HISTORY NOTES

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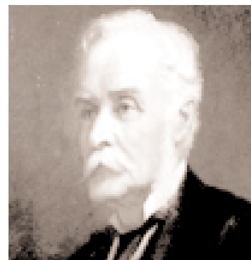
Casimir Gzowski



Thomas C. Keefer

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A BACKGROUND HISTORY OF THE CSCE

By Peter R. Hart, FCSCE

The history of the profession of Civil Engineering can be traced back for many centuries, in much further than the recorded history of self-serving groups that developed, in the tenth century, into the guilds and, subsequently, the learned societies and trade unions.

There is a certain amount of controversy over the origin of the word "engineer" and it seems most likely to have come from the Latin word for an invention or engine, "tingenium", which not only appears to be the root of the English word "engineer" but also the French word "ingénieur". However, the asset that most engineers have, ingenuity, appears to come from the Latin word "ingenuita". Both "ingenuita" and "ingenium" have a common Latin root – "gen" (to bear, to give birth to, to produce).

John Smeaton, in 1 782, was the first engineer to call and sign himself "Civil Engineer". Having been elected a Fellow of the Royal Society (FRS) at the age of 29, he had founded a Society of Engineers, in 1771. After his death, in 1792, the Society of Engineers was re-established and held its first meeting, as the Society of Civil Engineers, on April 15th, 1793. This Society eventually became the Institution of Civil Engineers (ICE) which received a Royal Charter in 1825.

Engineers in non-English speaking European countries also formed special interest groups which were rather more academic in nature, due mainly to the different education received by engineers in Europe, where the engineer was trained very thoroughly academically with little or no practical working experience. This practical side of engineering was provided by the artisan who had trained as a pupil on the job. However, in Great Britain a major emphasis in the training of an engineer was the gaining of practical skills, usually through apprentice-ship to a fully qualified engineer as his "pupil", later called his "engineer-in-training". This method allowed the acquisition of the necessary academic skills for the design arts to be obtained at the same time and, not surprisingly, North American engineering training closely followed this pattern.

In the United States, the Franklin Institute (established in 1824) attracted many engineers and, in 1852, a group of engineers met in New York which resulted in the establishment of the American Society of Engineers and Architects which was renamed the American Society of Civil Engineers (ASCE) in 1869.

In British North America, the political advantages of a unified country "from sea to sea" in part to provide a stop to the territorial ambitions of the United States of America, were realized and, in 1867, The British North America Act (BNA) was passed by the British Parliament in Westminster.

In 1931, as the result of the Statute of Westminster, the British Parliament gave up all sovereign legislative authority over Canada but, at the request of the provinces, they retained the right to approve any amendments to the BNA. In 1981 the Canada Act was passed which transferred the British North America Act into the Constitution of Canada, together with a Charter of Rights and an amending procedure. This became law on April 17th, 1982.

The BNA had assigned certain legislative powers, including the regulation of the professions for the protection of the public, to the provinces in order to govern the vast, largely unpopulated, country it had created.

Prior to Confederation, engineers working in the Provinces and Territories of Canada had tried to set up learned societies with little success. Sir Sandford Fleming was closely associated with the Canadian Institute, founded in 1849, which, having broadened its areas of interest, became incorporated in 1851 as the Royal Canadian Institute, "*more particularly for promoting surveying engineering and architecture*" as Thomas Keefer states in the first presidential address to the newly formed Canadian Society of Civil Engineers in 1888.

The formation of Canadian engineering educational establishments started in the mid-19th century with the first program in civil engineering being given at King's College. in Fredericton, in 1854: this college later became part of the University of New Brunswick. The graduates of this and the other recently established late-19th century programs were looking for recognition so that, after Confederation, the spirit of Canadian nationalism rose in the engineering profession.

