CIMA+
Partners in excellence

# A Bridge Design Rarely Seen in Canada

## 2012 CANADIAN CONSULTING ENGINEERING AWARDS

### Transportation

ARCH BRIDGE
IN STONEHAM, QUEBEC

ASSOCIATION OF CONSULTING ENGINEERING COMPANIES | CANADA
ASSOCIATION DES FIRMES D'INGÉNIEURS-CONSEILS | CANADA

CANADIAN CONSULTING engineer

## The Arch Bridge: A Bridge Design Rarely Seen in Canada

The bridge in question is located in the Stoneham-et-Tewkesbury municipality north of Quebec City and is part of the Highway73/175 project, which includes building a four-lane dual carriageway over 175 km between Quebec City and Saguenay. This project was a significant challenge for CMA+ engineers, who from the onset, realized that Talbot Boulevard would cross the future Highway 73 with a significant bias of 49 degrees. Moreover, and according to the proposed route, engineers also noticed that, while within applicable standards, Highway 73 presented a significant slope and curvature where it would cross Talbot Boulevard.

CIMA+ was extremely proactive in defining this structure. The design team examined the overall project taking into account road geometry, the safety of users and technical difficulties associated with the construction of a pier with a 49-degree bias. A number of concepts were considered throughout the project, including types of bridges uncommon to Canada.

To incorporate all the constraints in an original way, CIMA+ proposed building a through arch bridge, eliminating the construction of a pier in the central median of the highway and avoiding any modifications to the proposed profiles of Highway 73 and Talbot Boulevard due to the shallowness of this type of deck. Through arch bridges are not common in Canada. In Quebec, it will only be the second one of its kind built in the last 50 years, the previous one dating back to the late 60s on Autoroute 15 in the Laurentians.

## Original Solutions

CIMA+ proposed original and audacious solutions to meet challenges it faced. Taking the site's topographical constraints into account, CIMA+ recommended the construction of a through arch bridge with a span of 72 metres and width of 13.4 metres.

CIMA+ designers opted for two parabolic funicular arches; a shape specifically chosen to minimize bending in the arches, the latter designed to work more efficiently when subjected to axial compression forces. The height of each arch is about 14 metres from the deck, and 20 metres from Highway 73. The arch sections varied from 800 x 1200 mm (width x height) at the top to 1500 x 2400 mm at the base. The two arches were fitted at the bottom in a base integrated to the abutments. The base-abutment set was supported in the rock and would resist overturning and sliding induced by the weight and friction of the arches. The overall width of the bridge, including arches and overhangs, is 18.5 meters. The span of the arch bridge from either axis is 68.5 m.

The bridge deck was suspended at every two arches with 34 steel cables 48 mm in diameter. The cables were attached to each arch with anchor plates embedded in concrete. On the deck, the cables were attached to the overhang extremities of the cross beams forming the deck. It should be noted that the cross beams are the backbone of the main deck, unlike conventional bridges where this role is played by the longitudinal beams.

The designers favoured monolithic arches to eliminate joints that can cause, as any break in a concrete element would, a decrease in the structure's durability. A comprehensive study of volumetric changes in the arches, due to shrinkage and creep of concrete as well as thermal shifts and gradients, was required to verify and monitor their cracking. This study revealed the need to apply a bending and compression at the base of the arches in order to control cracking on the upper surface. To that effect, a novel solution was proposed by the lead CIMA+ designer. This solution was to apply a lateral load at the top of each arch by building them in semi-arches. The load applied aimed to induce sufficient bending and compression in the parts of the arches most likely to crack under certain loads such as thermal loads in winter. Thus, it was identified in the plans and specifications to stop the construction of the arches and leave an opening of 1.5 meters at the top of each one. A jack was installed there to open the arches; the two semi-arches were then spread apart by a few millimetres before the 1.5-metre opening was filled with concrete.

We should also emphasize that the geometry of the arches was optimized to minimize flexion induced by volumetric loads and deformations of the concrete. It was, however, impossible to completely eliminate bending caused by imposed loads and deformations. The main effects the arches are submitted to are shrinkage, creep, thermal shifts, loads from the deck ties, seismic loads and actual weight of the arches. A parabolic funicular shape was used as it minimizes bending from gravity loads.

The lateral stability of the arches was closely scrutinized. Wind and seismic loads were meticulously analyzed. In fact, the seismic analysis also considered the use of the bridge as an "emergency-route" bridge.

