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CANADIAN CONSULTING ENGINEERING AWARDS 2011

Transportation Category

PETITE-NATION RIVER BRIDGE
HIGHWAY 50, LOCHABER, QUEBEC

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

CANADIAN CONSULTING engineer

THE PETITE NATION RIVER BRIDGE CONSTRUCTION PROJECT IN LOCHABER, QUÉBEC

Construction of a Large-Scale "Lifeline Bridge" Within the Context of Challenging Geotechnical Conditions

This project posed a major challenge for CIMA+ engineers, who were responsible for designing a "Lifeline Bridge" to span 425-meters with the deck running 35 meters above the valley, without building in the river below. As the bridge was to be part of the extension of Autoroute 50, the project had to be executed within a very tight schedule.

The "lifeline bridge" concept was first developed by the California Department of Transportation after two major seismic events: The 1971 "San Fernando earthquake"; and the more recent "Loma Prieta earthquake" in 1989. Lifeline bridges are built to ensure the safety of users during the earthquake itself, and to guarantee that certain roads remain accessible in the aftermath. This was the first lifeline bridge of its size built in Québec, where earthquake engineering has only recently implemented.

However, CIMA+ engineers faced yet another challenge. They had to find a solution to the varying pier heights caused by the site's rugged topography and complex and varying geotechnical conditions. The 24.5 m high Pier 2, which is seated directly on bedrock, is much shorter than the 32.5 m high Pier 3, which rests on drilled shafts that pass through 35 m of ground before bearing on bedrock, for a total height of approximately 70 m. Such a difference in pier heights and foundations, and therefore in their rigidity, results in a concentration of seismic loads in the shorter piers, placing them at a very high risk.

At the start, we had learned that the only information that was available was the plan and profile of the highway, and a digital model of the terrain based on aerial photos. CIMA+ carried out data collection, a preliminary study of the geometry and profile of the structures, cost estimates for different options, planning and identification of borehole locations, planning of bathymetric surveys, and a definition of the design criteria. We commissioned hydraulic, geotechnical, soil and environmental studies, along with additional topographic surveys.

Through the innovative approach of our engineers, the support of the various experts and the use of leading-edge software, we developed a state-of-the-art and straightforward approach that met the client's needs efficiently. CIMA+ engineers designed a bridge that was ideally suited to the geographic location and heterogeneous stratigraphic profile of the valley, in full compliance with the new earthquake code. This design also helped to control costs and to respect the timelines for the project.

1. State-of-the-Art Pier Design

CIMA+ designed a hollow pier in order to obtain all of the required rigidity from its base while reducing its mass. The greater the mass on top during an earthquake, the greater the resistance required to withstand such an event. We needed produce a design that lightens the structure. CIMA+'s solution for designing a "regular" bridge was to design a pier with a pier cap beam supported by four ductile rectangular columns of equal height, which are supported by a multi-cellular truncated pyramid at the base of the pier. Although the ductile columns and pier cap beams were identical for all of the piers, the pyramids consisted of three cells for each pier, with walls of varying thickness. We were able to obtain a uniform distribution of pier rigidity by adjusting the wall thickness of the cell according to the height of the pier, thus creating a "regular" bridge, the behaviour of which complies with existing regulatory specifications for seismic calculation, while preserving identical exterior appearances.

2. Large Diameter Drilled Shafts and Active Rock Anchors to Secure Footings to the Bedrock

CIMA+'s innovative solution was to use drilled shafts to permit the seismic loads to be transmitted to the bedrock through 35 metres of ground, and also to install active rock anchors to avoid any rotation of footings. This consists of a new approach for designing foundations coupling these kinds of piers and rock anchors. Highly detailed soil-structure interaction analyses were required. The diameter that we selected allowed for use of a large-diameter boring machine that recently became available in Québec. These drilled shafts permitted seismic loads to be transmitted to the bedrock through 35 metres of ground, and provided the stability and resistance required for the highest central pier. Soil-structure interaction analyses that are rarely used in Québec were preformed for this solution.

3. Efficient and Transparent Earthquake Resistant System

CIMA+ designed a longitudinal bridge restraint system that consists of three fixed bearings (one for each pier), and developed an innovative design that employs steel shear keys for increasing resistance to transverse loads. The structure's protected components (pier cap, bearings and foundations) were designed to withstand the maximum probable forces that are likely to develop in the plastic hinges of the ductile column. CIMA+ adopted this approach because it provides a safer design accompanied by better control in a rupture scenario. This approach is also currently recommended by the Department of Structures at the Ministère des Transports du Québec (MTQ).

4. Strict Quality Control

The footings have large dimensions, with thicknesses of 2,500 mm (Piers 2 and 4) and 2,600 mm (Pier 3). Such dimensions require strict quality control, especially with respect to the temperature of the concrete. Measuring equipment, which involved the installation of thermocouples, was used from the pouring of the concrete until it had completely cured in order to monitor the temperature of the concrete inside and on the surface of the footings, along with ambient temperature. CIMA+ introduced an innovative ultrasound monitoring technique that is capable of verifying the quality of concrete used for the drilled shafts throughout their entire length.

5. A Light and Highly Efficient Bridge

CIMA+'s engineers recommended a light, steel, perfectly symmetrical superstructure, which provides certain benefits in terms of seismic performance and the structure's behaviour in service. This meant that the forces in each span were perfectly balanced, minimizing the mass of steel required for the girders and limiting all of the adverse effects of fatigue that occur in such structures. The length of the central spans was limited to 85 m in order to avoid the need for major work in the riverbed. The bridge was originally intended to be 425 metres long. CIMA+'s studies revealed that the length could be reduced by more than 100 metres. This represented substantial savings in terms of the total cost.

6. A Mobilized Team

The mobilization of CIMA+'s staff was central to the innovative concepts that were deployed in building the Petite-Nation River Bridge. The mobilization of all of the other parties involved was also crucial to the success of the project. CIMA+ teamed closely with various experts, including two university professors and a veteran geotechnical engineer from Qualitas. Good interaction between the structural engineer and the geotechnical engineer was also critical. This broad-based effort served to maximize the benefits of the project. In addition, the contractor (Pomerleau) built the bridge precisely as designed.

CIMA+'s Role

CIMA+ designed the entire project to be as surprise-free as possible during construction. In addition, the contractors had few questions to ask during the tendering process, because of the exceptional clarity of our documents and plans. Our constant emphasis on optimization enabled us to cut both construction and maintenance costs. In this particular case, the optimization enabled us to opt for simple bridge geometry in response to complex design requirements. The plans and specifications were all successfully implemented. CIMA+ and its engineers built a bridge using conventional methods, although pushing them to their limits under the circumstances.

