



## Engineering and Designing Aluminum Structural Solutions

*Interview with Alexandre de la Chevrotière, CEO of MAADI Group*

MAADI supplied this aluminum equestrian bridge for the city of Blainville, Québec, Canada that is 20 m (65 ft 6 in) long and 3 m (10 ft 0 in) wide. The bridge allows horses, pedestrians, and 3.5 ton vehicles.

Alexandre de la Chevrotière, P.E. is president and ceo of the MAADI Group Inc., based in Montréal, Québec, Canada, since 2005 (Figure 1). MAADI is involved in aluminum design and engineering of civil, architectural, and maritime structures and has grown to be a major international designer for bridges and floating structures such as barges, wave attenuators, and breakwaters. A professional engineer and graduate of the Université du Québec – Ecole de Technologie Supérieure (Mechanical Engineering), as well as from the Québec Maritime Institute (Naval Architecture), he worked in several maritime design engineering capacities before becoming director of engineering at Norcan Aluminium and then forming MAADI. De la Chevrotière is a member of the International Aluminium Conference (INALCO) committee, and this year's 12<sup>th</sup> INALCO will be included as part of the first Canadian International Aluminium Conference (CIAC) from October 21-25, 2013 to be held in Montréal, Québec.



Figure 1. Alexandre de la Chevrotière

*Describe MAADI's overall business structure, mission, and its involvement in aluminum design of bridges and other maritime structures.*

MAADI Group is an independent legal entity (corporation). It has one shareholder (the founder) and share options to Centech (Centre de l'entrepreneuriage technologique), a startup center at the engineering school École de Technologie Supérieure (ÉTS). Centech is an organization that fosters the startup of technological enterprises that contribute to job creation and the advancement of know-how in Canada.

MAADI was created in 2005 at the demand of the CQRDA (Aluminium Research and Development Centre of Québec), an aluminum liaison and transfer center

in the Saguenay-Lac-Saint-Jean region, while I was working since early 2004 on Make-A-Bridge™, an aluminum bridge kit that is IKEA-style, an off-the-shelf pedestrian bridge structure that is ready to ship anywhere in the world for indoor/outdoor commercial, industrial, and recreational applications (Figure 2). The CQRDA wanted to provide funds to develop the Make-A-Bridge system kit, but it could only do this through a corporation, not with consultants. The money raised from CQRDA allowed MAADI to finance development and testing of the concept. The Make-A-Bridge's bridge joints (moment-resisting joints and system) have been granted two patents, while four other patents are still pending. These patents may apply to other types of aluminum lattice structures.

As founder of the corporation, I started to offer exclusive aluminum engineering services as a consultant back in 2003 (design of welded aluminum structures). Later, when MAADI was formed in 2005, the company added design/build to the engineering services for the civil, architectural, and maritime industries. The company is composed of professional engineers, industrial design-

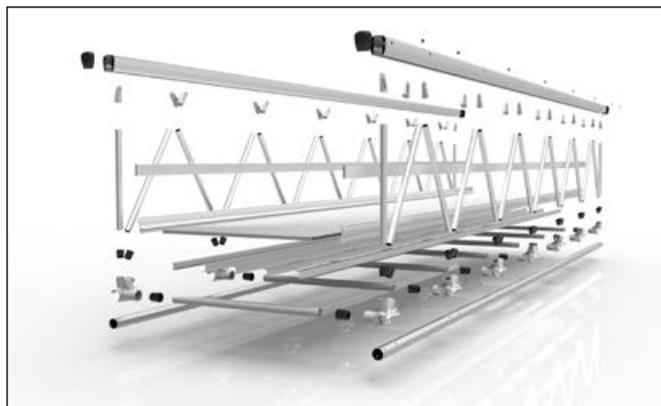


Figure 2. The multi-purpose Make-A-Bridge system uses interlocking aluminum extrusion components to build a structurally strong pedestrian bridge. The patented no-weld design increases aluminum's yield strength and eliminates thermally affected zones on the walkway structure.

ers, and technologists that can manage projects from the preliminary design to final installation steps. The entire team is dedicated to working with our customers to create structures that are maintenance-free, durable, aesthetically pleasing, economical, and fully sustainable for generations to come.

