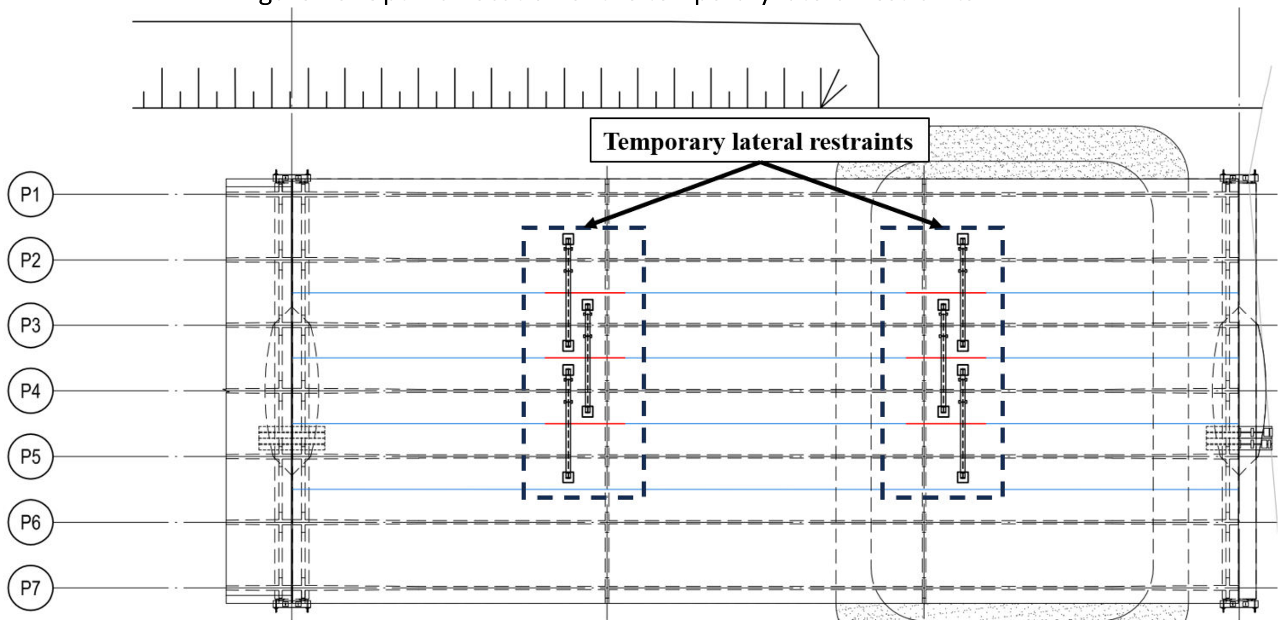
- A.1: Mechanical demolition of the jerseys
- A.2: Local sawing of the girders
- A.3: Installation of the temporary lateral restraint support
- A.4: Sawing of the remaining slab and diaphragm

One main challenge of this method arose from the cutting of the deck and diaphragm longitudinally between the girders at step A.4. This action removed the lateral restraint provided by the deck and diaphragm, posing a concern for the lateral stability of the girders.

One critical aspect involved the girder rollover at the support, as the girders became free to rotate over the supports after being cut. Additionally, lateral torsion of the girders was a significant concern, as cutting the diaphragms which provide lateral support increased the girder's buckling length. A solution was needed to provide lateral support to the girder without hindering its demolition. The goal of this solution was to stabilize the girder before it was dropped while allowing it to fall when it is demolished. A solution was developed and the girder’s stability was verified according to the FHWA recommandations[11]. The implemented solution was a custom temporary lateral restraint that would allow the girder to fall during the controlled drop.