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1. INNOVATIVE SOLUTIONS FOR AN EXCEPTIONAL PROJECT

1.1 BACKGROUND

The Petite Nation River Bridge is part of the project to extend Autoroute 50 from Masson-Angers to Lachute, Québec. One of the requirements of our client, the Ministère des Transports du Québec (MTQ), was to design a "lifeline bridge" in accordance with the seismic design requirements of the Canadian Highway Bridge Design Code. This would be a first in Québec for a structure of this size.

CIMA+ engineers were responsible for designing a "lifeline bridge" to span 425-metres with the deck running 35 meters above the valley, without building in the river below. As the bridge was to be part of the extension of Autoroute 50, the project had to be executed within a very tight schedule.

After being awarded the contract, CIMA+ learned that no preliminary engineering studies had yet been conducted for this structure. The only information that was available was the plan and profile of the highway, and a digital model of the terrain based on aerial photos. It was necessary to undertake a number of studies in order to define the optimal design strategy.

In light of this, CIMA+ carried out data collection, a preliminary analysis of the geometry and profile of the structures, a cost estimate for the options under study, planning and identification of borehole locations, planning of bathymetric surveys, and a definition of the design criteria. We commissioned hydraulic, geotechnical, soil and environmental studies, along with additional topographic surveys.

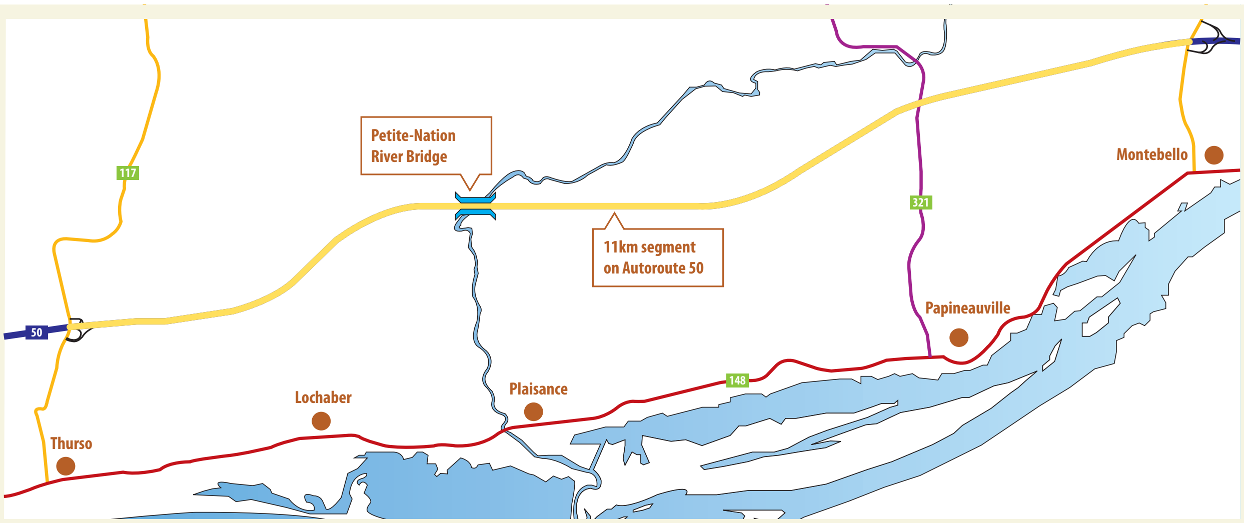
CIMA+ provided a complete range of expertise in transportation engineering in designing the alignment of Autoroute 50.

CIMA+ then studied the key parameters and analyzed a number of different scenarios. From the start, the engineers began to search for the appropriate solution for the high piers, which posed a serious challenge in terms of earthquake resistance.

The Petite Nation River Bridge is on a highway, and therefore, the MTQ classified it as a "lifeline bridge". A bridge in this category must be able to withstand major earthquakes in order to permit the passage of emergency and rescue vehicles and food supplies in the event of a catastrophe. The Canadian Highway Bridge Design Code (CAN/CSA-S6) defines such bridges as part of the strategic highway system, which must be able to remain open to all traffic following an earthquake with a return period of once in 475 years.

"Lifeline bridges" must also remain open to emergency vehicles for safety and defence in the case of a probable major earthquake (once in 1,000 years). In other words, a "lifeline bridge" must be designed for enhanced ductility and redundancy, with a clear rupture mechanism that guarantees safety and limits damage in the event of a major earthquake.

The "lifeline bridge" concept was first developed by the California Department of Transportation (CALTRAN) after two major seismic events: The 1971 "San Fernando earthquake"; and the more recent "Loma Prieta earthquake" in 1989. Lifeline bridges are built to ensure the safety of users during the earthquake itself, and to guarantee that certain roads remain accessible in the aftermath. The Canadian Highway Bridge



Design Code draws extensively from the US Code, which was largely rewritten after the October 17, 1989 earthquake in San Francisco.

Seismic forces in the earthquake-resistant components of a "lifeline bridge" must be multiplied by a factor of 3, as compared to a factor of 1.5 for an "emergency-route bridge", which is the next lower category.

At the beginning, our bridge engineers asked our highway design team if the profile of the highway in this sector could be lowered in order to reduce the seismic loads on the structure. However, factors such as the presence of a rocky mountain at the western approach to the bridge and efforts to minimize cut and fill quantities dictated that Autoroute 50 had to cross more than 30 metres above the river. Therefore, we had to tailor our plan to this requirement.

We also examined other solutions for reducing the cost of the project. Our engineers evaluated such criteria as bridge length, the number of spans, and consequently the number of piers, along with their locations and ideal embankment height at the approaches. The bridge was originally intended to be 425 metres long. CIMA+'s studies revealed that the length could be reduced by more than 100 metres. This represented substantial savings in terms of the total cost.

Highly specialized geotechnical studies were required in order to properly define the parameters of the project. Solid communication and mutual understanding between our geotechnical and structural engineers made a significant contribution to the success of this project.

The "lifeline bridge" concept was first developed by the California Department of Transportation after two major seismic events: The 1971 "San Fernando earthquake"; and the more recent "Loma Prieta earthquake" in 1989. Lifeline bridges are built to ensure the safety of users during the earthquake itself, and to guarantee that certain roads remain accessible in the aftermath.