In 1881, a bill to regulate civil engineers in Ontario failed to gain the necessary support to become law. F.W. Plunkett probably influenced this bill. He was an Irish-Canadian who, in 1880, had started to interest his colleagues in a national group of engineers, unfortunately unsuccessfully. In 1886 Alan MacDougall, a Scots-Canadian, tried to do the same and meetings were held in Toronto, Montréal and Ottawa to explore the possibilities of such a group. The Montréal meeting, chaired by MacDougall, passed a resolution to form a society of engineers. A preliminary meeting was held later in that year to arrange for the establishment of the society, its name and its constitution. This meeting was attended by representatives from Montréal, Ottawa and Toronto.

In January 1887, a group of engineers met, again in Montréal, to elect members to the newly-established Canadian Society of Civil Engineers (CSCE). Members (162) were duly elected and 126 more were added when the First General Meeting of the Society was held, in Montréal, on February 24th, 1887. Officers were elected and an application to Parliament for a Charter was approved. As the result of the efforts of the Irish-Canadian civil engineer Walter Shanly (the subject, with his brother Frank, of a recent book by Richard White) who, as a Member of Parliament, sponsored the Private Member's Bill to which Royal Assent was given on June 23rd, 1887, the Society obtained its Charter. Two days later, Thomas C. Keefer was named Founding President (throughout this mid- to late-19th century period Keefer had been actively promoting some type of professional society, so that his installation as the Founding President was highly appropriate). Casimir Gzowski, John Kennedy and Walter Shanly were the vice-presidents, and Henry T. Bovey the Secretary and Treasurer. MacDougall was elected to the Society's Council. The Society, which had members from the several different engineering disciplines extant at that time, made its headquarters in Montréal.

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The First World War marked the emergence of civil engineering as a specific discipline in Canada along with mechanical and electrical engineering. Following a report tabled by H.E.T. Haultain, in 1917, the Society decided to change its name to the Engineering Institute of Canada (EIC) in order to continue to represent all engineering disciplines, although the civil engineering membership was in the majority. The 1887 Act was amended in April 1918 to enable this change to the Charter.

There was a great deal of debate in the early days of the Canadian Society of Civil Engineers concerning the qualifications and expertise that a member of the public should seek from an engineer and, at that time, the Society decided that the regulation of engineers and the practice of engineering, by means of provincial legislation under the BNA, was not in the best interest of its members.

In spite of this the young Province of Manitoba appears to have been the first to regulate engineering, as it passed "An Act respecting the Profession of Civil Engineer", in 1896:

> *"...for the better protection of the public's interests and more particularly for promoting the acquisition of that species of knowledge which has reference to the profession of a Civil Engineer... and in order to enable persons requiring professional aid in any work, to which such knowledge of Civil Engineering is applicable or necessary, to distinguish between qualified and unqualified Civil Engineers."*

This act, known as "The Manitoba Civil Engineers Act", provided that:

> *"...no person shall be entitled within this Province to take or use the name and title of 'Civil Engineer' implying that he is a member of the said [Canadian] Society of Civil Engineers, or act as Engineer... [on] any work upon which public money is expended... unless such person is a member of the Society..."*

The aftermath of the First World War saw the need for an attitudinal change amongst engineers and, shortly after the CSCE became the EIC, it was decided at a Special Meeting held in Saskatoon in 1920, that a registry of properly qualified engineers was desirable and that the best way to achieve this was to encourage the provinces to use their powers, granted under the BNA, to set up registration bodies to become self-governing associations of professional engineers. Incorporation of these provincial registration bodies started in the 1920s and many of them have now celebrated their 75th anniversary.

Attempts to consolidate the engineering profession into a single national organization have always failed to gain the required support. The first, in the 1930s, did not act as divisively as the second, in 1957, when, in spite of the EIC and the Canadian Council of Professional Engineers (CCPE) forming committees to study the proposal in depth, the voting (the CCPE membership being in favour and the EIC opposed) was against the concept.