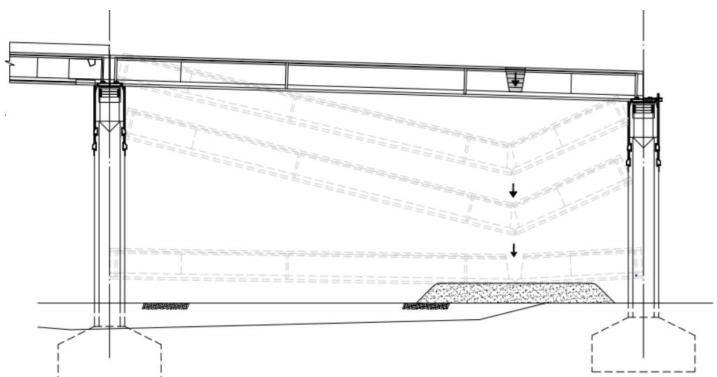
An analysis was performed to optimize the number and placement of temporary restraints to allow the girder to fall while providing enough support to the girders to resist the rollover effect and lateral torsion. An optimization was also necessary to avoid overstressing the temporary restraints. Figure 10 shows the location of the temporary restraints on the span:

Figure 10. Optimal location of the temporary lateral restraints



Another main challenge of this method was the resistance of the piers when the girders were being dropped. The method involved cutting the girder at approximately one third of the span so that when it fell, it would break into two pieces, with one part hitting the piers. Analysis and simulations were performed to determine the most probable fall trajectory resulting in the most critical forces on the piers. The projected trajectory of the girder's fall is shown in Figure 11.

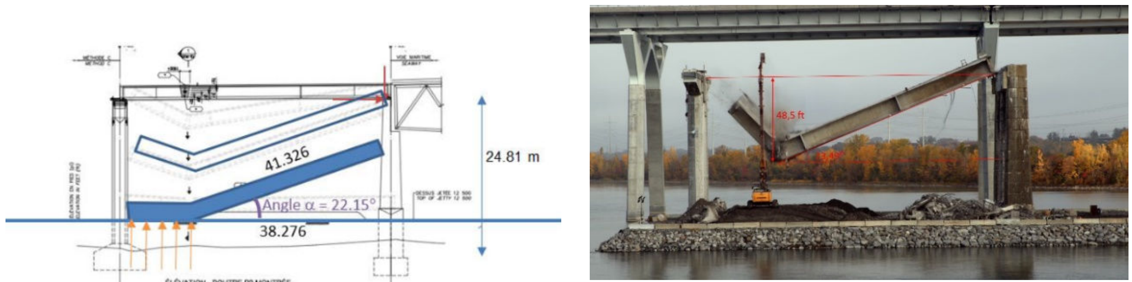
Figure 11. Projected trajectory of the girders controlled drop



The piers were originally not designed to resist the full impact force generated by the falling girder sections, resulting in a demand that greatly exceeded their capacity. Mitigation measures had to be put in place to reduce the kinetic energy generated from the fall of the girders on the piers. Key factors influencing the impact force included the weight of the falling element and the speed and acceleration at which it hit the pier, which is dependent on the height of the fall. To effectively reduce the impact force, mitigation measures had to address these elements. The first measure was to optimize the location where the girder was cut allowing to reduce the weight hitting the pier. The second measure was to put in place an embankment under the location where the girder falls. The embankment height was adapted to required height of the fall for each span. This allowed to greatly reduce the height of the fall of the girder thus reducing the speed and acceleration at which it hits the pier.

These measures successfully mitigated the impact force on the piers and the deconstruction of those span proceeded as planned and designed. The Figure 12 illustrates the comparison between the simulation of the method during the design phase and the actual method on site.

Figure 12. Comparison between the simulation and the actual deconstruction of the controlled drop of the girders



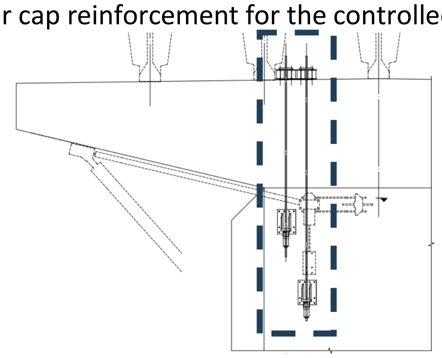
(Credit NHSL)

Simulation | During construction

As depicted in Figure 12, the simulation accurately predicted the manner in which the girder would fall, validating the structural analysis conducted.

The sequence of deconstruction of the deck had an important effect on the stability of the pier cap. Since the girders were not removed at the same time, the loading on the piercap became asymmetric transversally and this created additional flexural demands on the pier cap. The spans on each side of the piercap were also not removed simultaneously. This created torsion on the pier cap. Both the additional flexure and torsion induced by the deconstruction sequence caused instability on the pier caps. A mitigation solution had to be designed to strengthen the pier cap against these forces. To maintain the stability of the pier cap during deconstruction, four externals prestressed Dywidag threadbars were installed on the pier cap. The Dywidag threadbars were held down on top of the pier cap with external beams. At the pier shaft, they were tied down with a steel assembly anchored to the shaft with chemical anchors. The detail of the reinforcement is shown on Figure 13.