**Ingredients for Success**

In June 2011, CIMA+ delivered a through arch bridge with reinforced concrete deck that overlaps the future Highway 73, with total respect for the schedule and budget. This structure is currently in use and all inspections it has undergone since its opening, including the first general inspection conducted by the Ministry in June 2011, allowed us to conclude that the structure meets design expectations.

This project is much more complex than it appears. To ensure complete success, CIMA+ was proactively involved in its completion by supervising the construction site and delegating a highly experienced representative. The CIMA+ supervisor's planning for any potential construction problems, especially with regard to the two concrete arches, was at the core of the project's success.

Furthermore, CIMA+ assisted the contractor during each stage of the project, from being on site at the concrete factory to validate work methods and quality, to overseeing each step of the concreting stage. Because of the project's size and complexity, the supervision team and contractor had to work in close collaboration. This synergy between all parties assured the Ministry that the finished product would be of the highest quality, corresponding to the designer's vision and the client's needs.

Above all, this project promoted collaboration between experts, enabling a knowledge transfer to take place between designers, architects and construction workers. In addition, the builder’s extensive experience proved invaluable on several occasions. Finally, all the companies supporting the CIMA+ team benefited from the experience. The firm strongly believes that image of the profession has greatly improved in the eyes of Quebecers, strengthening our desire to cultivate excellence within the company.

CIMA+ faced several engineering and construction challenges in this project. We were certain that the road to success meant preserving the interest and motivations of all persons associated with the arch bridge project. We are convinced that we provided our client with the best possible solution. It was another opportunity for the Canadian engineering industry to demonstrate its standard for excellence.

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## 1. PROJECT DETAILS AND ORIGINALITY OF SOLUTIONS

### 1.1 CONTEXT

The construction of the arch bridge located in the Stoneham-et-Tewkesbury municipality is part of the Highway 73/175 project, which includes building a four-lane dual carriageway over 175 km between Quebec City and Saguenay. The purpose of this project is to provide safe travel for users by reducing the risk of accidents and contributing significantly to economic growth in the Saguenay-Lac-Saint-Jean region.

Given the scale of the project, the design work for the highway and structures was divided into different lots by the Ministry of Transport (MTQ). In 2003, the MTQ launched a first series of public call for tenders for professional service mandates that would serve to prepare the plans and specifications for the extension of Highway 73, over a stretch located between kilometres 60 and 94.

It is in response to this public call for tenders for the execution of professional services that CIMA+ prepared and submitted a premium quality bid book to the MTQ, presenting the firm's experience in bridges, the project manager's skills and the expertise of the selected team to successfully carry out the proposed mandate. The bid book presented provided CIMA+ with first place among the series of mandates awarded by the MTQ.

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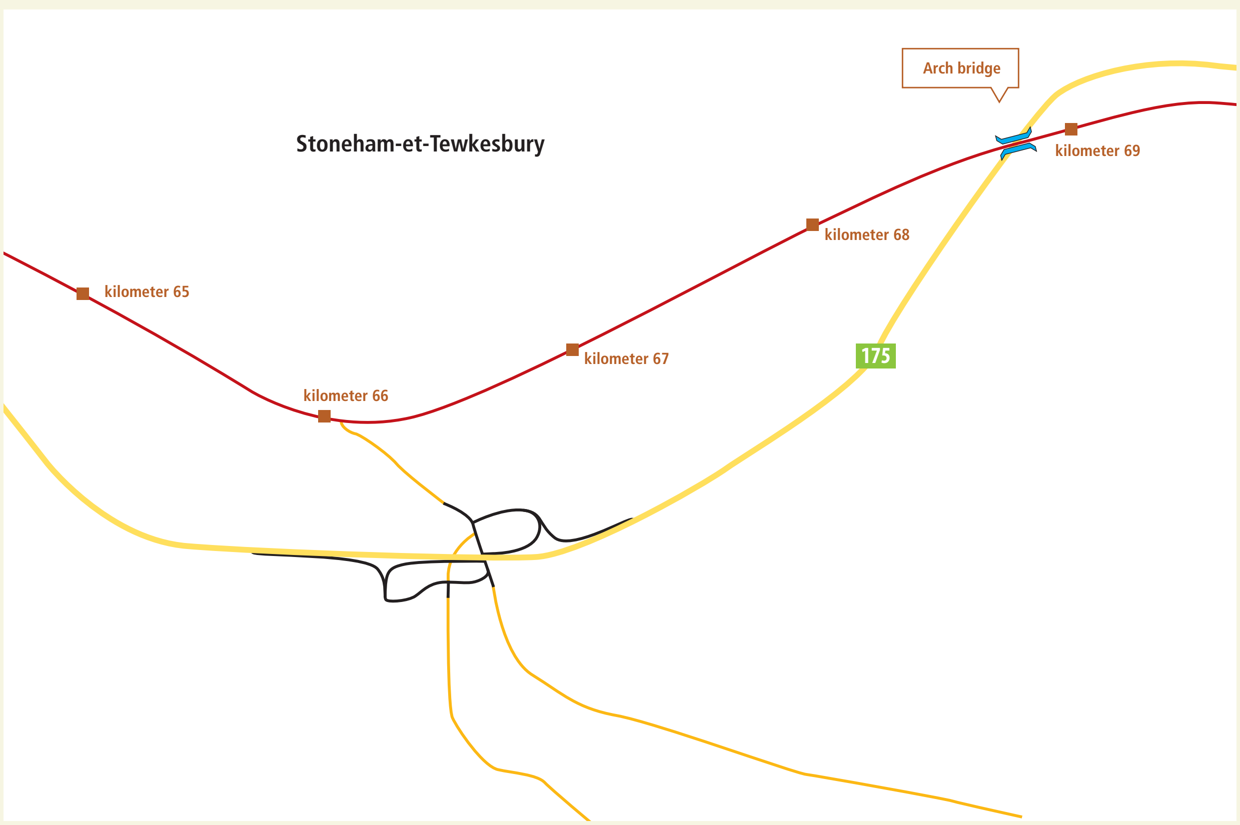
CIMA+ obtained top ranking due to the high quality of its proposal as well as the Ministry's selection process, which was not cost-based ("no cost offer"), but based rather on the firm's expertise and quality resources. The professional service mandate would allow us to take on an important and interesting challenge. We had the opportunity to conduct a pre-project study (concept development), to devise the plans and specifications, and to oversee the construction of the bridge discussed in the present document.