*Last year you coauthored a report on aluminum vehicular bridge construction for the Aluminium Association of Canada (AAC) detailing the need for upgrading the bridge infrastructure in North America and aluminum's advantages over conventional materials. How can aluminum compete with concrete and steel in this regard, especially considering current economic conditions?*

The main advantage of using aluminum over structural steel and concrete is that it is relatively maintenance-free (due to its high corrosion resistance), aesthetically pleasing, and can be transported and installed quickly (due to its low weight). Other advantages include its high formability (making it easy to extrude complex, custom shapes) and the ease with which it can be recycled at the end of its life. Aluminum has been used in a significant number of pedestrian and residential area bridge structures in Europe, Japan, and North America. In these applications, the primary reasons for choosing aluminum has been its light weight, aesthetic qualities, and durability of the unpainted metal. The London Millennium Bridge is an iconic example of a pedestrian bridge utilizing aluminum—the deck is constructed out of extruded aluminum sections.

Aluminum is not the cheapest material when only considering the acquisition costs. The material cost of aluminum alloys fluctuate in comparison with conventional construction materials such as steel. However, a cost per unit mass for aluminum that is greater than structural steel by a factor of four is typical. A 50% weight reduction can typically be achieved through the use of aluminum in place of structural steel, which translates to a two times greater material cost. Although this sounds like a high premium for building bridges out of aluminum, it should be noted that material costs make up only part of the total cost of constructing a new bridge. The primary reasons for choosing aluminum in pedestrian bridge applications will either be: 1) to reduce the erection costs by reducing the self-weight of the structure, or 2) to reduce the life-cycle costs by choosing a more durable material that requires virtually no maintenance. When these factors are considered, aluminum can be competitive, as demonstrated in a number of studies on structures including pedestrian bridges.

Lifecycle cost analyses have shown the economic benefits of using corrosion-resistant aluminum in bridge applications. The relative ease of transportation and erection of aluminum bridge components also lends itself well to accelerated construction projects and the erection of bridges in remote regions, because large parts of the structure can be prefabricated, shipped, and installed on-site.

*Lifecycle considerations have been successfully used by the aluminum industry to counter the arguments relating to higher initial cost of aluminum over steel in automotive vehicles. You had MAADI commission a Total Cost of Ownership Study (TCO) from Deloitte in regards to the lifecycle comparison of aluminum versus steel in pedestrian bridges. Can you give us a brief synopsis of this study?*

Aluminum is a corrosion-resistant material, making it a sustainable material for use in cold and corroding environments, such as in Canada. However, it is uncommon to see aluminum specified in call-for-tenders for large construction projects, such as highway and pedes-

trian bridges. In order to have aluminum specified in the future as a construction material, and knowing that the concrete and steel industries have very strong lobbies, MAADI felt it had to bring strong arguments about the economic advantages of using aluminum as a structural material. MAADI realized that few studies were done on the steel versus aluminum lifecycle cost comparison (including one study from the Technical University of Munich, Germany). MAADI asked for the financial support of the CQRDA back in 2010 to commission a study that would serve the entire industry. MAADI mandated the services of material scientist Frank Ajersch, P.Eng. Ph.D., from FABMATEK Inc. to produce a 33-page investigation report on the real cost of a 70 ft long ASTM 50W steel pedestrian bridge protected with three different coatings (those typically used in the bridge industry). Later, in 2012, MAADI asked the AAC to assist with financial support to complete the project and mandated Deloitte to complete a financial analysis following Ajersch's steel maintenance cost findings.

This led to a study entitled "Cost, Lifespan Considerations for Engineers: Aluminum is the Durable, Maintenance-Free Material Choice for Structural Building Projects." Study results show that when you compare the TCO of two comparative bridge structures made of steel and its aluminum equivalent over a 50 year period (based on the same design code: Canadian Highway Bridge Design Code), decision-makers can no longer assume that steel is always the best option economically when investing in civil engineering structures. This analysis demonstrates that aluminum competes with steel when the TCO is considered. The case for aluminum becomes even more apparent when the project is located in a highly corrosive environment.