1.2 SELECTED SOLUTION

CIMA+ engineers designed a bridge that was ideally suited to the geographic location and heterogeneous stratigraphic profile of the valley, in full compliance with the new earthquake code. This design also helped to control costs and to respect the timelines for the project. Given the circumstances, this was the best possible solution.

CIMA+ proposed a bridge with a final geometry consisting of four continuous spans comprising a first span of 67 m, the next two of 85 m, and the final span of 67 m, for a total length of 304 m. This design was achievable despite the presence of clay at the location of the bridge's western abutment. The clay would be excavated from a limited area at that site, and replaced with rock fill. The fill would have a height of approximately 15 metres at this location.

The design called for one foundation to be located on either side of the river, with the others positioned in such a way as to create symmetry within the superstructure. The bridge would be supported by two abutments on either end of the bridge, and by three central piers.

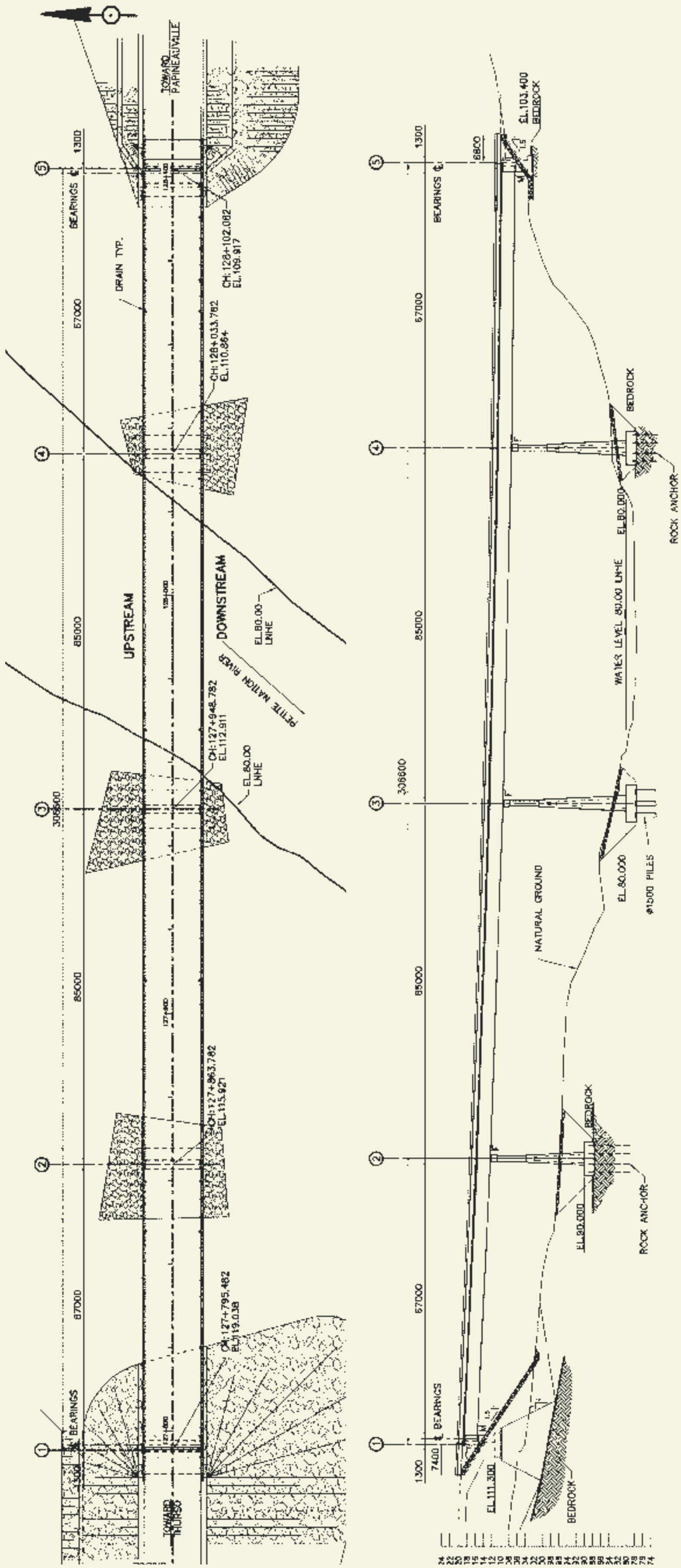
CIMA+'s engineers recommended a light, steel, perfectly symmetrical superstructure, which provides certain benefits in terms of seismic performance and the structure's behaviour in service. This meant that the forces in each span were impeccably balanced, minimizing the mass of steel required for the beams and limiting all of the adverse effects of fatigue that occur in such structures. This greatly diminished the risk of premature aging, and cut maintenance costs significantly.

CIMA+ engineers designed a bridge that was ideally suited to the geographic location and heterogeneous stratigraphic profile of the valley, in full compliance with the new seismic code, which is among the strictest codes in existence. Given the circumstances, the proposed design was the best possible solution.

The length of the central spans was limited to 85 m in order to avoid the need for major work in the riverbed. This approach minimized the environmental impact during and after construction. The maximum span length of 85 m allowed for the use of steel beams of up to 3.2 m metres high, which could be transported to the site without requiring a special permit. The chosen height, which is equal to what is readily available for steel plates from the suppliers, also served to avoid the requirement of welding along the entire core of the beam. Welds are always a concern, because they can reduce the service life of a bridge.

The roadway width for the deck was calculated according to the category of the road and its operational requirements. According to the MTQ's standards for an intercity highway, a roadway width of 13.4 m was required for Autoroute 50 (two 3.7 m lanes and two 3 m shoulders). In order to accommodate this roadway width, and to facilitate future deck maintenance, we decided to use five welded 3-plate girders with a composite reinforced concrete slab, cast on site.

The design of the new structure complied with the Canadian Highway Bridge Code (CAN/CSA-S6-06), which is among the most stringent in terms of seismic design. It also complies with the requirements of the even more demanding MTQ standard, which had been revised following the collapse of the De la Concorde overpass.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1.3 INNOVATIVE SOLUTIONS

CIMA+ developed totally new and innovative solutions in order to address the major issues related to this project.

1.3.1 State-of-the-Art Pier Design

CIMA+'s solution for having a "regular" bridge was to design a pier with a pier cap supported by four ductile rectangular columns of equal height, which are supported by a multi-cellular truncated pyramid at the base of the pier.