The mandate granted to CIMA+ initially involved structural identification and analysis. By studying the Ministry's sketched route, the CIMA+ team found that Talbot Boulevard would cross the future Highway 73 with a significant bias of 49 degrees. Moreover, and according to the proposed route, CIMA+ also noticed that, while within applicable standards, Highway 73 presented a significant slope and curvature where it would cross Talbot Boulevard.



Therefore, in order to respect horizontal clearance imposed to ensure compliance with sight distance for users, it appeared that the bridge to be built would need a considerable span of about 70 meters. Moreover, the site's geometry required that the future Highway 73 be excavated through rock. CIMA+ then found that the thickness of the projected bridge deck would have to be limited in view of minimizing the quantities of rock to be excavated, otherwise the profile of Talbot Boulevard, or of the future Highway 73, as established by the Ministry would need to be modified. However, the costs associated with these modifications were deemed too great for these solutions to be retained.

For economic reasons, the first structure concept considered by CIMA+ was that of a conventional beam bridge with a pier located in the median separating the two lanes of the projected highway. It should be noted that due to the significant 49-degree bias and considerable curvature of Highway 73 where it would cross Talbot Boulevard, the pier located in the median would have required the construction of nearly 600 metres of concrete barrier (Jersey barrier) along the northbound lane to protect users in case of skidding towards the pier. The costs would have been substantial. Also, the construction of a deck supported on a pier with a bias of 49 degrees presented major technical difficulties. All these constraints led CIMA+ designers to analyze other structural concepts.

Although quickly rejected by CIMA+, the solution to build a slab and beam overpass without a median pier was also considered. Indeed, this type of structure would have been enormous and expensive. It would have required very thick beams that would have lowered the profile of Highway 73 or increased that of Talbot Boulevard so that the vertical clearance under the proposed bridge would meet applicable standards. Either of these scenarios required large-scale earthworks, which would have been costly and would have caused delays in the project schedule.

## 1.2 SOLUTION RETAINED

The CIMA+ team was convinced that it was possible to both eliminate the median pier and minimize the thickness of the deck to meet vertical clearance constraints under the bridge. We also knew that this bridge would become the primary gateway to the Quebec City region from the Saguenay, making it an engineering structure of great significance for the area.

This is why CIMA+ recommended that the Ministry hire an architect to ensure the aesthetics of the structure. The latter acted as advisor to assist the project manager in establishing the shapes to give the bridge components and, where appropriate, to approve additional elements. During this part of the project, a brainstorming meeting attended by all of the team's experts was organized to find a solution to remove the pier, to deal with the site's topography, to improve user safety and ensure the aesthetics of the work. The purpose of this meeting was to create a creative synergy and it achieved expected outcomes. CIMA+ was able to provide an original technical solution that was both cost-effective and aesthetically pleasing: an arch bridge.