As a result of the Second World War and subsequent Cold War, many small specialized learned societies had been formed, causing splintering within some of the more traditional engineering disciplines. Canada was no exception to this trend, which was, in some cases, pushed by a nationalistic reaction to the plethora of groups, based in the United States of America, who regarded Canada as part of their territory. The Institute, concerned with the further splintering of the profession in Canada by foreign specialized groups, encouraged the formation of technical divisions, covering civil, mechanical, electrical, chemical, mining and hydro-electrical engineering within the Institute. In the late 1960s the EIC recommended that support and encouragement be given to its technical divisions to become autonomous constituent societies operating under the Institute's charter. A steering committee was set up, in 1968, to develop a proposal for a constituent society for mechanical engineering and an institute committee was established to ensure that the EIC's by-laws etc. were conducive to the establishment of constituent societies within the Institute. The proposed Constitution and By-laws of the Canadian Society for Mechanical Engineering (CSME) and the formation of the CSME in January 1970 were approved. In this way the EIC responded to the major Canadian engineering disciplines in the early 1970s by becoming a federation of constituent societies; the CSMF in 1970; the Canadian Geotechnical Society (CGS) (having already been loosely established and functioning since the 1950s as a group interested in Soil Mechanics, primarily as the result of the efforts of Robert Legget) in January 1972; the Canadian Society for Civil Engineering in June 1972 and, later, the Canadian Society for Electrical Engineering.

The slight change in the names, from *Canadian Society of "Xxxx" Engineers* to *Canadian Society for "Xxxx" Engineering*, was necessitated by the recognition that a constituent society's membership could include engineers, and possibly others, awaiting registration or not registered as professional engineers in Canada. In Québec the act establishing l'Ordre des ingénieurs du Québec (OIQ) restricted the use of the word "engineer", and therefore, any member of a society using that word in their membership designation, who was not registered as a professional engineer, could be liable to legal action. Other provincial associations also expressed concern with the name.

The CSCE was, therefore, re-established in 1972 and is looking forward to its sesqui-centennial in 2037. ■

Canals

By Ken Mackenzie, FCSCE

Canada is favoured with an inland waterways and canal system which is second to none in the world. The present St. Lawrence system by itself dwarfs all other inland waterway systems, however assessed. The system accommodates vessels up to 30,000 tons over a distance of about 3800 km from the Atlantic.

Most of the large works were built in the 20th century and this note pays particular attention to those, but it is instructive to put these very large works in their historical perspective.

PIONEERING 19th CENTURY CANAL WORKS

The earliest notable canal works in Canada were built by the British Royal Engineers on the Rideau and Cataraqui Rivers and the intervening lakes system. This is now known as the Rideau Canal. The Royal Engineers at that time were officered by men who had received a thorough education in what is now termed civil engineering. Their engineering works can be seen around the world, in roads, irrigation, canals, harbours and of course in fortifications. Many of them were accomplished watercolour artists whose paintings are now collected for their historic and technical interest. In the late 1700s they had been involved in navigation improvements on the St. Lawrence River to facilitate the movement of troops and matériel to Upper Canada. The British military staff was concerned that the Americans might entertain ideas of a further attempt to extend their hegemony northward. If they did, there was a vulnerable stretch of international border along the St. Lawrence River approximately between Kingston and Cornwall. A British army engineering unit unrelated to the Royal Engineers had, in the period 1819 to 1834, constructed a series of small canals to bypass rapids in the lower Ottawa River. The British government decided to provide a more easily defended east-west route by using this partly tamed length of the Ottawa River together with a new canal to be constructed from Ottawa south-west to Kingston. The Rideau Canal was constructed under the command of Lieutenant Colonel John By between the years 1827 and 1832. The waterway is an ingenious combination of excavated canal bed and the natural lake system. It was one of the largest construction projects in North America at the time. Thankfully, it was never used for its military purposes, but helped to peacefully open up Eastern Ontario to agriculture and industry. It passes through beautiful wooded country and is now a popular recreational linear park, beautifully maintained by Parks Canada. One of the beauty spots is at Jones Falls, where a remarkably innovative masonry dam was constructed to impound one of the lock head ponds. The horizontal arch of the dam gently curves 107 m along its crest and has a maximum height of 19 m. It has been visited and admired by generations of engineers.