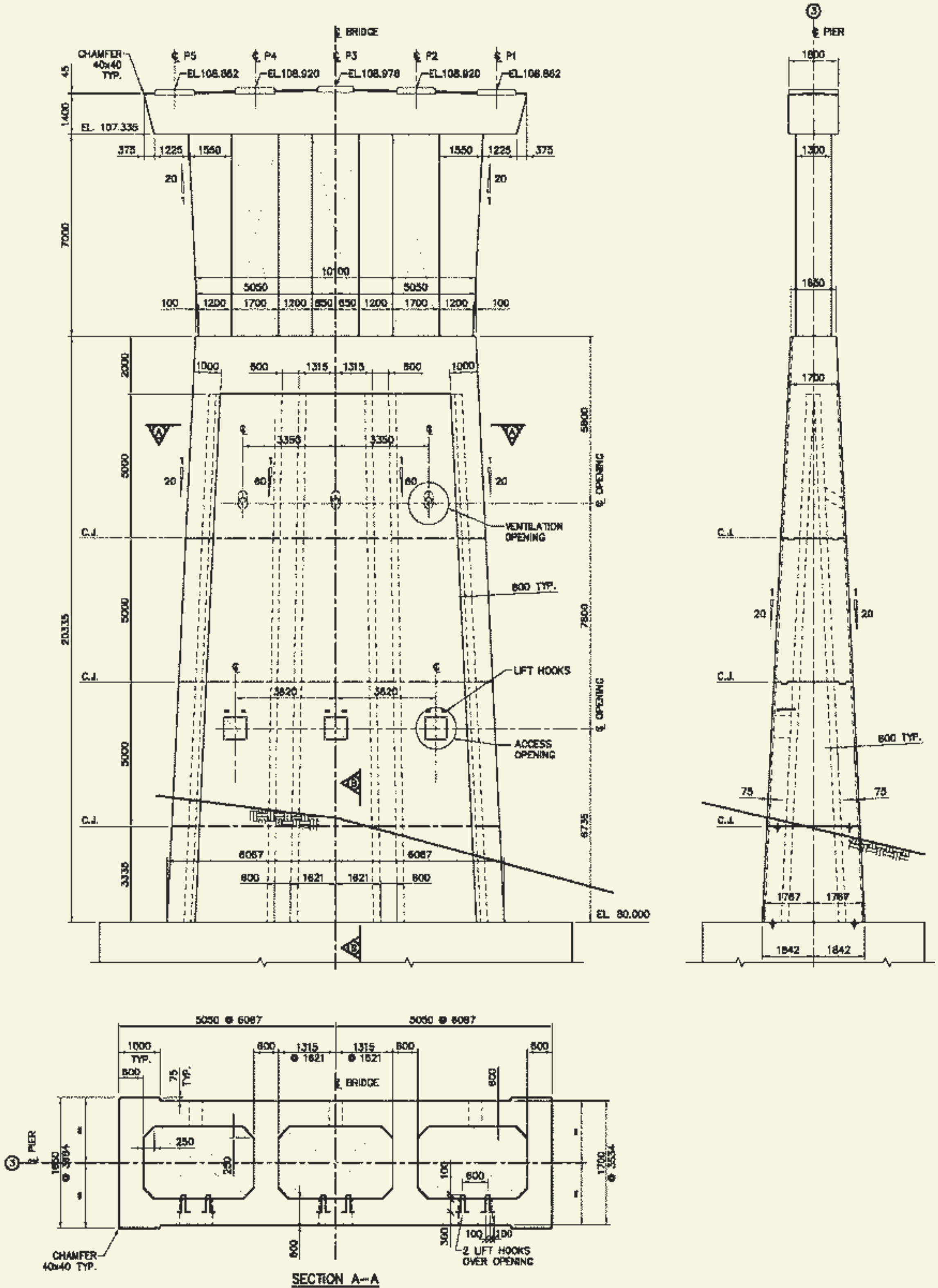
Although the ductile columns and pier cap were identical for all the piers, the base pyramids consisted of three cells for each pier, with walls of varying thickness. We were able to obtain a uniform distribution of pier rigidity by adjusting the thickness of the cell walls according to the height of the pier, thus creating a "regular" bridge, the behaviour of which complies with existing regulatory specifications for seismic calculation, while preserving identical exterior appearances.

The piers were designed to have a transparent rupture mechanism with maximum possible redundancy along the bridge's primary axes. The upper portion, which consists of multiple columns, guarantees the ductility of the structure and minimizes seismic forces. The multi-cellular piers in the lower portion provide the necessary resistance to the seismic forces transmitted by the columns.

We were able to obtain a uniform distribution of pier rigidity by adjusting the thickness of the cell walls according to the height of the pier, thus creating a "regular" bridge.

The structural system adopted by CIMA+ provided good energy dissipation through the placement of plastic hinges in the pier's ductile upper section, while keeping displacement at the top within acceptable limits.

This solution was used in order to have a "regular" bridge, eliminating the need for studies by other seismological experts or additional non-linear analyses that would not necessarily have ensured the desired optimal behaviour, and may have posed the risk of creating oversized foundations. Such studies would also have caused undesirable delays and additional costs.


℄ BRIDGE
CHAMFER 40x40 TYP.
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CHAMFER 40x40 TYP.
SECTION A–A

1.3.2 Large Diameter Drilled Shafts and Active Rock Anchors to Secure Footings to the Bedrock

Pier 3, which is the highest because of the topography, was located in the least stable ground. The bedrock at this location was more than 33 metres below the surface, and the existing ground could not support a superficial foundation. In light of this, we decided to seat the pier on a deep foundation comprised of ten 1.5 m diameter drilled shafts. Other solutions were considered, but none of them proved to be satisfactory.

CIMA+ was ready to innovate so that it could meet the schedule and comply with the new standard. The diameter that we selected allowed for use of a large-diameter boring machine that recently became available in Québec. These drilled shafts permit the seismic loads to be transmitted to the bedrock through 35 metres of ground, and provide the stability and resistance required for the highest central pier. Soil-structure interaction analyses that are rarely used in Québec were preformed for this solution.

No rotation in the foundations of Piers 2 and 4 could be tolerated, because of the structure's high sensitivity to foundation rotation and the major impact that this could have on structure's displacement and the P-Δ effect. These two piers, which were built on solid bedrock, were secured to the ground using active rock anchors. The foundations and the rock anchors were designed and sized to avoid any uplift of the foundation edges during an earthquake. A total of 68 rock anchors were used in the Pier 2 foundation, and 76 were used for Pier 4. The initial pretensioning force was 2,430 kN.