Once the concept was proposed, site visits were held with team experts to determine its feasibility in the field. It was immediately noted that site conditions were favourable for the construction of an arch bridge, since the rock was not very deep and of good quality. As the Ministry representative was quite receptive to the concept proposed by CIMA+, it was unanimously determined that the design was ideal to meet the various constraints identified.

To incorporate all the constraints in an original way, CIMA+ proposed building a through arch bridge. This type of bridge would eliminate the construction of a pier in the central median of the highway and avoid any modifications to the proposed profiles of Highway 73 and Talbot Boulevard due to the shallowness of this type of deck. In addition, removing the pier would serve to:

- eliminate constraints related to pier bias values;
- eliminate 600 metres of Jersey barriers along the northbound lane, which would have been necessary in case of skidding towards the pier;
- increase safety of users by eliminating obstacles (pier and protective Jersey barriers) by the roadside that could present a danger to road users;
- permit the construction of a deck less than 1000 mm in thickness.

Through arch bridges are not common in Canada. In Quebec, it will only be the second one of its kind built in the last 50 years, the previous one dating back to the late 60s on Autoroute 15 in the Laurentians.

Note that three amendments and additions proposed by the architect were retained by the designers and the Ministry following a cost analysis and assessment of their impact on the durability and maintenance of the structure. The front abutment walls were tilted so that the top would be recessed from the base. CIMA+ also widened the upper portion of the arches by 150 mm. The exterior face of the arches would also be tilted. Lastly, transition slabs in a contrasting colour were added to the deck overhang extremities.

CIMA+ was extremely proactive in defining the project. The design team examined the overall project taking into account road geometry, the safety of users and technical difficulties associated with the construction of a pier with a 49-degree bias. A number of concepts were considered throughout the project, including types of bridges uncommon to Canada. We advised the Transports Québec regional office in Quebec City in its efforts to gain approval of the concept at the highest levels in the Ministry. We also conducted several bibliographical searches to determine what was being done internationally.

CIMA+ has adopted an integrated design approach by proposing the construction of an arch bridge, which is more expensive to produce than a conventional bridge, but more cost-effective as a whole if one considers that the construction of a conventional bridge would have required higher road network costs. Moreover, CIMA+ has attached great importance to the durability and life cycle analysis of the structure. Note also that a three-dimensional analysis of the structure was performed using Visual Design software, which helped to optimize the design of all elements of the structure.

The CIMA+ team boldly demonstrated impeccable leadership, proactivity and organizational skills by closely collaborating with other professionals to facilitate the exchange of information and properly integrating this information in the project during its implementation. We believe that CIMA+ engineers designed a bridge that is fully adapted to the geographic location and safety requirements imposed by the proposed route of the future Highway 73.

The CIMA+ team boldly demonstrated impeccable leadership, proactivity and organizational skills by closely collaborating with other professionals

## 1.3 ORIGINAL SOLUTIONS

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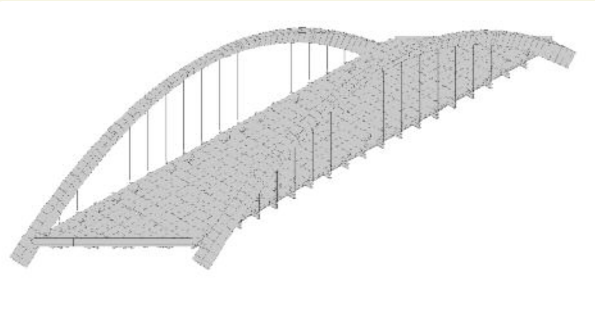
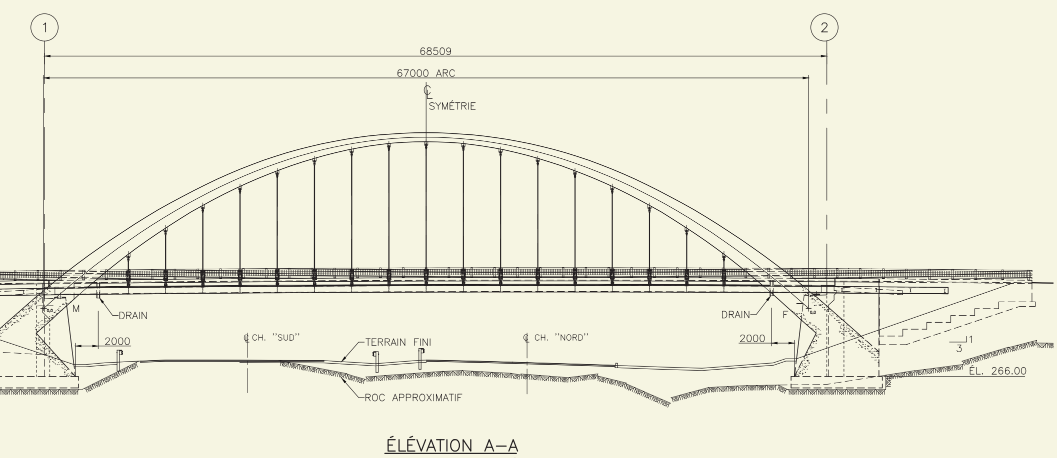
In order to evaluate the bridge's behaviour under various loads, a complete model of the deck was generated through the Visual Design software. To simulate arch behaviour (deformation and stress), construction phases were simulated using various models, i.e. construction of semi-arches, installation of steel structure and deck concrete, and finally, the bridge in service. The creation of a model for each step was necessary to separate the load and deformation values imposed on various parts of the structure according to work progress. Thus, deformation values noted at each stage of construction were integrated in the following model so as to obtain a realistically accurate simulation leading to the identification of any unwanted stresses.



