THE INCREMENTAL LAUNCHING OF BEAUHARNOIS BRIDGE

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ABSTRACT

With a total length of 2551 m, the bridge over the Beauharnois Canal is the main structure of the Nouvelle Autoroute 30 project in Montreal (Canada). It crosses the Beauharnois canal and the St-Laurent Seaway, which is the only waterway communication between the Great Lakes of North America and the Atlantic Sea. This crossing of 150 m has governed the design and construction of this project.

The article starts with a brief introduction to the incremental launching technique to allow the reader to understand the basic concepts of this method. Then, in the main content of the article, the key facts of the design and construction of the incremental launching procedure to fabricate and put in place two steel box girders of 1456 m and 7400 t are explained. In an effort to allow the reader to use the experience of this project in the future in similar scenarios, several particularities are explained:

- The technical and administrative constrains to cross the Saint Laurent Seaway.
- Equipment used during the launch of the typical spans (82 m).
- The requirements to be able to launch the box girders over the main span of 150 m.
- The procedure to make the launch feasible with a parabolic curve in the bridge elevation.
- Description of the assembling process at the launching yard.
- The particularities to use the incremental launching techniques in cold weather.
- The use of hybrid mechanical joints mixing welding and bolting.
- The control of monitoring methods of the launching.

The last part of the article is reserved to present some of the main conclusions and lessons learned of these engineering works along all the process.

INTRODUCTION TO LAUNCHED BRIDGES

Figure 1: Crossing of the main Span
Incremental Launching (IL) is often seen as an alternative to other methods to erect bridge decks, but any construction team that has worked with this method realizes that it’s more than that: in a world where industrialized construction means reduced cost, incremental launching is the key to success when the adequate conditions are met.

The increase of labour cost is governing the choices to be taken when planning a bridge construction. When the length of a bridge has a strong impact on its budget, labour cost will exceed those of material and industrialization will be a requirement. On the other hand the investment required to achieve it must be contained, and this is when incremental launching is a field that has been progressing with each project for the past 50 years.

Incremental launching seeks to industrialize the deck construction at a fixed point (usually at an abutment but not necessary) and mobilize it to put the deck in place as the industrialized construction advances.

The above introduces the main constrains of the method:

1. Geometry constrains of the bridge
2. Designing the deck for the temporary situation of the launch
3. Programing the industrialization at a fixed point.

To better understand how these constraints were exceeded in the Beauharnois Bridge we present them in brief lines. Additional information can be found at reference [1].

Geometry constrains

During the launching, the deck is continuously supported on the launching bearings and transversely guided with lateral guides that keep the deck within the launch path.

If any eccentricity is introduced at the support sections, due to misalignment between the deck geometry and the launching path, secondary stresses will be introduced in the structure. These additional stresses have to be kept low to avoid overdesigning and increasing wear of the sliding areas.

Since the centre of production is fixed at the launching area, another constraint is that the launching path has to be tangential and with a constant curve from this point. Therefore, for a rigid solid deck to be launched, the alignment in plan and/or elevation must be a circular curve or a straight line from the origin of launch.

Design for the launch

When launched, a deck goes through different stages that introduce stresses to the structure which are very different from those during its service life. The key aspects of these temporary stresses are:

- Every section of the bridge is, at a certain moment, a support section under the launching load (mainly the dead load of the deck portion that is launched).
- The leading part of the deck that advances as a cantilever will have the larger forces during the launching.

The design of the launch should seek temporary means to reduce these stresses and to avoid overdesigning the deck due to the temporary stages of the launch.

Some of these temporary elements that allow a reduction of stresses due to the launch are:

- Launching nose which reduces the weight of the leading part of the deck.
- Stayed front system.
- Temporary piers.
• Oversized temporary bearings.

Planning industrialization

When planning how to industrialize a bridge with the IL method, the way to organize the centre of production, the pre-assembling and the final assembling will very different depending the on the following factors:

• Type of structure.
• Available space at the launching area.
• Access to the launching area.
• Cost and quality of the labour work on-site and at the factory.

Once all the information regarding these factors have been collected for the particular case of the bridge, there are some key decisions to be taken to ensure success.

In the case of a composite bridge these key choices will be:

• Segmentation of the girder to be launched: size of segments to be transported and assembled at the launching area.
• Choice of transportation method.
• Type of splices to be assembled on-site.
• Organization of the launching area: space required for intermediate storage, pre-assembling and final assembling and painting.
• Erection equipment for segments.

The main principles to consider from the planning point of view are to keep the field works to the minimum and to organize the planning well in advance.

STRUCTURE DESCRIPTION: TECHNICAL AND ADMINISTRATIVE CONSTRAINTS TO SELECT THE LAUNCHING METHOD

The Beauharnois Bridge has a total length of 2551 m, and it crosses (from east to west) the Beauharnois Canal (BHC) and the Saint Laurent Seaway canal (SLS) with a twin deck.