*What technical guidelines does MAADI use in designing some of the impressive aluminum structures it has built, and are the safety and resistance factors in The Aluminum Association's Aluminum Design Manual 2010 used in MAADI designs?*

MAADI works with many different codes and standards, since most countries have their own design and construction standards and codes. MAADI, however, uses a design method called in Canada Limit States Design (LSD), rather than Allowable Strength Design (ASD), which is an older method still in use in the U.S. The main difference between each method is that the yield or ultimate strength of the material is divided by a factor of safety specific to the application of the structure (e.g., bridges and buildings each have their own different factor of safety) for ASD, rather than LSD or Load and Resistance Factor Design (LRFD) that have their loads factored. The LSD method is comparable to the LRFD method, newer in the U.S. Since MAADI is active in many different fields and regions in marine, civil, and transportation, the latest method is better suited to most of the Western countries and applies well to SI (International System of Units). The LRFD is now addressed in PART 1-B in the *Aluminum Design Manual*. The *Aluminum Design Manual* original edition dates from 1967, while the Canadian design code original edition (structural use of aluminum in buildings) CSA S157 dates from 1969.

There are very good textbooks for any engineer interested in aluminum design. In the U.S., it is *Aluminum Structures: A Guide to Their Specifications and Design*, by Randolph Kissell and Robert L. Ferry. In Canada, it is *Design of Aluminum Structures*, by Denis Beaulieu; and in Europe it is *Aluminium Alloy Structures*, by Federico Mazzolani. I would highly recommend each of them.

There are also very informative 1½ day seminars given across the continental U.S. every few months on the new

*Aluminum Design Manual.* These seminars are also offered online with Randolph Kissell, a P.E. specializing exclusively in aluminum in the U.S. I attended an American Society of Civil Engineers (ASCE) seminar back in 2002 in Pittsburg and definitely recommend it.

*What about fusion welding of aluminum versus steel? Is friction stir welding (FSW), successfully used for solid state joining of aluminum extrusions in ship decking and other applications, an option for joining bridge decking and other bridge structures?*

A considerable local strength loss can result from conventional fusion welding processes. There is a significant difference between aluminum and steel, which must be accounted for in the design. The effects of this strength loss can be minimized by smart detailing and using longitudinal, rather than transverse welds. I had been introduced to FSW back in 2004 at the International Aluminum Connections Conference at the Lincoln Electric Company, Cleveland, OH (now called the INALCO conferences being held every three years on all continents). FSW (dating from 1991) is a promising welding process and consists of a solid-state process that produces welds of high quality with low energy input that has been found to produce very high-strength welds. FSW has been successfully employed to join aluminum bridge deck sections. Applying FSW to other components of vehicular bridges is an area warranting further study.

*What is the basis for MAADI's aluminum alloy selection for maritime and architectural structures?*

Aluminum alloys, and in particular the 5xxx and 6xxx series, are known to be much more corrosion resistant than plain carbon or atmospheric corrosion resistant structural steel (Figure 3). This is of particular interest

in Canadian vehicular bridge applications, where heavy road salt use in the winters is prevalent. Although there is much in the way of anecdotal evidence of the good corrosion performance of aluminum in marine and highly corrosive industrial environments, further research to quantify this benefit would be beneficial. In one study where this benefit was quantified, the results for aluminum were highly favorable. In an environment with high salt exposure and medium exposure to pollutants, an annual thickness loss of 0.0194 mm/year was reported for aluminum, versus 0.81 mm/year for weathering steel and 2.19 mm/year for carbon steel (Houska, C., "Deicing Salt – Recognizing the Corrosion Threat," [www.imoa.info/\\_files/pdf/DeicingSalt.pdf](http://www.imoa.info/_files/pdf/DeicingSalt.pdf)).

In highway bridge applications, several of the older aluminum structures still in service are providing evidence of strong corrosion performance for service periods exceeding 45 years. Evidence of poor corrosion performance of aluminum structures has also been reported. This can generally be attributed to the use of older, less corrosion resistant aluminum alloys (such as 2xxx alloys), or to poor detailing that resulted in direct contact between aluminum and concrete or locations on the structure where water could sit in close proximity to lap joints, thus creating conditions for crevice corrosion to occur.