Final bridge model

The designers favoured monolithic arches to eliminate joints that can cause, as any break in a concrete element would, a decrease in the structure's durability. A comprehensive study of volumetric changes in the arches, due to shrinkage and creep of concrete as well as thermal shifts and gradients, was required to verify and monitor their cracking. This study revealed the need to apply a bending and compression at the base of the arches in order to control the cracking of the upper surface. To that effect, a novel solution was proposed by the lead CIMA+ designer. This solution was to apply a lateral load at the top of each arch by building them in semi-arches. The load applied aimed to induce sufficient bending and compression in the parts of the arches most likely to crack under certain loads such as thermal loads in winter. Thus, it was identified in the plans and specifications to stop the construction of the arches and leave an opening of 1.5 meters at the top of each one. A jack was installed there to open the arches; the two semi-arches were then spread apart by a few millimetres before the 1.5 metre opening was filled with concrete.




Elevation drawing

We should also emphasize that the geometry of the arches was optimized to minimize flexion induced by volumetric loads and deformations of the concrete. It was, however, impossible to completely eliminate bending caused by imposed loads and deformations. The main effects the arches are submitted to are shrinkage, creep, thermal shifts, loads from the deck ties, seismic loads and actual weight of the arches. A parabolic funicular shape was used as it minimizes bending from gravity loads.

The lateral stability of the arches was closely scrutinized. Wind and seismic loads were meticulously analyzed. In fact, the seismic analysis also considered the use of the bridge as an "emergency-route" bridge.

## 1.4 AN EXCEPTIONAL LEARNING EXPERIENCE

This unique project designed by CIMA+ resulted in several benefits for the profession. For example, the arch bridge made the cover of the MTQ's 2011 CCDG specifications book. This project was an engineering challenge for both the design and the construction of the structure. This type of bridge is unusual and technical articles dealing with the specifics of its design and construction were presented in 2011 by CIMA+ engineers. In fact, to date, two technical papers were prepared: one for the American Concrete Institute (Boucherville, 2011) and one for the MTQ's *Colloque sur la progression de la recherche québécoise sur les ouvrages d'art* (Quebec, 2011).

This project showcased Canadian knowhow and enabled the collaboration between engineers and architects. The realization of such a structure also required impeccable cooperation between the various stakeholders of the project, from the general contractor Enterprise Alfred Boivin, who coordinated the work; Coffrage Provincial, who produced the formwork and poured the concrete and ABF, who supplied and installed the reinforcement; and LVM, responsible for materials testing; to the MTQ and the team overseeing the work of CIMA+.

In fact, this project has been an exceptional learning opportunity and has produced a wealth of new knowledge. Not only does this structure provide excellent visibility for the engineering profession, its uniqueness is a great source of pride for CIMA+.

Above all, this project promoted collaboration between experts, enabling a knowledge transfer to take place between designers, architects and construction workers. In addition, the builder's extensive experience proved invaluable on several occasions. Finally, all the companies supporting the CIMA+ team benefited from the experience. The firm strongly believes that image of the profession has greatly improved in the eyes of Quebecers, strengthening our desire to cultivate excellence within the company.