The SLS is an international navigational infrastructure connecting the Great Lakes of North America with the Atlantic Ocean through the Québec region in Canada. This strategic point governs the conditions under which the bridge has been designed and built.

The bridge length is divided in three parts:

1. Western approach, over land, from west abutment (axis 1) to the transition pier 26.
2. Area of the main span over the SLS between pier 26 and 31.
3. Eastern approach, over the Beauharnois Canal waters, between pier 31 and the east abutment (axis 44).
The design of the bridge carried out by Arup is divided into two different parts: The **East Part** with a length of 1457 m, is divided in 17 typical spans of 81.9 m and 63 m and the main span of 150 m. The 14 m width twin decks are formed by a steel composite box girder.

The **West Part** has 1094 m divided in 25 typical spans of approximately 44.5 m. It is composed of continuous decks with 5 precast concrete beams. (See reference [2] for more information regarding this part)

Initially, the constrains of the contract only left a 3 month winter construction season per year over the navigational channel. Due to this requirement, incremental launching was selected as the most adequate construction method to erect the steel structure over the water.

The launching option allowed progress of the works of both decks without disturbing the traffic of the navigational channel, and to cross with both decks during the winter. The result was a design of the main span launch under winter conditions.

**The Deck**

The east deck is 13.7 m wide and has a composite section with a steel box girder 8.2 m wide, 3.7 m height and inclined webs (1H/5V) which results on a bottom base width of 5.4 m.

The entire length of 1457 m is continuous with no intermediate expansion joints. The box girder was assembled at the east abutment and erected with the launching towards pier 26 located in the west.
The concrete deck is designed with full width precast prestressed slabs. These slabs were all installed after the launching with the exception of those covering the main span over the SLS.

The purpose of the design of the full width precast panels was to maximize the speed of the deck construction right after the launching. With this system, once the slabs were installed, the rest of the deck was cast with rates of 82 m every 3 days per concreting crew.

**The Bridge Geometry**

Beauharnois Bridge’s geometry is not common for launching. The straight alignment in plan is ideal for launching but the vertical alignment is composed of a 3.4% constant slope between abutment 44 (launching point) and pier 34 plus a parabolic curve between pier 34 and pier 26 (transition pier with the west part). Initially this geometry would not be eligible for the launching method.

In order to launch the bridge, the parabolic shape had to be deformed in the first launching stages where the path to follow is a straight line.
This geometry introduced additional complexity to the launching design\(^3\) and to the assembling as described below. To achieve it, the steel box girder was designed with enough flexibility to be able to deform without major stresses.

**LAUNCHING STAGES**

The launching stages had to be chosen taking into account all these constrains to fabricate and assemble the segments at the launching yard.

In this case a typical launching length of 164 m was selected in order to maximize these operations, and also to match the length to be launched over the main span. With this length fixed, the segments were fabricated at the shop in lengths between 18 m and 40.5 m and transported to the bridge by barges.

Based on these dimensions, 10 launched stages were programed:

- **Stages 1 to 7:** Typical launching over two spans of 81.9 m. The first stages were carried out without activating the front stayed system. From stages 4 to 7 this system was used facilitating the pier entry. (see figure 8)

![Figure 7: Typical launching stage](image-url)

- **Stage 8:** A preparation stage before the main span launch. It only had a 60 m length and the precast slabs of the main spans were installed at this stage to reduce the dead load in the previous ones.

![Figure 8: Launching stage 8](image-url)

- **Stage 9:** Crossing of the main span. Due to the location of the temporary bearings, the real length of the launch was 130m, but even with this reduction it is one of the longest spans ever launched.
• **Stage 10: Final launching** to end at the transition pier. To allow the deck to enter this pier, the launching nose had to be disassembled.

Assembling at launching yard

The longitudinal profile of the box girder is divided in 40 segments with lengths that range from 18m to 41.7 m, the weight of the segments vary from 180 t to 240 t.

The assembling was organized in the following areas:

1. Dock for segment reception (segments were transported by barges). This area also included the sheds to fabricate some of the segments on-site.
2. Segment storage area. Segments were mobilized by means of dollies and two overhead gantries of 120 t.
3. Preassembling area, where the segment splices were prepared. This area was prepared to accommodate 1 module of four segments to be able to properly control the bridge’s geometry.
4. Launching area: where the hybrid splices were welded, bolted and painted.
Assembling of the first modules

The assembling of the first two modules was governed by two mayor difficulties:

- It was the leading part of the launching: they were the heaviest and most complex segments since their design was influenced by the main span launch. Also it's where all the temporary elements used for this method were located. The welding hours in the hybrid splices (described below) of the first two modules were the same as in all the other 8 modules.