Figure 13. Pier cap reinforcement for the controlled drop method

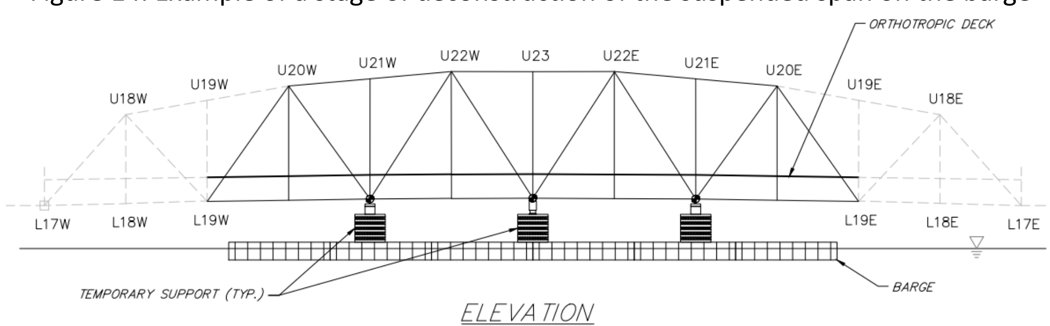


Lowering of the suspended span with strand jacks

Due to the strategic importance of the Saint-Lawrence River, the method of deconstruction for the suspended span over the navigation channel needed to minimize any maritime traffic closures. To respect this constraint, the selected method was to lower the suspended span onto a barge with strand jacks, followed by the demolition of the suspended span while it remained on the barge. Lowering of the suspended span was also done during the winter seaway closure to eliminate any need to close the seaway. The main deconstruction steps were as follows:

- Stage 1
  - Remove the wearing surface from the bridge to reduce its weight.
  - Remove the shear connectors coupling the orthotropic deck to the truss. Leaving them in place could lead to the accumulation of forces during subsequent deconstruction, making removal more difficult.
  - Strengthen the connections of some of the members framing into the "knuckle" joints at the piers so that they can carry tension into the knuckle and strengthen some bridge members.
  - Install a strand jack system on top of the trusses. This will be used to lower the suspended span.
- Stage 2
  - Engage the strand jack lowering system;
  - Disengage bottom chord members and upper chord members on each side of the suspended span. Also, disengage the wind tongues that transfer lateral loads from the suspended span to the cantilever arms by cutting the gusset plates located on the floorbeam.
  - Disengage the vertical members at the jacking point and lower the suspended span to the float-out barge.
- Stage 3
  - Deconstruct the suspended span while supported on the barge. An example of a stage of deconstruction of the span on the barge is shown on Figure 14 where the members being removed are shown in dashed lines.

Figure 14. Example of a stage of deconstruction of the suspended span on the barge



Modeling challenges and solutions for the suspended span deconstruction

The main challenge was to model the structure across its various deconstruction stages, as the forces in the members varied significantly depending on the configuration of the suspended span. To address this, a staged-construction model was developed using the CSiBridge software for structural analysis. The number of different built-up members with their different level of degradation, including section losses, was a significant challenge for modelling the structure. The final model is illustrated in Figure 15 and Figure 16.

Figure 15. Global structural analysis model for the lowering of the suspended span