## 2. COMPLEXITY

### 2.1 BRIDGE DESIGN RARELY SEEN IN CANADA

#### Arch Design

CIMA+ closely examined various types of arch bridges before recommending the best solution. These bridges are classified into three types depending on the deck's position according to the arch: deck arch bridges (upper deck), half-though arch bridges (intermediate deck) and through arch bridges (lower deck). The topographical and vertical clearance constraints required for the Talbot Boulevard bridge necessitated the construction of a through arch bridge.

In this case, the deck is suspended under two arches, which are the main supporting elements of the structure. Two materials were studied for the composition of the arches, reinforced concrete and steel. Since neither of these two materials demonstrated a particular advantage with regards to constructability, maintenance and durability during the study phase, the selection rested upon economic considerations. CIMA+ opted to use reinforced concrete arches because they were more cost-effective.

CIMA+ opted to use reinforced concrete arches because they were more cost-effective.

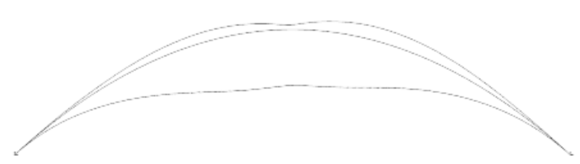
Arch envelope at ultimate moments

As reinforced concrete is heavier than steel, the arches had to be designed to withstand greater seismic loads, the latter being proportional to the weight of the elements submitted to the earthquake. Moreover, as there was no question of the arches sustaining any damage following an earthquake, each of the two was designed to remain elastic (no plastic joints) in an earthquake, as required by the Canadian Highway Bridge Design Code. In imposing an elastic behaviour to the arches during an earthquake, CIMA+ designers had to carefully position large amounts of reinforced steel in the arches, so as to resist bending and shear induced by a subsequent earthquake.

#### Foundation Element Design

The foundation units are composed of standard abutments in reinforced concrete with a base on either side, which allows the arches to be the fitted and supported. The bases are joined and integral with the front wall for a monolithic base-abutment structure. Foundation elements are supported by the rock and the friction between the rock and the shoe prevents any sliding. The size of the bases was determined so as to allow for a fitting of the arch bases.

Note that the design of foundation elements, especially regarding the one used to support the deck in an earthquake (north abutment), was a highly complex stage of the project that required considerable time and energy for the CIMA+ design team. In fact, due to its 70-metre span, anchoring the deck's great mass to the north abutment (fixed foundation unit) necessitated the development of special steel bumpers. These would help keep the apron in place both transversely and longitudinally in an earthquake. The forces transmitted by the deck to this abutment through the steel bumpers were also meticulously analyzed to ensure that the abutment would not overturn during an earthquake. Efforts to consider in such cases were critical,



Arch envelope at ultimate bending loads

because the Ministry required that the proposed bridge also serve as an "emergency-route" bridge, which, as specified in the Canadian Highway Bridge Design Code, is to remain open to all traffic after a severe earthquake.

## Deck Design

The bridge's deck design differs from that of a standard deck primarily because the main beams of the deck are perpendicular to the road and are supported by cables. This specific design feature is based on the behaviour of the entire deck during the passing of a truck. In fact, deformations between each main beam under the load of a passing truck had to be considered in view of preventing cracks in the slab and enhancing its durability. CIMA+ paid particular attention to this issue when designing the deck in order to limit deformations between two adjacent beams, and vibrations. To reduce vibrations, the design team elected to use a relatively thick slab that would increase deck inertia and, as a result, would increase the comfort of users travelling on the structure.

Cable and arch deformation also greatly affects deck behaviour. Since cables all vary in length, their elongation under a same load differs throughout. Cable elongation and arch movement were therefore evaluated accordingly and included in the deck behaviour analysis. The deformation of the cables and arch under the weight of the slab, the bituminous overlay and the curb was determined in view of adjusting the elevation of the steel structure to achieve planned pavement profile results.

As the deck is held by cables, there is very little load on the bearings compared to what is typically observed on a conventional bridge. Moreover, the presence of a deck with a significant bias incurs less stress in sharp corners. CIMA+ had to take into account the possible lifting of the deck at the beams under certain load conditions. Thus, the bearings were designed accordingly.

## 2.2 COMPLEX UNDERTAKING

### Foundation Element Construction

The construction of the foundation elements began with the excavation and cleaning of the rock. A cushion block was installed, followed by the concreting of the base-abutment shoes. The formwork of the assembly was monolithic. The construction of this formwork was particularly complex, considering the steep bias and the quirky geometry of the bases, the significant pressure put on the formwork during the concreting (10 m in height) and the formwork overhanging the bases and arches.