The Rideau Canal was constructed by both direct labour and by tendered contract. Most of the other 19th century canals were built by contractors, and were constructed for government agencies, sometimes after private company promoters had foundered. A good example of government being obliged to assume ownership occurred later with the first Welland Canal.

Even before the military navigations there were much smaller commercial works in various parts of the country. In 1797 a canoe lock was built at Sault Ste. Marie by the North West Company. Probably the first "real" canal in Canada was the early Lachine canal, built between the years 1821 and 1825.

The first short canal in Upper Canada, known as the Desjardins Canal, had been completed in Burlington Bay in 1826. Its remnants can still be seen. This was the beginning of Canada's period of "canal fever", a phenomenon also seen in many European countries and the United States. Promoters launched schemes which in many cases lacked both technical and economic viability.

Residents of the Niagara peninsula had keenly observed the progress and tribulations of the Erie Canal in neighbouring New York State. It was feared that if nothing was done in Canada the enterprising Americans would next build a canal in New York State to provide navigation around Niagara Falls from Lake Ontario. A group was formed in St. Catharines, Ontario, to promote the construction of a Canadian canal between Lake Ontario and Lake Erie. The first of the four Welland Canals was largely the result of the foresight and persistence of William Hamilton Merritt. He had returned to St. Catharines from captivity as an American prisoner-of-war in 1815 to set up in business and to operate mills on Twelve Mile Creek. Merritt, like his fellow millers, was frustrated by the erratic creek flow, and he concluded that it would be economically feasible to construct a canal which would include controlled stream flow. The initial canal route would be from Port Dalhousie on Lake Ontario, up the face of the Niagara escarpment and then to meet with the Chippawa Creek which flowed into the Niagara River some distance above Niagara Falls.

The Welland Canal Company, with George Keefer as president, was incorporated and started on its turbulent three-decade course. The first Welland canal opened in 1829 after five years of financial travail, internecine strife in the work force, and epidemics of cholera, "swamp fever", plague and dysentery. There were 40 wooden locks which could take vessels of up to about 180 tons. Adding to Merritt's problems, particularly as he attempted to attract more investors, was the threatened arrival of the railroad, the nemesis of many canal projects. The Canal Company attempted to improve its operation by extending the canal alignment south directly to Lake Erie. It became even more financially extended and was glad to have the government buy shares. Finally, in 1839, the Upper Canada Legislature decided it had to take over the company.

During the 1840s there was a great deal of canal activity in various parts of the country. On the Welland the prohibitive cost of maintaining the wooden locks drove the government to build the second Welland Canal of cut-stone masonry locks. The improved construction methods of the new canal, which opened in 1845, reduced the number of locks from 40 to 27. In Québec the nine-lock Chambly Canal and the single lock Ste. Anne's canals were built, the former to connect with U.S. canals and the latter, between Île Perrot and Montréal, as part of the Ottawa River improvements. The Chambly gave the Americans their first direct water navigation connection to the St. Lawrence River. The Ste. Anne's, with improvements in 1878 and 1886, is still functional.

There was more activity in the 1870s, on the Trent River system in the Muskokas in Ontario, and on the third Welland Canal starting in 1875. In the Maritimes there were the Chignecto canal/railway project which was stopped when partially completed, the St. Peter's at the Great Bras d'Or channel, and the Shubenacadie.

At the end of the century, work continued on the St. Lawrence River system at the Lachine Canal and its enlargements, the Beauharnois and its successor the Soulange Canal, and the Cornwall system around the Long Sault. The Canadian Sault Ste. Marie canal opened in 1895 with the impressive lock dimensions 273 m by 18 m, and a sill depth of 5.5 m.