CIMA+ was ready to innovate so that it could meet the schedule and comply with the new standard. The use of large-diameter drilled shafts permits seismic loads to be transmitted to the bedrock through 35 metres of ground.

1.3.3 Efficient and Transparent Earthquake-Resistant System

CIMA+ designed a longitudinal bridge restraint system that consists of three consecutive fixed supports (one for each pier), and developed an innovative design that employs steel shear keys for increasing resistance to transverse loads. CIMA+ placed eight plastic hinges in the ductile portion of each pier in order to dissipate seismic energy, which substantially reduces the seismic loads transmitted to the foundation units.

The structure's protected components (pier caps, bearings and foundations) were designed and sized in order to withstand the maximum probable forces that are likely to develop in the plastic hinges of the ductile column. This led to the design of structures that can withstand seismic forces greater than those corresponding to elastic forces, as required by the CAN/CSA-S6-06 Code. CIMA+ adopted this approach because it provides a safer design accompanied by better control in a rupture scenario. This approach is also currently recommended by the MTQ's Department of structures.

1.3.4 Strict Quality Control and Innovative Solutions

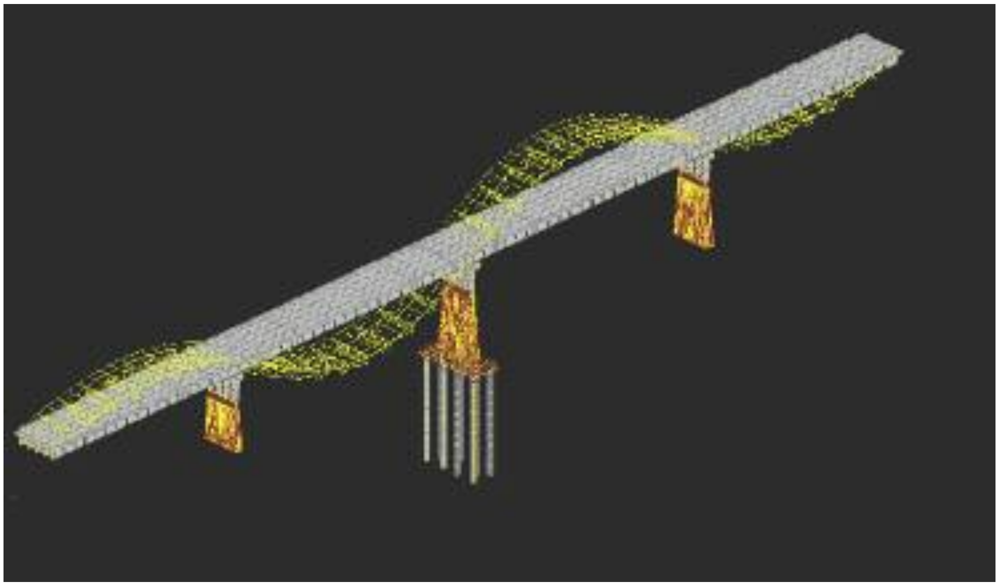
It is worth noting that the footings have large dimensions, with thicknesses of 2,500 mm (Piers 2 and 4) and 2,600 mm (Pier 3). Such dimensions require strict quality control, especially with respect to the temperature of the concrete. Measuring equipment, which involved the installation of thermocouples, was used from the pouring of the concrete until it had completely cured in order to monitor the temperature of the concrete inside and on the surface of the footings, along with ambient temperature. Measurements were taken at set intervals.

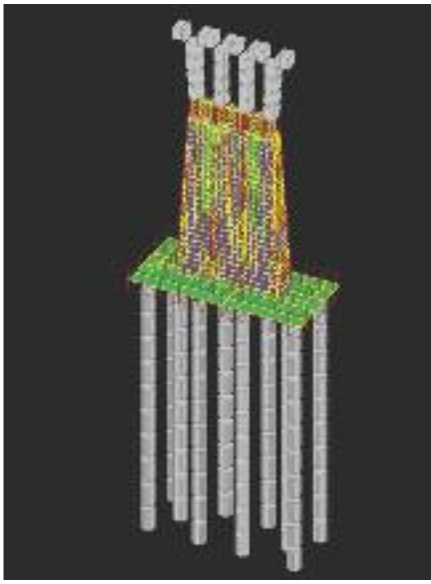
CIMA+ introduced an innovative ultrasound monitoring technique that is capable of verifying the quality of concrete used for drilled shafts throughout their entire length . No such monitoring technique had been required in the past for an MTQ project.

CIMA+ introduced an innovative ultrasound monitoring technique for an MTQ project, thus enabling the verification of the quality of concrete of the drilled shafts throughout their entire length.

CIMA+ constructed a massive rock fill for the foundation of the western abutment. This unusual approach served to reuse large quantities of surplus rock and to significantly reduce the length of the bridge. The rock fill was 100 metres long and up to 15 metres high.

Special attention was also given to the placement of the reinforcing steel and the concreting, particularly in the areas where the plastic hinges were placed. Because of their function, such areas were heavily reinforced. CIMA+ also adjusted the concrete formulation that was used at the tops of the truncated pyramids, where the columns were fixed.





1.4 THIS PROJECT CONSIDERABLY ENHANCED BRIDGE EXPERTISE AMONG CIMA+ ENGINEERS

A project that required such a high degree of precision also required a major effort in terms of design and adapting to a new "lifeline bridge" standard. It proved to be an exceptional learning experience, resulting in a wide range of new knowledge. We created an internal earthquake-resistance design committee, and we now train our engineers in deep foundation design, focusing on drilled shafts. CIMA+'s expertise increasingly serves as a benchmark in this field, and our other divisions benefit accordingly.

The close partnership that we forged with Groupe Qualitas throughout the project helped this company to further develop its own geotechnical expertise. Similarly, the contractor, Pomerleau, told us that this project helped it to acquire leading-edge expertise that would prove to be of great value in similar projects. Such an outcome was made possible by CIMA+'s ongoing concern for maintaining constructive relations with contractors and helping them to improve their construction techniques.

CIMA+ is highly committed to developing excellence among its workforce, and wanted to ensure that this project generated significant benefits for its engineers.

CIMA+'s implementation of this project required an innovative and faithful interpretation of the new Canadian "lifeline bridge" standard. We are especially proud to have transferred our knowledge to engineers in the MTQ's Department of structures. Through their cooperation, they benefited from the research that we conducted in connection with this undertaking. The excellence of our results also led to the modification of the structural design manual. CIMA+ believes that the profession as a whole would profit form the knowledge acquired by the Department of structures.