*How do local and country building codes affect aluminum bridge design in Canada, U.S., and other countries?*

The CSA-S157 standard has been available for quite some time (1969) for the design of aluminum structures in Canada. Although it was recently renewed in 2005, it has been a while since the code has been thoroughly reviewed and updated. This standard is most applicable in Canada for the design of aluminum building structures. However, the design

procedures in this code enable determination of the ultimate resistances of members and connections. Thus, CSA-S157 has general validity and has been applied to all types of load-bearing aluminum assemblies for which there is no separate design code. This includes such applications as lattice towers, cranes, vehicles, rolling stock, and (until recently) pedestrian and vehicular bridges. Aircraft design, pressure vessel design, and other well-established fields have their own bodies of rules. A much more recently updated example of an international standard for aluminum structure design is the Eurocode 9 standard "Design of Aluminum Structures." This code applies to aluminum structures in general (i.e., not only building structures), and could be used in conjunction with the related Eurocode 1 standard for "Actions on Structures" to design aluminum pedestrian and vehicular bridges.

In the U.S., the Aluminum Association regularly updates and maintains the *Aluminum Design Manual*. The focus of this manual is on the determination of the resistance of members and structures. However, this manual also contains a wealth of information concerning material and section properties.

For the design of aluminum bridge structures using one of these general standards for aluminum structure design, engineers might consider using a general standard for calculating structural resistance, along with appropriate bridge



Figure 3. Top: Rendering of aluminum barge MAADI designed and built in October 2012. 5083 plate was used for the hull of the structure during the construction process and marine bulbs were extruded from 6061 T6 alloy. Bottom: The internal structure of the port side of the barge is shown. The structural arrangement sustains the pressure of one meter of ice thickness.

design code provisions for calculating the loads and load effects. One problem with this approach is that modern building and bridge codes contain load and resistance factors that are calibrated to ensure acceptably small probabilities of failure. The different factors are linked, so if you take load factors from one code and resistance factors from another, then there is a risk that the safety objectives of one code or the other will not be achieved. This approach should therefore be avoided.

One reason for the limited use of aluminum in vehicular bridges is the lack of familiarity that most bridge engineers have with aluminum structure design and the historical lack of suitable codes and standards on the design of aluminum bridges.

In the U.S., the American Association of State Highways and Transportation Officials (AASHTO) specification for highway bridge design has included a chapter on aluminum structures for many years. This chapter shares many common elements with the *Aluminum Design Manual*. Importantly, this code contains both resistance and load provisions for aluminum highway bridges, resulting in a level of safety for aluminum bridge structures that is consistent with the level of safety specified for concrete and steel bridges. In Canada, it was recently recognized by the aluminum industry and the Canadian Standards Association that information was needed in a single code for designing aluminum bridges. This led to the formation of a new technical committee for the Canadian Highway Bridge Design Code (CAN/CSA-S6), chaired by Professor Beaulieu from Université Laval. This committee completed its work on the new Chapter 17 for *Aluminum Structures*, which was recently published in a 2<sup>nd</sup> supplement to the 2006 code in the fall of 2011.

In developing the new code chapter for CAN/CSA-S6, a conscious decision was made to organize the chapter in the same way as the current steel chapter, so that bridge designers more familiar with structural steel design would have minimal difficulties applying the new code provisions. Provisions from the CSA-S157 aluminum structures code were used as a starting point. However, where these provisions were deemed to be outdated, the existing American and European standards were looked to for guidance.