When the century began, the science and art of canal building was new to the Continent. Construction methods were primitive and based almost entirely on human and animal effort. By the end of the century Canada had developed navigation capability into the heart of the continent. Complex heavy construction equipment and techniques were available. The civil engineering profession was soundly established and experienced for the demands of the 1900s.

MATURITY — THE 20th CENTURY

By the year 1900 Canada possessed a commercial waterway system between the Atlantic Ocean and the Great Lakes which substantially fulfilled the dreams of the early European settlers. The extensive channel improvements and canal works on the St. Lawrence, together with the construction of the third Welland Canal, now meant that ships up to 85 m long of 13 m beam and 4.2 m draft had access throughout the Great Lakes. In the years before the First World War, huge dredging contracts were carried out in the St. Lawrence so that, by 1914, depths of 10 m had been cleared. There was constant need to accommodate increased shipping. Other canals provided additional commercial access. Many were increasingly used for recreation, as the railways, and later the highways, took over more and more freight haulage.

By the year 1900 it was also clear that ship sizes, both on the upper lakes and internationally, now exceeded the capacity of the upper St. Lawrence River and the third Welland Canal. The country had now developed the ability and economic strength to tackle the challenge of yet another series of massive canal projects. Once again Government was heavily involved in planning, and it was now felt that the required skills and methods were available. A number of parliamentary reports were tabled, leading to the concept of a coordinated St. Lawrence Seaway.

Most importantly there now existed a cadre of experienced professional engineers capable of proficiently handling the work. The Canadian Society of Civil Engineers had been organized in 1887. The first president of the Society was Thomas Coltrin Keefer, who had been involved in the planning of the second Welland Canal and had worked on the Ottawa and the St. Lawrence Canals. He was the author of an essay "The Canals of Canada" published in 1850. T.C. Keefer died aged 94 in 1915, having had a lifelong interest in the development of the country's waterways systems. The scale of inland navigation projects had increased greatly in the last decades of the old century. One of the decisive factors in planning such grand scale enterprises was the more widespread use of Portland cement concrete, which had been first used in large civil works in Canada as recently as 1835. Engineers had been unnecessarily concerned about its cost, and more understandably concerned about its freeze-thaw resistance. Mechanical excavating, dredging and hoisting equipment had more than kept pace with ever-increasing project size. Much had been learned from the sizeable works on the third Welland Canal which continued well into the 20th century.

THE FOURTH WELLAND CANAL

Before the 1914–1918 war, and indeed from the time of the opening of the third Welland canal in 1887, there were groups pressing for a larger canal into the upper Great Lakes. There were excellent reasons for the lobbying. The third Welland canal was a bottleneck which required the large upper lakers to trans-ship their downbound cargoes onto smaller ships at the southern end of the third Welland at great expense and with serious loss of time. There were still at this time many who favoured the Georgian Bay Ship Canal proposal which would use the Ottawa River route to Lake Huron. Even though this Ottawa River route had the distinct advantage of bypassing the 14-foot (4.3 m) depth restriction of the St. Lawrence locks, the end result of a number of parliamentary reports was the decision in 1909 to construct a new Welland canal. It appears that this had been foreseen by the local engineers of the Federal Department of Railways and Canals, who had been quietly running route surveys across the Niagara Peninsula since about 1906.