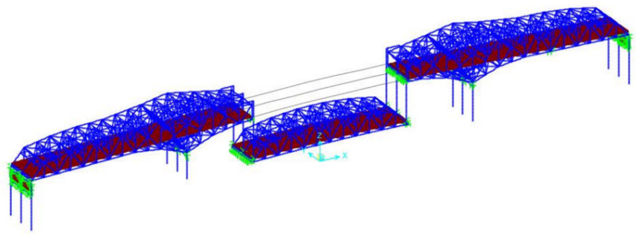
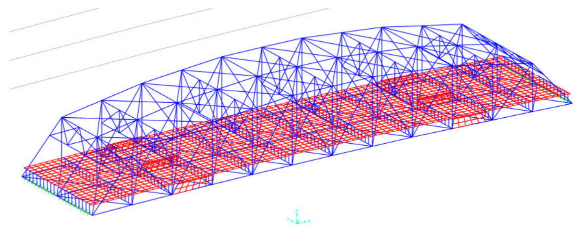
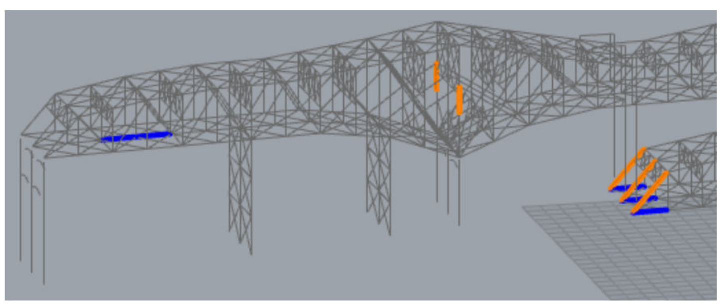


Figure 16. Local structural analysis model for the deconstruction of the suspended span on the barge

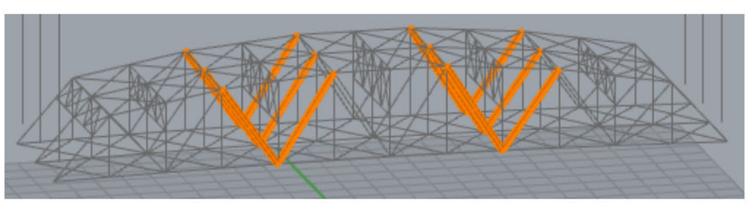


The model was used to calculate the forces acting on the strands and strand jacks since the strand jacks and the supporting framework had to resist to both the weight of the suspended span being lowered and the wind loads during the process. Additionally, the model was used to identify the members and connections that would be overstressed during the lowering or deconstruction of the suspended span on the barge. These members and connections were reinforced with additionnal steel plates bolted onto them according to FHWA recommandations[12]. Figure 17 illustrates an example of critical members identified through structural analysis.

Figure 17. Critical members to strengthen before the deconstruction work



Critical members during the lowering of the span



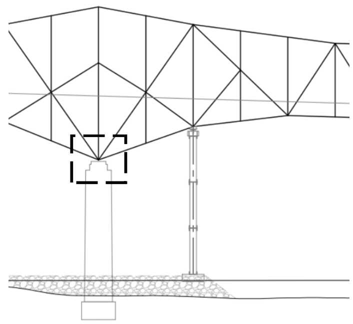
Critical members during the deconstruction on the barge

The overstress on the critical members during the deconstruction on the barge arose from the concentrated reactions at the panel point where the span was supported on the barge.

Knuckle joint challenges and proposed solution

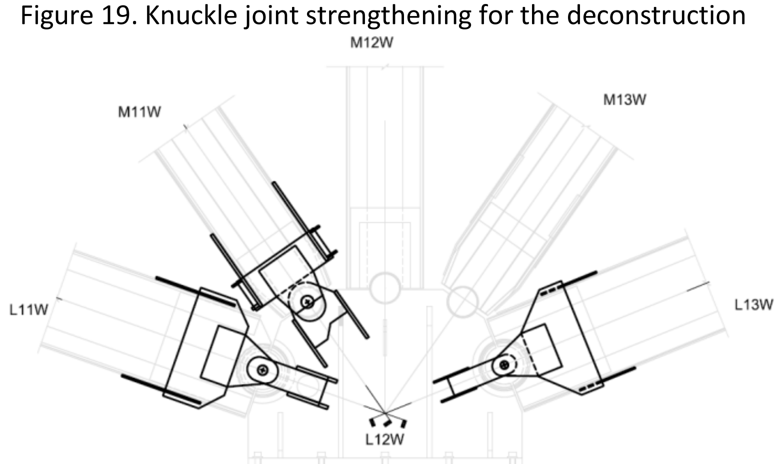
A critical element for the lowering of the span was the knuckle joint connecting the truss to the piers. Two chord members, two diagonals, and a vertical connect into the joint were each bearing on a pin supported on the knuckle as shown in Figure 18.