CIMA+ engineers helped to enhance Québec's expertise in designing and building drilled shafts. This technique is now common practice in bridge projects. In the past, large-diameter drilled shafts had always been built using trepanning . The method had a significant impact on the construction schedule. With the new equipment, we were able to drill one pile socket per day, where traditional methods would have allowed us to install only two per year. The builder was able to excavate all of the pile sockets within 23 weeks, a record for a Québec construction site!

This project also provided Marie-Claude Michaud, who was the Senior bridge Engineer, and Munzer Hassan, the engineer who conducted the seismic analysis and designed the piers, with sufficient material for two scientific papers, which were presented at such international conferences as the 8th International Conference on Short and Medium Span Bridges in Niagara Falls, Canada in 2010, and the 17th Colloque sur la progression de la recherche québécoise sur les ouvrages d'art (17th Conference on Developments in Québec Research on Bridge Infrastructure) in Québec City in May 2010. Through these papers, CIMA+ helped to disseminate scientific knowledge at home and abroad.

2. CHALLENGES

2.1 CONSTRUCTION OF A LARGE-SCALE "LIFELINE BRIDGE" WITHIN THE CONTEXT OF CHALLENGING GEOTECHNICAL CONDITIONS

CIMA+ considered a variety of structural systems that had the potential for ensuring ductile behaviour in the "lifeline bridge" during an earthquake. The primary challenge was actually related to the varying pier heights combined with the highly heterogeneous geotechnical profile. In other words, the 24.5 m Pier 2, which is seated directly on bedrock, is much shorter than the 32.5 m Pier 3, which rests on drilled shafts that pass through 35 m of ground before reaching the deeper bedrock, for a total height of approximately 70 m.

Such a difference in pier heights and foundations, and therefore, in their rigidity, results in a concentration of seismic loads in the shorter piers due to their relatively higher rigidity, which places them at a very high risk. The regulatory requirements in the CAN/CSA-S6 Code with respect to seismic calculations clearly state: a structure's ductile components must be of similar rigidity in order to permit a desirable behaviour involving simultaneous plastification of ductile components. If this is not the case, piers of varying heights will rupture in sequence.

CIMA+ pioneered the design of such key structural components as the piers and the foundations in light of the unique geotechnical profile of the Petite Nation River Bridge.

The CAN/CSA-S6 Code states that multimodal spectral analysis must be conducted for a lifeline bridge located in a seismic zone 3. These dynamic analyses require the use of specialized software to create 3D models representing the entire structure, including its soil-structure interaction. Such modelling also requires in-depth knowledge of the dynamic behaviour of the structures and of the software used to carry out the calculations.

In order to permit such studies, the bridge must be specifically classified as "regular" in terms of the relative rigidities of the components of its substructure. However, the bridge's profile, which comprises piers of varying heights and a heterogeneous geotechnical profile, fails to meet the requirements for a "regular" bridge. Therefore, the major issue involved developing a pier and foundation design that would allow it to meet the criteria of being a "regular" bridge, so that seismic studies could be carried out in compliance with the CAN/CSA-S6 Code.

The very tall piers also posed other problems with respect to the secondary P Δ effect. Sensitivity studies related to foundation rotation and the impact of such rotation on structural force redistribution and displacement were required. Such studies involved stringent non-linear analyses.

2.2. DEADLINE IMPOSES THE USE OF CONVENTIONAL CONSTRUCTION TECHNIQUES

CIMA+ was aware that a bridge of this size would benefit from the utilization of leading-edge methods to reduce seismic loads, such as the use of seismic isolators . However, the use of such techniques was not possible given the time frame, because it would have required additional studies and the active participation of a specialist in the field, along with experimental testing of the prototypes and equipment to be installed, as per the standard. This approach would have delayed delivery by at least one year.

The implementation of the project not only required a specific and realistic deadline for construction, but also the preparation of plans and specifications in time for the contractor to meet the deadline. In light of this, CIMA+ rejected any design that would result in schedule overruns. We relied on the contractor's experience and its ability to deliver a bridge within deadline and budget using known and mastered techniques.

2.3 DIFFICULT CONSTRUCTION AT A RUGGED WILDERNESS SITE WITH UNDERGROUND ARTESIAN PRESSURES

CIMA+ had to build a major structure at a site that is completely in the wilderness. There was no access, and the drilling of boreholes for the geotechnical study required highly complex logistics from the start, particularly in terms of transporting the drill. We also had to determine the best possible access to the site for the contractor. CIMA+ carefully evaluated the transportation of girders, because roadway clearance limits were at the maximums for several routes between the production plant and the site.

Not only was the situation complicated, but the bedrock for certain foundations had steep longitudinal and transversal slopes. Underground water appears on the natural surfaces of the terrain at foundations 1, 2, 3 and 4, which complicated the foundation work. In addition, access to the site was very difficult, and shoring was virtually impossible.

Large quantities of rock fill had to be placed on ground that was not stable at the start and that featured underground artesian pressures. It was necessary to install discharge wells prior to excavating the clay. Many precautions had to be taken in order to prevent serious difficulties from arising during the contractor's foundation work.

This project also required a great deal of work at heights, which posed a risk to the safety of workers. The contractor tried to pre-assemble as many steel reinforcement cages as possible, rather than assembling them on the site, as is typically done for reinforced concrete structures. The contractor requested several changes during the pier construction phase in order to facilitate placement of the reinforcements, and in order to pre-assemble them where possible. CIMA+'s engineers were very open to all of these requests, which resulted in an exceptional construction process.

At another point, the contractor wanted to use a formwork removal walkway that it had developed for projects executed in Ontario. Formwork panels are typically allowed to fall to the ground, although doing so increases the risk of accidents. The contractor wanted to avoid this situation at all cost. The formwork removal walkway required our cooperation, because the bridge had not been designed for this. Thanks to their excellent teamwork, the contractor's engineers and the deck designer found a safe and acceptable solution.

When dealing with a project of this scope, the details are of utmost importance. Structural inspections provide a good illustration of this. The bridge must be inspected and periodic follow-ups must be conducted throughout its service life. To this end, we designed an inspection system for girders and, for economical purposes, we installed a minimum number of fasteners and clasps inside the empty piers so that the inspector could climb them.