The Welland Ship Canal, as it was then named, would run south from a new Lake Ontario entrance to be called Port Weller, about five kilometres east of the earlier entrances at Port Dalhousie. It would run south for about 10 km with three single-chamber locks to the foot of the Niagara escarpment, where it would climb 45 m in three twinned pairs of locks. There would be a single lock between the top of the escarpment and the Lake Erie guard lock at Port Colbourne. The canal would be 43 km in length with a total lift of 100 m. The lock widths were 24.3 m, the lengths 222.5 m, except for the Guard Lock no. 8 at Port Colbourne, which was 350 m in length. The general canal prism dimensions were 94 m on top, 60 m bottom and 8.2 m depth. The canal was sized for vessels of about 30,000 tonnes deadweight. It was thought that, all being well, the canal could be constructed in about five years, starting in 1913. The canal in fact opened 19 years later, on August 6th, 1932, after being halted in 1917 during the Great War, and only restarting in 1919.

The sheer size of the enterprise was unprecedented, and the logistics were daunting. Popular imagination was intrigued by the idea of lifting 30,000-ton ships nearly 50 m up such a steep incline. Worldwide attention was directed at the mammoth project, to continue during the ups and downs of the next 20 years.

The new alignment of the fourth Welland canal meant that the city of St. Catharines was essentially bypassed, but the line went through Thorold, Welland, Port Colbourne and several smaller communities. It went through a region of richly productive farmland. It cut across a complex road system and five major railroads, which serviced a mature industrial and commercial area. The new route conflicted with much of the busy third canal. Keeping navigation on the third unimpeded while constructing the fourth, building 20 new bridges, handling road and rail traffic, and moving several existing bridges called for exceptional planning and execution. At times the demand for labour, steel, cement and skilled contractors put a strain on the provincial economy. Land assembly costs alone finally amounted to about $ 2 million or 1.5% of the final project cost of $130 million; the cost of engineering was almost $9 million.

The contracts called in 1913 were mostly based on unit price. The canal line was divided into eight sections, and some of the excavation contracts were for an entire section. Labourer wage rates were about 20 cents per hour. With the loss of men to the armed forces after 1914, and the lessened priority given to the canal, the pace of the work slackened and a halt was called in 1917.

When the work began again in 1919, labour was at first plentiful, and the labourer's wage rates had increased to 40 cents an hour. The contractors were reluctant to take fixed price work or even unit price work, so the contracts were now called cost plus. The pace of work picked up, and a vast array of men, equipment and materials was mobilized. In 1919 the work was put in the hands of Alexander J. Grant as Engineer-in-Chief. Grant was a native of Banffshire, Scotland, who had joined the federal Department of Railways and Canals in 1886, just before the third Welland canal was opened and not long after the Department was established. He worked on the Soulanges Canal, and on the harbour improvements at Port Colbourne from 1903 to 1906. He was in charge of the Trent Canal works from 1906 until he arrived on the Welland in 1919, and did not retire until after the new canal opened. Grant at one time was president of the Engineering Institute of Canada.

The large staff assembled under their new Engineer-in-Chief faced a formidable series of challenges in the next 14 years. They could count on many capable and experienced construction people in their own ranks and those of the contractors as they built up their companies after the war. They now had at their disposal equipment developed and improved by the demands of pre-war heavy construction. The canal works would require 40,000,000 m^3 of earth excavation, 7,000,000 m^3 of rock excavation and they would consume 2,300,000 m^3 of concrete. Excavation equipment ranged from 5 m^3 steam and electric power shovels to grader mule teams, which were still used as late as the early 1930s. Single-lift moveable concrete forms 30 m in height were in general use on the lock walls. Reliable underwater blasting techniques were developed.

The temporary works such as concreting towers, very large cranes and hoists mounted on rail track, piling rigs and coffer dams were on the same massive scale. An early decision had to be made during the course of the work to change from the proposed single leaf lock gates to double mitre gates. So that these 30 m by 15 m steel gates could be readily transported and placed in position, a pontoon was devised to incorporate a 25-ton crane. This remarkable craft stood about 40 m high and its stability and verticality were controlled by raising or lowering the level of ballast water in tanks on its periphery. A submarine saw, mounted on a tapered structural frame, was built to cut pile caps at a depth of over 20 m.