*Describe your committee work with INALCO and synergy with MAADI. How and why did you become involved with organizing INALCO 2013 in Montréal in conjunction with the CIAC?*

I always found there was a lack of information or education regarding designing of aluminum structures. Since 2002, I started to attend as many congresses as I could, to find answers to my constant curiosity about aluminum design while I was working as a design engineer for an aluminum fabricator in the marine industry. In 2002, I attended the 2<sup>nd</sup> International TransAl 2002 Conference in Lyon, France, and the same year I attended an aluminum workshop in Boston, MA, organized by Prof. Teoman Pekoz from the Cornell Civil and Environmental Engineering faculty. During these events, I had the pleasure of meeting influential people in the aluminum industry. In 2004, I attended my first INALCO conference, which was my first contact with INALCO in Cleveland. I found it very interesting that designers, researchers, and production managers from various industries nevertheless had the common point that all of them use aluminum and could share knowledge and solve problems related to aluminum design and construction in automotive, aerospace, shipbuilding, and infrastructure, etc.

In engineering, most of the knowledge is transferable from one industry to another. For rupture mechanics, fabrication process, or welding, etc., the same rules usu-

ally apply to different applications. At the moment, MAADI is working on a project with Bombardier Aerospace for the C-Series jetliners. The next month, MAADI may work on a project that consists of a wave attenuator for the Bahamas or a bridge for the city of Ottawa. The only common points are 'aluminum' and stress design.

A few months before June 2010, the date at which the last INALCO conference was held in the Netherlands, I was contacted by my colleague Randy Kissell, a well-known pioneer in the worldwide aluminum industry and also known as pioneer for the INALCO organization in the U.S. He told me that INALCO would come back to America (after an absence of nine years), and he remembered I had told him back in 2004 that I would be pleased to be involved in the organization of an INALCO conference in Montréal (that would be for the first time in Canada). He then offered me to bring the 12<sup>th</sup> INALCO conference to Montréal. The conference is now organized under the CIAC, which is an umbrella over four aluminum conferences during a complete week: INALCO 2013, Mission Design, AluSolutions 2013, and Recyc-Québec). MAADI, the engineering school ÉTS, CQRDA, the AAC, and Aluminium Research Centre (REGAL) are the organizers of the INALCO 2013 conference. The CIAC has mandated The Sanford Organization (TSO) to set up and manage the technical presentations and call for papers for the INALCO conference.

*As a structural engineer who works extensively with aluminum, in addition to attendance by aluminum industry professionals, why do you believe the CIAC and INALCO conferences are important for product designers and engineers to attend?*

Aluminum doesn't get all the attention it merits and surprisingly, it is still an unknown metal for some professional engineers and architects, because it is not usually taught in universities at the undergrad level. Aluminum may not come to mind in some buying processes, or to contractors, architects, and design engineers when the time comes to make a material selection.

A designer who is familiar with aluminum extrusion takes great advantages from this powerful and creative tool. In fact, this is the number one advantage that MAADI cherishes! The extrusion process, almost exclusive to aluminum alloys, is the main advantage that makes it possible to do smart and highly creative distinctive design in order to add functionality and better mechanical design, because smart detailing allows better resistance to bending, spot or torsion stresses, or simply enables us to integrate a number of features into the design, such as t-slots, teeth to prevent skidding, or adding the tongue-and-groove feature to facilitate joining.

While a designer must have a good understanding of aluminum, he must also be familiar with the material's opportunities and limitations. INALCO is a well-chosen conference for them to get more familiar with aluminum and its latest developments, including design and transformation within different industries. From an engineering design perspective, INALCO 2013 presents the most important aluminum seminar for industrial products or structures.

*Editor's Note: Two of the reports coauthored by Alexandre de la Chevrotière are available as pdf downloads from the MAADI Group website: "Opportunities for the Use of Aluminum in Vehicular Bridge Construction" ([www.maadigroup.com/wp-content/uploads/2012/11/AAC-Aluminum-Bridge-Report.pdf](http://www.maadigroup.com/wp-content/uploads/2012/11/AAC-Aluminum-Bridge-Report.pdf)) and "Cost, Lifespan Considerations for Engineers: Aluminum is the Durable, Maintenance-Free Material Choice for Structural Building Projects" ([www.maadigroup.com/wp-content/uploads/2012/03/ID-Etude-manufacturiere\\_MAADI-EN-Web-2-.pdf](http://www.maadigroup.com/wp-content/uploads/2012/03/ID-Etude-manufacturiere_MAADI-EN-Web-2-.pdf)).*