However, during construction, the client asked us to add inspection walkways in order to improve safety for inspectors during routine inspections, considering the height of the piers. CIMA+ designed these walkways in conjunction with the contractor in order to find an optimal and safe solution for routine inspections.

3. ENVIRONMENTAL IMPACT

CIMA+ designed a highly economical bridge by substantially reducing its length thanks to a design that involved the placement of an abutment on a large quantity of rock fill. Doing so also allowed excess rock to be ecologically and economically recycled. The number of girders used will allow for future replacement of the deck slab without interrupting traffic.

We sought to economize, starting with the design phase and continuing throughout the entire project. We designed the bridge for a service life of 75 years. No component of the bridge will require any maintenance during its lifetime, with the exception of the deck slab, which is exposed to the worst conditions, as is the case with any bridge built in Québec.

CIMA+ engineers designed a superstructure of weathering steel that would not require paint. The chemical properties of the steel generate a rust-coloured, corrosion-resistant layer of oxides when exposed to weather.

We used a ternary concrete for the deck and the parapets. This concrete has a very long service life, and provides excellent resistance to such external chemicals as de-icing salts. Within the context of our environmentally friendly approach to construction, the concrete binder was mixed with cementitious products derived from recycled industrial waste.

We used many premium products in order to ensure a long service life, including galvanized reinforcing steel for the deck slab, the parapets, the deck joints and the bearings, all of which are frequently exposed to de-icing salts. We also used a waterproof membrane to protect the deck slab.

We paid close attention to the installation of strategically positioned air vents and a drainage system with a view to preventing the typical issues that affect hollow concrete components from reducing the service life. These components were also equipped with a waterproof membrane, rigid insulation, and a perforated drain.

We complied with the client's request to not build a pier in the river, and we are certain that none of the work caused any lasting damage to an environment that one study revealed to be quite hardy. Therefore, our environmental impact was virtually nonexistent.

We were able to recycle almost all the rock as fill, and soil tests revealed no abnormalities or contaminants.

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4. SOCIAL AND ECONOMIC IMPACT

Situated in western Québec, Autoroute 50, which is also known as the Autoroute de l'Outaouais along its western stretch, is an intercity Québec highway. It serves the Ottawa Valley and Laurentian regions, and also represents the main highway link between Greater Montréal and Gatineau-Ottawa (the National Capital Region) along the north shore of the Ottawa River. Its current length is 106 kilometres. Once completed, it will be 158 kilometres in length.

The Ministère des Transports du Québec (MTQ) justified the construction of Autoroute 50 as a dual carriageway for the following reasons:

- To upgrade the highway links between Hull-Ottawa (the National Capital Region) and Montréal (a major international entry point to North America);
- To support economic development (industry and tourism);
- To meet the demand for long-distance and regional travel;
- To remedy geometric deficiencies and traffic along Route 148 (poor visibility when passing, passing through several villages with posted speed limits of 50 kph, multiple access points, large numbers of trucks, and safety issues). The service level offered by this route is not appropriate to that of an intercity route.

Two decades before the Petite Nation Bridge was planned, the need to build a good highway between Hull-Ottawa and Montréal had already been discussed:

"Construction of Autoroute 50 as a dual carriageway with overpasses at intersections seems to be the most appropriate solution in order to ensure efficient regional service and improve the safety and security of users […]. This project largely exceeds the simple notion of deploying resources in order to ensure the movement of people and merchandise between the different regions. But rather, it corresponds to a dynamic and competitive socio-economic context, and is part of a longer term outlook."

MINISTÈRE DES TRANSPORTS. Étude d'opportunité portant sur la construction des autoroutes 13 et 50 dans l'axe Montréal-Mirabel-Hull (*Opportunity study related to the construction of Autoroutes 13 and 50 in the Montréal–Mirabel–Hull corridor*), December 1987, pages 51 and 105.

CIMA+ is very well established in the region. At the time when the contract was awarded, we had just acquired Stantec in Gatineau and Audy, Farley, Lalande, La Berge in Saint-Jérôme. These acquisitions put CIMA+ in an excellent position in terms of offering the most comprehensive transportation expertise in the regions that Autoroute 50 was to pass through. For this project, CIMA+ also retained the services of Groupe Qualitas, which not only possess outstanding experience with geotechnical studies, but is also well established in the region.

The project allowed several regional firms to acquire expertise while also drawing on and applying the knowledge of a number of experts, specialists, consulting firms, contractors and workers. A large workforce with all levels of qualification benefited economically from the two years that it took to build the bridge. However, Autoroute 50 will have been a major income generator for a period of five years.

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5. MEETING AND EXCEEDING THE CLIENT'S NEEDS

5.1 ON TIME AND UNDER BUDGET

CIMA+ and its engineers built a bridge using conventional methods, pushing them to their limits under the circumstances. This was the first lifeline bridge of its size built in Québec under the new CAN/CSA-S6 Code.

CIMA+ developed a concept that was suitable for implementing the overall project, including unforeseen developments during construction, for 11% less than our own cost estimate. We had prepared a $29 million budget, but the final price tag came in at only $26.5 million.

The Petite Nation Bridge cost $4,900 per square metre, which is the average price for a standard overpass in Montréal. CIMA+ designed an economical and optimal bridge, considering its size.

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According to the MTQ's schedule, Autoroute 50 should be open to all traffic in the fall of 2012. The Petite Nation Bridge is also part of the extension of Autoroute 50. Oversized trucks already use it to transport large quantities of rocky rubble produced by the construction of Autoroute 50 west of the bridge, which is needed to complete the section east of the bridge.

CIMA+ was required to carry out a comprehensive exercise in order to draw up a realistic construction schedule within the context of its tender documents. The work was scheduled to be completed by September 30, 2010, and was completed with an extension of five-calendar days due to the client's request that inspection platforms be installed inside the piers.

CIMA+ met all deadlines for plans, specifications and construction, and fully complied with the deadline, despite the many difficulties involved in building the Petite Nation River Bridge.

5.2 FULL SUPPORT FOR THE CLIENT

All parties involved in the project expressed their complete satisfaction at every stage of construction. CIMA+ mobilized a highly qualified team to work on the Petite Nation River Bridge project. We proposed the best possible solution after consulting with the leading experts in the field. CIMA+ also consulted with such specialized contractors and subcontractors as drilled shafts workers, steel erectors and formwork assemblers, along with manufacturers of bearings, expansion joints and concrete. We sought to ensure that our designs could be constructed at reasonable cost.