Grant and his people knew that they could expect some mishaps. At the north end of the canal there was one of the great harbour works for the canal, at Fort Weller. Among the early work here were two groynes or training walls of rock fill which were being constructed about one kilometre into Lake Ontario using a temporary rail bridge. A fierce winter storm late in 1915 took out much of the work, fortunately with no loss of life, but adding huge cost. The early 20th century engineers suffered like their predecessors on the first Welland Canal from their imperfect knowledge of soil behaviour. There were many embarrassing slides into the work, sometimes only from a side cut excavation, but also at times involving constructed facilities such as piers and piled foundations. It is interesting to note that in those less litigious times accidents and failures were not only thoroughly investigated, but their lessons were widely disseminated.

Over and above the straightforward work of the canal proper there were the two large port facilities, an aqueduct at Welland which was a large project in itself to take the Chippawa Creek under the new canal, several dams as high as 30 m to impound the various head ponds, a power station utilizing the fall of water down the escarpment to generate enough electric power to supply the entire canal system, as well as the 20 bridges. These are impressively-sized structures, providing either open overhead clearance, in the case of the rolling lift bridges, or a minimum 36 m clearance in the case of the lift bridges. The bridges are only minor auxiliary elements in the system, but when their number and size are considered, the magnitude of the fourth Canal is again put into perspective.

The economic cost for the fourth Welland Canal was stated to be $130 million. The cost in human life is shocking to engineers of the late 20th century. One hundred and eighteen men died in building the canal.

There have been a number of related construction projects since World War II which add to the efficiency and serviceability of the Welland Canal. In 1963 the high-level Garden City Skyway at St. Catharines provided uninterrupted vehicle passage over the canal. In 1968 the Thorold Tunnel under the canal retired two of the 20 original bridges. The 13 km Welland Canal Bypass opened in 1973, replacing some of the winding original channel, and providing the community with a lovely linear park.

THE ST. LAWRENCE SEAWAY

The second of the two canal megaprojects upgraded the combined navigation and power works between Lake Ontario and the port of Montréal. This brought the full extent of the waterway to its present uniform standard. The entire length of man-made waterway now constitutes the St. Lawrence Seaway.

Keefer's 1850 canal essay contained the following prescient passage (the italics are his):

> "Our canals were not built for Canada, but for the *valley of the St. Lawrence;* we ought therefore to 'club together' with our neighbours, on the opposite side in order to place this noble outlet in the most efficient state, by giving it as large a support as possible."

In 1895 the Deep Waterway Commission was established jointly by Canada and the United States to study all feasible routes from the Atlantic to the Great Lakes. Their 1897 recommendation was for the St. Lawrence route. The International Joint Commission was established in 1909, specifically to manage the proposed waterway in the interests of both countries. An enabling treaty was signed by the Prime Minister and the President in 1932, the year the fourth Welland Canal opened. The U.S. Congress, under intense lobbying pressure from many vested interests, refused to ratify the treaty, and it was only in 1954 that they did ratify. Canada had stated that it was prepared to proceed alone if necessary. Support for the venture had grown in the U.S., influenced at least in part by the huge iron ore discoveries in Québec.

When the way was cleared for action, the speed of construction was extraordinary. Work started in 1954 and this huge development was opened in 1959 by the Queen and the U.S. Vice-President, President Eisenhower being too ill to attend.

This stretch of the St. Lawrence River still presented a 14-foot bottleneck to navigation. Part of the international agreement was to now meet the lock dimensions of the Welland Canal, and to construct two of the navigation locks, the Snell and the Eisenhower, on the U.S. side of the river. Several large hydroelectric power plants had been built at the rapids on the St. Lawrence, and these had to be accommodated. An immense international power house a kilometre long would be constructed to take advantage of most of the 30 m head between Lakes Ontario and Francis. Its full rating was 2,400,000 horsepower. The final cost of the new power projects was $600 million, considerably more than the $470 million cost of the navigation work. At peak employment, twenty thousand people worked on the projects.