Figure 18. Knuckle joint on the original Champlain Bridge



These members were all in compression during normal operation of the structure and were unable to carry any tensile force. However, some of these members were subject to tensile forces during the deconstruction process. Therefore, it was necessary to supplement the existing connections and directly connect the members across the pins to the knuckle to resist these tensile forces. Strengthening of the knuckle connection was proposed to increase its tension capacity during the deconstruction process. The aim of the reinforcement was to minimally impact the existing structural elements and behavior of the knuckle. A pinned connection centered in the existing bearing pins was designed to ensure that the rotation center of the structure remained unaffected. The strengthening method is shown in Figure 19.

Figure 19. Knuckle joint strengthening for the deconstruction



Results

The lowering of the suspended span and its deconstruction on the barge were successful with the implementation of the proposed measures and strengthening approach. The on-site result of the deconstruction method is shown in Figure 20.

Figure 20. On-site photo of the lowering of the span

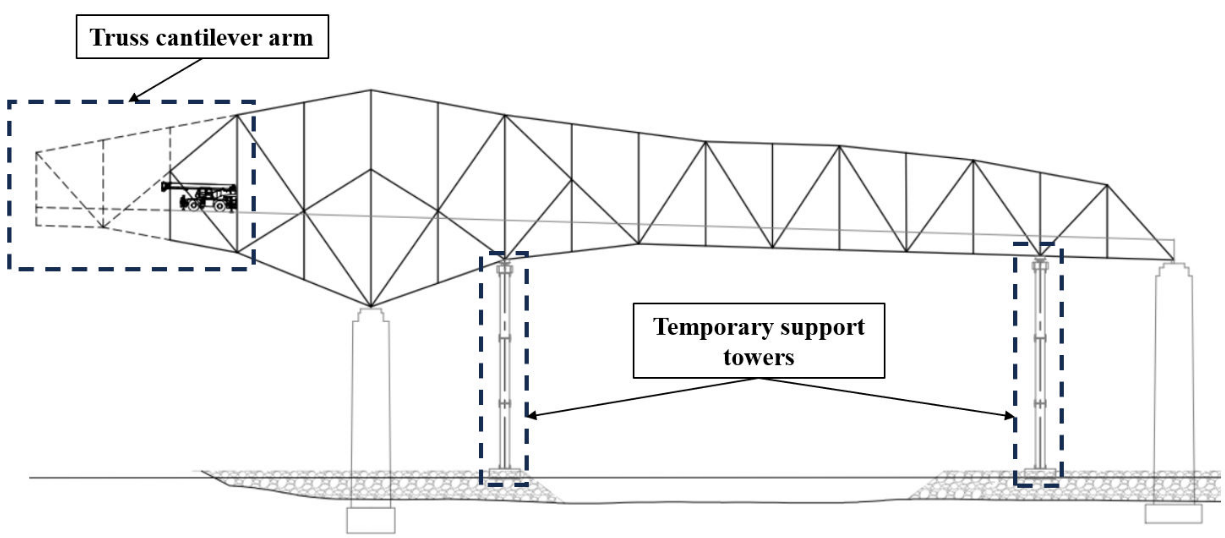
Reverse construction of the cantilever section and anchor spans

The cantilever arms and anchor spans of the Section 6 of the Champlain bridge were deconstructed following a method resembling a reverse construction. However, due to constraints on jetty construction, it was not possible to deconstruct the bridge by reversing its original construction sequence. An adapted sequence had to be developed specifically for the project to remove the trusses with the limited available space. Thus, a detailed analysis was made of the deconstruction sequence.

The main steps of the deconstruction were:

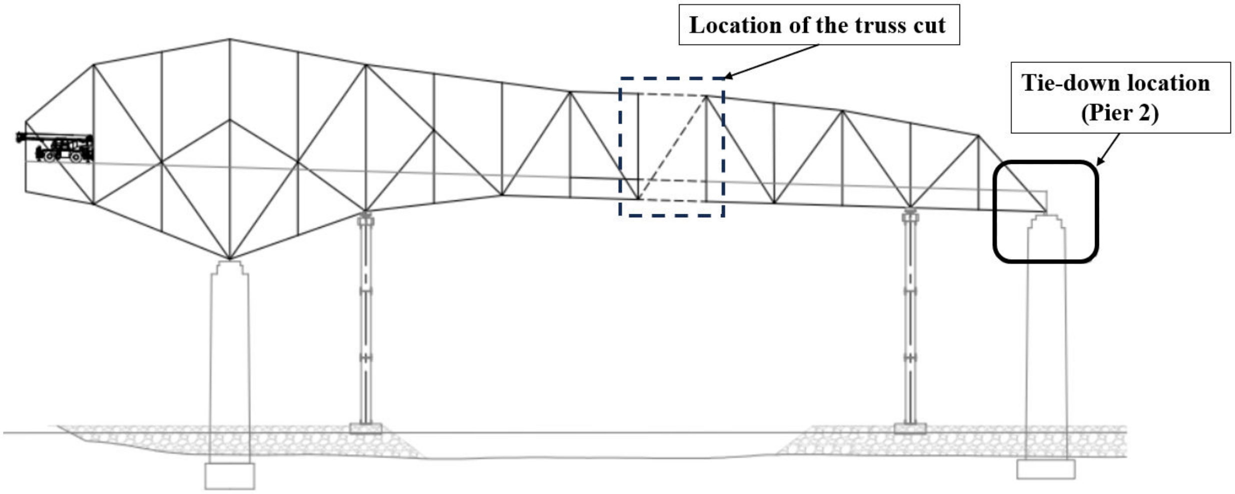
- Strengthen the critical members that will be overloaded during the deconstruction.
- Install the temporary towers to support the anchor span and cantilever arm.
- Use a deck crane to deconstruct the cantilever arm as illustrated in Figure 21 where the dashed lines represent the members being removed.

Figure 21. Deconstruction of the cantilever arm



- Cut the top chords, diagonals at a specific location, install tie-downs and horizontal restraints at Pier 2 and cut the bottom chords at the same specific location as shown in Figure 22.

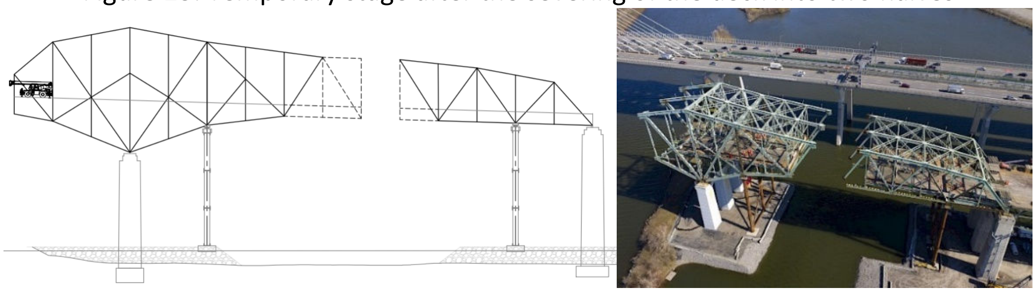
Figure 22. Pier 2 vertical and horizontal restraints



The bridge was now separated into two independent halves. Each of the half was supported on a pier and a temporary support tower.

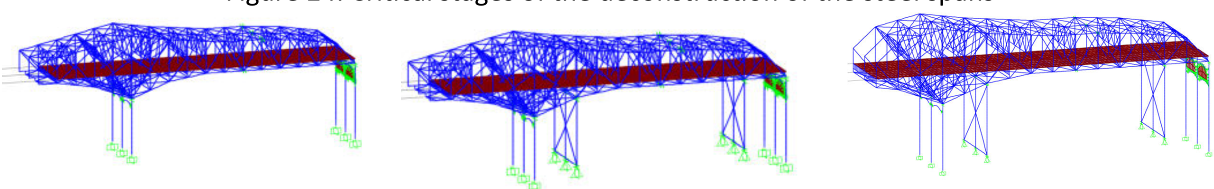
- Jack the bridge up from the temporary towers and adjusting the supports to compensate for the differential settlement.
- Progressively deconstruct the remaining halves of the bridge. An example of one stage is shown in Figure 23.

Figure 23. Temporary stage after the severing of the deck into two halves



Since it was not possible to deconstruct the bridge by reversing its original construction sequence, the new sequence induced new forces in the members for which they were not designed for originally. A global model integrating all the different construction stages was developed. Some stages of the model are shown in Figure 24.