Our efforts were built around the goal of delivering an outstanding structure in compliance with existing standards. We were able to accomplish this thanks to the close communication among all parties concerned, as well as the excellent plans provided, the thorough planning of each construction phase, and constant mobilization of the construction crew.

As is the case with all projects of this magnitude, a number of problems arose during construction, despite CIMA+'s decision to employ conventional construction techniques and the exceptional clarity of the plans and details provided. CIMA+ was able to meet these challenges by working closely with the designer, the supervisor and the contractor. In this way, we could be sure that the contractor would deliver a superior bridge, in full compliance with the designer's vision.

CIMA+ supervised the entire project, and was proactively involved in executing every phase. Construction of the Petite Nation Bridge and its approaches was supervised by a highly qualified team residing on site. By having the supervisor and his crew on site at all times, CIMA+ was able to ensure that every detail and all delivered products fulfilled the client's expectations. All of the work was carried out according to the MTQ's exacting standards. As the results demonstrate, we spared no effort in providing constant attention to the contractor's needs, with the approval of the MTQ.

We prepared a guided tour by our supervisor for our Gatineau bridge team and for our client, the MTQ's Outaouais Territorial Department. Some 30 individuals, including engineers, technicians and administrators, witnessed the progress and scope of the work.

CIMA+ designed the entire project to have as few unforeseen complications as possible during construction. In addition, contractors had few questions to ask during the tendering process, because of the exceptional clarity of our documents and plans.

Our constant emphasis on optimization enabled us to cut both direct costs during construction and maintenance costs once the bridge was put into service. In this particular case, the optimization effort enabled us to opt for simple bridge geometry in response to complex design requirements.

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We set up a team of exceptional and experienced engineers to address the challenges and issues posed by designing the Petite Nation River Bridge. The principal engineering team for this vast project remained the same throughout its five years of implementation. CIMA+ advises clients on what it is doing throughout all of its projects. We did likewise with the Petite Nation River Bridge project. We believe that this approach helped to put our client at ease during each phase of construction. The key individuals assigned to this task are listed in the following paragraphs.

5.3 DESIGN TEAM

Denis Gamache, P. Eng., M.Sc. A., Senior Structural Engineer and Principal Partner at CIMA+ and head of the Metropolitan Montréal Bridge Engineering Division, oversaw engineering structures used in the construction of the stretch of Autoroute 50 involved in this project. His 26 years of experience in managing the design of bridges and viaducts make him one of Québec's top engineers in this field.

Mr. Gamache asked Marie-Claude Michaud, P. Eng., M.Sc. A., who is now Project Manager and Design Coordinator for the Metropolitan Montréal Bridge Engineering Division, to serve as Senior Engineer. Ms. Michaud has acquired vast experience in the area of bridges and viaducts. This appointment allowed Ms. Michaud to transfer her broad experience to this major project. Specializing in the design of new structures, she developed a variety of computer software used to standardize the design process and accelerate the design of key bridge components, and to increase the level of confidence in these designs.

Munzer Hassan, P. Eng., Ph. D., and a graduate of the Swiss Federal Institute of Technology of Lausanne, brought his expertise and research experience to this project. He conducted the seismic analysis of the bridge and designed its piers and various earthquake-resistant components that had to meet the CAN/CSA-S6-06 Code.

Aleksander Mossor, P. Eng., Ph. D., has broad experience designing all kinds of bridge infrastructure and building structures. Mr. Mossor holds a doctoral degree and has more than 30 years of experience in the implementation and design of structures. He designed the deck for the Petite Nation River Bridge.

5.4 EXTERNAL EXPERTS

Always attuned to excellence, CIMA+ frequently retains top external resources. We consulted with leading experts in meeting the new CAN/CSA-S6 "lifeline bridge" Code requirements. They helped us to more fully understand the Code and to incorporate its requirements into our design.

Robert Tremblay, P. Eng., Ph. D., Professor at the École Polytechnique de Montréal, is an expert in seismic engineering and a member of the "Seismic Design" subcommittee of the Canadian Highway Bridge Design Code (CAN/CSA-S6). He helped us to interpret the new seismic standard, and supported our concept.

Professor Omar Challal, P. Eng., Ph. D., and Professor at the École de technologie supérieure de Montréal, is an expert in soil-structure interaction. He validated our plan to place the foundations on drilled shafts, and helped us to better understand soil-structure interaction in seismic analysis.

The new standard requires close teamwork between the structural engineer and the geotechnical engineer. We believe that the Petite Nation River Bridge is a benchmark for success in this regard. In a similar spirit of partnership, CIMA+ reached out to Québec's best resources in this field. Groupe Qualitas was put in charge of the geotechnical work. Jean-Hugues Deschênes, P. Eng., Ph. D., who has more than 30 years of experience in this field, and who has served as a project authority for the MTQ on many occasions, was familiar with the requirements of such a project.

Mr. Deschênes was the Senior Geotechnical Supervisor for the entire project. He directed the technical crew and coordinated operations and the review of site reports. He took great care to grasp every aspect of our requests, given the unique earthquake-resistant design of this bridge. This project presented a challenge for him.

5.5 CONSTRUCTION MANAGEMENT TEAM

CIMA+ set up a large on-site team to supervise the construction. Because the structure was so unique and the design was so advanced, the supervisor had to attend to each detail carefully, communicate clearly with the designer and contractor, and possess solid experience in constructing large engineering structures. This team included Pierre Meilleur, a Senior Engineer and Technical Bridge Manager, who has 32 years of experience, and Serge Desjardins, a Senior Engineer with 23 years of experience. This project posed a personal challenge to Mr. Desjardins, who specializes in dams and other large-scale civil infrastructure projects.

5.6 OUTSTANDING SUCCESS

This project provided a platform for teamwork among the various experts, thereby promoting the transfer of knowledge among designers, trainees, and construction workers. We also drew upon the builder's experience on numerous occasions. All of CIMA+'s partner firms benefited from the experience that was acquired in this project.

In this particular project, the mobilization of team members was crucial to the creative spirit required for the construction of the Petite Nation River Bridge. We maintained a highly constructive dialogue between the site's supervising staff and the contractor. We are of the opinion that this was a unique construction for this type of structure. We had to overcome numerous engineering and construction issues. We believe the best way to do this is to maximize the interest and motivation of everyone involved in the project.

CIMA+ not only brought together the best experts and teams, but also maintained an exceptional quality of communication and mobilization throughout the project. We are convinced that this effort enhanced the image of the profession in Québec and Canada, further increasing our desire to cultivate excellence within our firm.

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