The volume of concrete used for the foundation element's base-abutment set was about 450 m3. Pouring the concrete for this feature was a massive undertaking that took about 12 hours to complete. This significant quantity of concrete required controlled temperature to ensure durability of the material. The CIMA+ supervision team was well aware that if the temperature was too high, it could create problems with the durability of the structure. It is also worth noting that the concreting of the foundation took place during an exceptionally warm period during the summer of 2010.

Shoring and formwork of arches

## Arch Construction

The formwork, reinforcement and concreting of the arches were not standard and were relatively complex to execute. These difficulties were due to the parabolic shape of the arches and the varying height and width of the formwork. Furthermore, the top of the arch was 150 mm wider than the lower part, the defined surface was not vertical and the angle was variable. The bottom of the formwork was prefabricated in a factory, following the parabolic profile, and then assembled on-site, using scaffolds.

Installing the reinforcement also required special efforts by metal workers. The narrow work zone and substantial quantity of reinforcing steel to install made solid coordination between stakeholders essential to install the reinforcement, the hitch plates and formwork in good order. The wider and asymmetrical shape of the top of the arches created problems for the metal workers: the weight of the reinforcement was unstable, with a tendency to list to one side.

## Deck Construction

The construction of the deck was also non-standard because the main beams were perpendicular to the road and were retained by cables. While installing these beams, special attention was given to adjusting the elevation of teach beam extremity, so that the final profile of the road would fully correspond to the plans and specifications.

Construction of the formwork and slab began after installation and adjustment of the steel structure. The adjustment of the formwork elevation also required special attention because the deformation of the deck differed from that of a conventional bridge. In fact, the slab formwork was adjusted on each of the main beams, perpendicular to the road. The main challenge of the adjustment work was taking into account the deformations stemming from the cable elongations and the deformation from the arches and beams.

## 3. ENVIRONMENTAL IMPACT

High-performance concrete was used to increase the durability of all structural elements. Note that all concrete contained supplementary cementing material (fly ash, blast furnace slag), which are industrial process residues. By using these types of binding materials, we were able to reduce GHGs by 30% during manufacturing of the cement. Three-component concrete is also highly resistant to penetration from de-icing salt, highly durable and, compared to concrete made only with Portland cement, has lower permeability to external chemical stressors.

CIMA+ made several interventions on an environmental level for this project, namely:

- reducing rock excavation, which minimized the environmental footprint;
- using a waterproofing membrane on the slab to increase its durability;
- a design with a life expectancy of 75 years with minimal maintenance requirements. With the exception of the deck (slab, membrane and bituminous overlay) which is exposed to the worst conditions (de-icing salt), and which may require maintenance every 20 to 25 years, all other elements of the deck will require no maintenance during the useful life of the structure.

This MTQ project is one of the largest in its history and represents an investment of approximately one billion dollars.

## 4. SOCIOECONOMIC IMPACT

It is important to note, that for the 300,000 people living in the Saguenay-Lac-Saint-Jean region, Highway 73/175 is their main link to the Quebec City region and to the provincial highway network. Over the years, it had become imperative to improve this road for residents, tourists and companies in the region.

The redevelopment of Highway 73/175, which began in the 2000s, is a large-scale project that required construction of 174 km of road, a complex geographical context, a dense environment and impressive technical constraints. Out of the 174 km of road to be built, 102 km are now in service.

This MTQ project is one of the largest in its history and represents an investment of approximately one billion dollars. According to the MTQ, the project will promote safe travel by reducing the risk of head-on collisions and accidents involving large wildlife. It will also permit greater traffic fluidity, to cope with the forecast increase in traffic, while contributing to the economic development of the Saguenay-Lac-Saint-Jean region and all of Quebec. This project alone will help to preserve or create more than 1300 direct jobs a year.

The MTQ also points out that: "The advantages of improved road safety and reduction in travel time will be the direct results of this project. However, the main issue is to create favourable conditions for steady socioeconomic development in the Saguenay-Lac-Saint-Jean region, by providing the region with a sufficient connecting road to one of the six main urban areas of Quebec, the city of Saguenay. The building of a major transportation infrastructure in rural areas always results in a structuring effect on the socioeconomic development of the territory served."