- The geometry of these modules was parabolic, but had to be assembled in an area with a constant slope (3.4%). To overpass this obstacle, boxes had to be deformed using jacks as the assembling of the module progressed (see figure 13).

Assembling with hybrid mechanical joints

Each pair of segments is joined using a hybrid mechanical joint that combines welding and bolted techniques in the same joint. The top flanges and webs were bolted and the bottom flange was partially welded and bolted.
The reason for this system is to be able to slide the box girder supported on the bottom flange. This 300 mm wide sliding area was required to be continuous all along the entire length of the bridge with no bolts. For this reason the sliding area had to be welded at each mechanical joint. On the other hand, to optimize assembly works, especially during winter, all other parts of the section had to be bolted.

This double constraint introduced a new concept of hybrid joint with two technological obstacles:

1. If welding is done first with no constrains from the bolting, the geometry of the joint could not have been controlled since the weld deformation introduced important variations in the joint angle.
2. If bolting was fixed at the beginning of the operations, the welding introduced important tensions in the nearer bolts that were not considered in the joint design.

The final method statement was sought through a process to fix the geometry with some bolts and pins introduced at the holes surrounding the weld. These pins were removed when the first passes of the weld were done.

LAUNCHING OF TYPICAL SPANS

The typical launching stage covered two spans of 81.2 m and was achieved with the following standard equipment:

1. Two 500 t jacks were used as a pulling force. They were anchored to the abutment through pulling beams.
2. The jacks were connected to the rear of the module with post tension cables, where they were anchored with a pin joint.
3. The module was mobilized at the launching area over skid shoes. They were equipped with jacks that allowed control of reactions at all times. They run over rails with sliding neoprene-teflon pads.
4. Pier temporary bearing: each had 5 sliding neoprene pads to be able to maximize the support area, and to better resist the patch loading in the box girder.
5. Lateral guides: designed not only to guide the bridge during the launch, but also to retain it at parking stages, when maximum wind loads occurred.
6. Launching nose: a 50 t truss, designed to reduce stresses in the box girder and equipped with two 80 t recovery jacks and folding doors for the operation to entry the piers.
When entering the pier, the recovery jacks are placed over the headstock edge, after which the deformation is recovered and the lateral doors of the nose are closed to place them over the temporary bearings. Once the doors are over the bearings, jacks are retracted to support the nose and the launching continues (see stages at figure 16).

**Figure 14: Typical launching equipment**

**Figure 15: Stages of pier entry with nose**

### MAIN SPAN AND FINAL LAUNCH

The principles to launch the deck over the main span are the same, but the forces in all elements are much larger. The challenge is to be able to launch the same box girder over 130 m.

The box girder section was designed to resist the launching forces of the typical span, but it did not have enough rigidity to launch the box girder over the main span. For this reason additional temporary equipment was required:

1. The front stayed tower was used to reduce the stresses in the box girder. This tower also allowed controlling the deflection at the tip of the launching nose. It had a height of 35 m and the stayed area covered a deck length of 320 m. Passive anchors were located at the front and active anchors with two jack units of 500 t at the back.
2. Balanced bearing system: To be able to support the loads at the main piers, it was decided to install 4 temporary bearings with 850 t jacks. Each pair of bearings at each side of the pier, were separated 20 m apart and connected hydraulically. The result was a “swing bearing system” that reduced the effective span to launch to 130 m and allowed equal distribution of the maximum reaction of 21200 kN over the four bearings (see figure 18).

3. The same swing bearing system had to be used in piers 30, 31 and 32 adjacent to the main span (see figures 17 and 21). In this case the system was equipped with 4 temporary bearings with 250 t jacks.

End launch at transition pier 26

The final stage presented as many difficulties as the crossing of the main span.
The first obstacle was the geometry of the final pier 26 where the launch ended (see figure 21). It was required to dismantle the nose at the highest piers of the deck. For this operation a 1000 t crane was used, the biggest crane available in the Quebec province at the time.

During this phase the stayed tower, with its 80 t had to cross the main span. This load produced such deformations in the deck that it was difficult to achieve support on the piers located next to the main span (63 m adjacent spans versus the 150 m of the main one. See figures 2, 11 and 20).

To achieve the support before reaching the ultimate forces of the deck, continuous operations had to be carried out with the stayed system to obtain the desired deck deformation.

Another obstacle was the connection at the transition pier:

The transition between the two different decks was done at pier 26 with a singular pier head that combines the support for both decks at two different levels (see figure 21).