Figure 24. Critical stages of the deconstruction of the steel spans



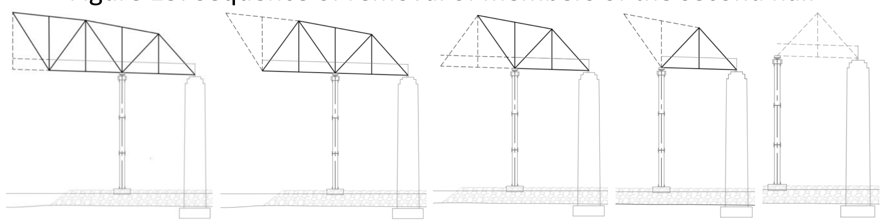
At the start of the deconstruction	Installation of the temporary support towers	Deconstruction of the cantilever arm

Following the detailed structural analysis, it was found that some members became overloaded during certain steps of the new sequence. The overloaded members were reinforced before starting the deconstruction process.

One of the features of the proposed method was the separation of the span into two halves to accommodate the site constraint for the temporary jetties. This allowed the deconstruction of the steel trusses with a crane installed on the jetties on either side of the span. In order to maintain the stability of the structure after the span separation, tie-downs, longitudinal and transverse restraints were installed at the end of the truss at pier 2. These elements counteracted the cantilever effect from the half of the span that was supported on pier 2 and a temporary tower.

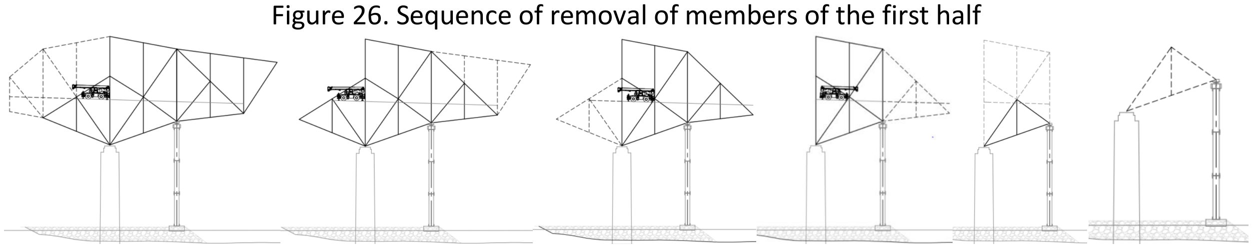
The sequence of deconstruction for the half supported on pier 2 is shown on Figure 25.

Figure 25. Sequence of removal of members of the second half



The distinctive feature of the half supported by pier 1 was related to its sequence of the deconstruction. The removal sequence of the members had to minimize the asymmetry of the truss on either side of the pier and the temporary tower to reduce moment and the uplift at the pier. The sequence is shown on Figure 26.

Figure 26. Sequence of removal of members of the first half



Traditional mechanical demolition of the span and piers

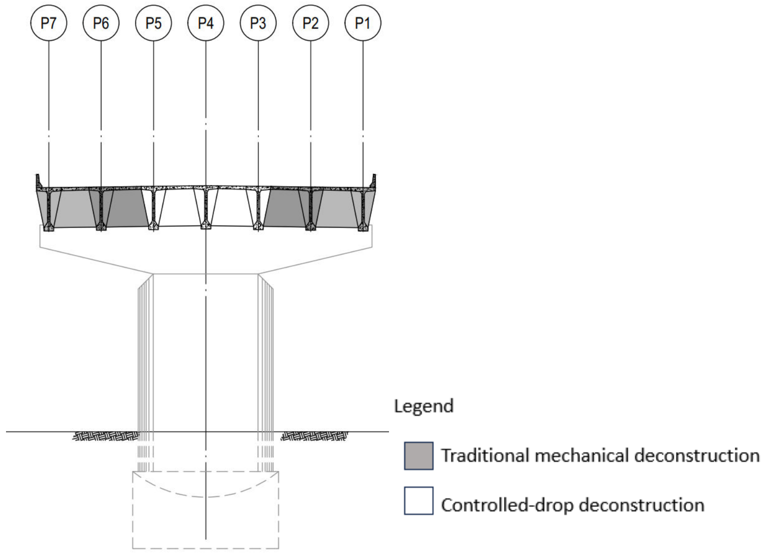
The method used for the deconstruction of the spans and piers on the portion of the Section 5 of the bridge located on the jetty was the traditional mechanical demolition. This method was selected since there was no specific restriction at this location. Figure 27 illustrates the traditional mechanical demolition of the span and piers at the deconstruction site.