## 5. MEETING AND EXCEEDING CLIENT EXPECTATIONS

In June 2011, CIMA+ delivered a through arch bridge with reinforced concrete deck that overlaps the future Highway 73, with total respect for the schedule and budget. This structure is currently in use. All inspections it has undergone since its opening, including the first general inspection conducted by the Ministry in June 2011, allowed us to conclude that the structure meets design expectations. Furthermore, we must point out that vibrations caused by heavily loaded trucks are low, and that there is no observable cracking, even at the base of the arches, which is a sensitive area where bending forces can be substantial.

We must also point out that the structure was designed by CIMA+ so that it would retain its functionality if an accident on the bridge were to cause a break in one of the cables supporting the deck. In that case, the Ministry would be able to proceed with replacement of the cable in question, without having to limit traffic on the bridge. Furthermore, the structure would be capable of supporting the loss of two cables without risk of the deck collapsing. However, heavy vehicle traffic on the bridge would need to be prohibited during that time, in order to affect the necessary repairs.

Finally, we must mention that the geometry of the deck (number of lanes on the bridge) meets the needs of the Ministry by providing users with the necessary fluidity. The wide shoulders provide enhanced safety for drivers if necessary.

### 5.1 RESPECTING BUDGET AND SCHEDULE

CIMA+ and its engineers built an arch bridge at a higher cost than that of a conventional bridge. In fact, the bridge cost nearly $4500 per square meter, compared to the typical $4000 per square meter for a conventional overpass bridge. However, considerable savings were made for the overall project thanks to the thinness of the arch bridge deck. This factor helped avoid a significant increase in quantities of rock to excavate in order to respect the vertical clearance under the structure, as per on applicable standards. The thickness of the arch bridge deck is less than one meter, as opposed to a thickness which would have been over 2.5 meters with a conventional beam bridge. Furthermore, because of the arch bridge design, we were able to avoid building 600 meters of Jersey barrier, which would have been necessary for a conventional bridge with a pier in the median.

CIMA+ created a design that could be optimized throughout the project, including unexpected on-site situations, for a cost of about 20% lower than estimated during the preparation phase of the plans and specifications. In summary, the costs were:

- the price tendered by the contractor: $4,413,000;
- the estimation of the works by CIMA+: $6,100,000;
- The final cost of the project: $4,404,246.

CIMA+ created a design that could be optimized throughout the project

The CIMA+ team respected the overall construction schedule of this section, including the bridge and the road. However, it is necessary to point out that construction of the bridge exceeded the initial planned schedule of 38 weeks, because the client and the designers decided to postpone the end of the construction in favour of better weather conditions. To ensure the durability of the structure, the concreting of the foundation slab was postponed by the supervisor from late autumn to spring, due to cold weather. This did not affect the overall contract schedule because Highway 73, which passes under the bridge, did not have to open to traffic until after construction was complete.

CIMA+ was concerned with economy in carrying out this project. With this in mind, the firm's engineers designed monolithic and continuous arches, without joints, from one abutment to the next. This choice was made in view of reducing maintenance costs of the structure and ensure greater durability. Galvanized reinforcing steel was used for all elements exposed to salt, to significantly extend the life of the structure at a very low cost. This decision was especially important for the arches, where any future repairs would be very complex due to the nature of the deck support elements.

## 5.2 INGREDIENTS FOR SUCCESS

This project is much more complex than it appears. To ensure complete success, CIMA+ was proactively involved in its completion by supervising the construction site and delegating a highly experienced representative. The CIMA+ supervisor's planning for any potential construction problems, especially with regard to the two concrete arches, was at the core of the project's success. The CIMA+ supervisor also had to validate all work methods employed by the contractor several weeks before implementation and had to make numerous quick and effective decisions at the construction site.

Furthermore, CIMA+ assisted the contractor during each stage of the project, from being on site at the concrete factory to validate work methods and quality, to overseeing each step of the concreting stage. Because of the project's size and complexity, the supervision team and contractor had to work in close collaboration. This synergy between all parties assured the Ministry that the finished product would be of the highest quality, corresponding to the designer's vision and the client's needs.

CIMA+ successfully faced several engineering and construction challenges in this project.

CIMA+ guaranteed continual presence of a site supervisor so that all the details would meet the client's expectations and the products delivered would be of the highest quality. These components were carried out according the Ministry's standards. We must point out that CIMA+ devoted considerable effort and energy in supporting the contractor, in informing the Ministry representative, and in ensuring the designed concept would be maintained, all within established budget and schedule.

CIMA+ successfully faced several engineering and construction challenges in this project. We believe that the best policy was to protect the interest and motivations of all persons associated with the arch bridge project. We are convinced that we provided our client with the best possible solution. It was another opportunity for the Canadian engineering industry to demonstrate its standard for excellence.

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