This pier has been designed as a mobile point on the western approach and as a fixed point on the eastern part. This double function is achieved with a seismic retainer that links together the box girder with the pier head. To be able to connect the seismic retainer with the box, the fixed point of the bridge had to be moved from the abutment to the main piers (these operations is explained further below) and then the seismic retainer could be placed.

![Figure 19: Crossing of the main span with the stayed tower](image)

![Figure 20: Entry and fixing pier 26](image)
OTHER SINGULARITIES

Different constrains have introduced other singularities in the launching design and operation:

- Launching monitoring
- Wind tunnel test
- Winter conditions.

Launching monitoring

The complexity of the launch is also reflected in the monitoring system. During launching the following variables were monitored:

<table>
<thead>
<tr>
<th>Variable</th>
<th>System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deflection at the tip of the nose</td>
<td>GPS and Total station (double system)</td>
</tr>
<tr>
<td>Pier displacements</td>
<td>Robotic total station: continuous monitoring with cycles of 30s.</td>
</tr>
<tr>
<td>Displacement at top level of the stayed tower</td>
<td>GPS</td>
</tr>
<tr>
<td>Jacking force</td>
<td>Jack pressure</td>
</tr>
<tr>
<td>Forces at stayed cables</td>
<td>Jack pressure and string gauges in anchorage (double system)</td>
</tr>
<tr>
<td>Skid shoes reactions at launching area</td>
<td>Jack pressure</td>
</tr>
<tr>
<td>Reactions at swing bearing systems (piers 28, 29, 30, 31 &amp; 32)</td>
<td>Jack pressure</td>
</tr>
</tbody>
</table>

Wind tunnel test

Although launching operations are not carried out with wind speeds higher than 30 km/h, the main span had to be studied in the wind tunnel test at the construction stages to discard possible instabilities during the parking stages (once the bridge is in position or if the launched has to be stopped in the middle of the stage).

There were two main concerns regarding the launch that this test clarified: possible instabilities at maximum cantilever, and interaction between decks when one is at its final position and the other is crossing the main span.
Launching in winter conditions

There were many aspects of the launching that could be affected by the winter conditions that could be present in the Montreal area: temperatures below -30 °C, high snow precipitations and ice accretion up to 30 mm.

The following issues had to be evaluated carefully during the launching design and planning phases:

- Snow and ice accretion during the launching (parking and launching stages).
- Performance of hydraulic equipment at low temperature.
- Teflon friction factors at low temperatures.
- Material resilience of critical elements to be able to operate at low temperatures.

CONCLUSION

We would like to conclude the article with some lessons learned in this project:

- When using the incremental launching forward planning and minimizing field works, are key factors to success.
- Geometry control is critical during the pre-assembling, but in this case due to the parabolic curve to be launched, it was crucial.
- Larger spans to be launched mean larger forces. To be able to minimize the impact on the final structure, the design of the temporary elements requires good doses of innovation.
- Innovation in this case meant to be able to use standard elements with non-standard combinations of design and operation.
- Winter conditions introduce additional loads and additional protections to be consider in the design and planning of the launch.

The different construction singularities used to design and operate the launching of the bridge has allowed assembly and installation of 15 500 t and 2914 m of steel deck in 12 months to finish the project on schedule in December 2012.

When winter and technical requirements introduce important constrains to the schedule, industrialized solutions like the incremental launching, has proven to be very successful.
Table 2: Beauharnois Launching in data Block

<table>
<thead>
<tr>
<th>Element</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Owner:</td>
<td>Ministère de Transport du Québec &amp; Nouvell Autorute 30 S.E.N.C (Acciona-Iridium)</td>
</tr>
<tr>
<td>Project Contractor:</td>
<td>Nouvell Autorute 30 CJV (Dragados-Acciona-Aecon-Verrault)</td>
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<td>Bridge designer</td>
<td>Arup HK</td>
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<tr>
<td>Launching designer</td>
<td>Fhechor &amp; Ideam DJV</td>
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<td>Launching operations</td>
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<td>Structural steel</td>
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<td>Welding hours in splices</td>
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<td>Launching stages</td>
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<td>Average speed (of all stages)</td>
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<td>Maximum speed (of one day)</td>
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<tr>
<td>Typical dynamic friction</td>
<td>2-4%</td>
</tr>
</tbody>
</table>

REFERENCES

[1] Bridge Launching – Marco Rosignoli

AUTHOR BIOGRAPHIES

Alejandro Acerete has more than 16 yrs of experience proving his capability to deliver design and construction projects of civil construction structures. Alejandro has successfully led design on the recently completed A30 project in Canada. This project included a number of relevant challenges including the design and construct of the second longest incrementally launched bridge in the world (2.5km).

Javier Ayala has more than 40 yr of experience in bridge design and construction all around the world. His wide professional experience includes the technical leading of the Tink Kao bridge design and construction in Hong Kong.

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