Figure 27. Pictures of the traditional mechanical demolition of the spans and piers

Combination of the methods for the highway 132 deconstruction

The method used for the deconstruction of the spans over highway 132 in Section 7 of the bridge was a combination of traditional mechanical demolition for the edge girders (P1, P2, P6 and P7) and a controlled drop for the girders in the middle (P3 to P5). This is shown in Figure 28.

Figure 28. Combination of deconstruction methods for the spans over the highway 132

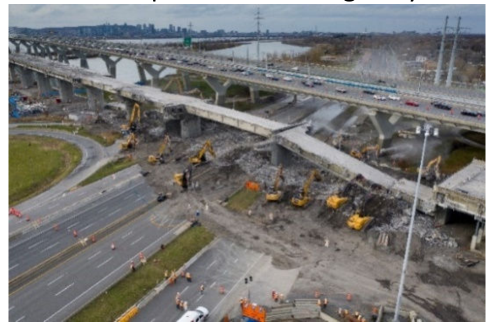


Unlike the controlled drop method used for the other spans of Section 7, the girders were not longitudinally cut before being dropped ensuring no issue with their lateral stability. Additionally, due to the lower height of fall for the girders, no additional measures were required to protect the piers from impact.

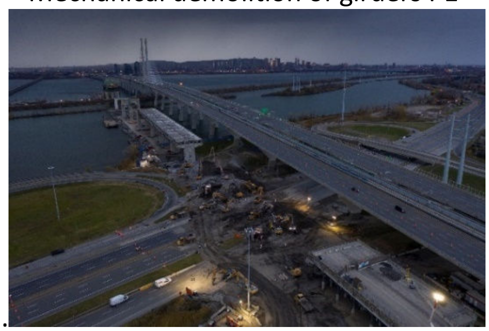
One major challenge was the fact that highway R132 is a major road with strategic importance for the Montreal region. Any road closure or interruption on highway 132 had to be minimized. This created a time constraint for both the deconstruction of the spans above highway 132 and the reopening of the highway 132 afterwards. In order to minimize the time between the deconstruction and the reopening of the road, it was decided to protect highway R132 and the public utilities before starting any controlled drop of the girders. The protection system's role was to reduce the impact of the falling girders on the highway. This protection system was composed of uncompacted backfill which helped preserve the road and utilities. As a result, the road could be reopened after only cleaning up the debris. Figure 29 shows the whole process of the method used for the spans over highway R132.

Figure 29. Pictures of the stages for the deconstruction of the spans over the highway 132

Mechanical demolition of girders P1



Controlled drop of P3 to P5



Cleaning up the debris from the deconstruction

Cleaning up the highway for the reopening

Conclusion

The deconstruction of the original Champlain bridge was a high-profile project where a sustainable approach was integrated due to the different constraints including the ones regarding the environment and the stakeholders. Instead of a traditional demolition, the bridge was carefully dismantled to minimize the impact on the environment and promote the reuse of the materials. However, this approach brought many technical challenges, particularly because of the deteriorated existing condition of the bridge. To overcome these challenges, the following innovative methods were developed and thoroughly analyzed:

- Jacking of the spans from a platform on a catamaran barge;
- Controlled drop of the deck;
- Lowering of the suspended spans with strand jacks;
- Modified reverse construction of the cantilever and anchor span of the truss section;
- Combination of traditional mechanical demolition and controlled drop for the spans over the highway R132.

The deconstruction of the original Champlain bridge allowed to revalorize 250,000 tonnes of concrete, 25,000 tonnes of steel and 12,000 tonnes of asphalt. The impact of the project on the surrounding environment was also significantly minimized. Due to the implementation of different structural mitigation measures and a robust structural maintenance plan, no issues relating to structural integrity were encountered throughout the entire deconstruction phase. The deconstruction of the original Champlain bridge was successfully completed within the initial budget and two months ahead of schedule. The lessons learned through the challenges encountered for each of the deconstruction method will inform and improve the process of future deconstruction projects.

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