As in other parts of the Seaway there was much work off the actual canal line. About 20,000 hectares of land were inundated. Several communities, mostly on the Canadian side, were at least partially flooded. Three new towns were built, with many new homes and about 500 houses relocated from the flooded areas. House moving trailers rated up to 200 tonnes were used to move these houses and many buildings of historic and cultural interest. Thirty kilometres of the very busy CN railroad had to be relocated. Four of the bridges across the St. Lawrence in Montréal had to be reconstructed for Seaway clearance.

This enormous project is notable not only for its sheer size and its demonstration of engineering expertise, but also for the unique cooperation of the two countries involved.

OTHER 20th CENTURY WORKS

The two huge Seaway projects dwarf other canal works built in the same period, but those others are in themselves impressive. The Trent Canal, originally intended to encourage commerce, was built over a lengthy period, right into the 20th century. It included two lift locks and two inclined marine railways. Nowadays one can enjoy almost 400 km of relaxed travel from Trenton on Lake Ontario to the summit, 180 m higher, at Balsam Lake and from there to Georgian Bay at Big Chute.

Some of the 20th century construction was for the benefit of commerce. In 1910 the St. Andrew's lock was built to permit navigation on the Red River in Manitoba. The well-used Canso Lock, finished in 1956, allows salt-water ships passage through the Cape Breton Causeway. In 1963 the most recent work on the Ottawa River was completed for the Carillon Canal to ascend Hydro Québec's power dam.

THE FUTURE

All of our canal works were built to last. Some provide us with small-boat access to some of the loveliest and most tranquil parts of the country, and they will continue to be enjoyed by more and more people. In the past two years large cruise ships have begun to appear on the Great Lakes after an absence of several decades, some of them from Europe.

Most of our canals handle a substantial amount of Canada's long-distance freight and are an essential part of the national economy. It is possible that as environmental concerns become even stronger, more of this kind of traffic will be diverted to water transport. ■

Major Canadian Bridge Projects of the 20th Century

By Roger Dorton, FCSCE

1. Background

The end of the 19th century saw railroad bridge construction still booming in Canada, with steel having replaced wrought iron as the main superstructure material. The Dominion Bridge Company was formed in Lachine, Québec in 1882 and was to play a major role in steel bridge construction for over 100 years. Their first major bridge was the 145 m cantilever span over the Reversing Falls at St. John, New Brunswick in 1884, followed by the Canadian Pacific Railway continuous truss bridge over the St. Lawrence River at Lachine in 1886. The days when major bridges were designed and fabricated outside the country, such as Montréal's famous Victoria Bridge taking the Grand Trunk Railway over the St. Lawrence in 1859, were passing.

The use of timber for railway bridges was in decline, but would continue to be popular for the growing need of road bridges. The piers and abutments of large bridges were generally of masonry, but the use of concrete was increasing and would first be used for bridge superstructure construction in Canada in about 1906.

This retrospective of significant major bridges in Canada in the 20th century will be divided into two parts, grouping bridges by material or type in the first half of the century and the last half.

2. The First Five Decades, 1900 to 1949

2.1 Steel Railway Bridges

The first major bridge to be completed at the turn of the century, in 1900, was the Interprovincial Bridge linking Ottawa and Hull, later named the Alexandra Bridge. It was a 170 m span cantilever bridge built by Dominion Bridge and was designed for both rail and road traffic. It is still in use today, following renovations, and was designated as a National Historic Civil Engineering Site by CSCE in 1995.

The record 126 m simple span CPR bridge over the French River in Ontario was completed in 1907. It dispensed with the common eyebar pinned connected members by using all riveted fabrication of members and their connections. The Canadian Bridge Company used an innovative end launching erection method. One end of the preassembled structure was pulled across the river on a scow, with the other end sliding on greased rails. The same company built the spectacular Lethbridge Viaduct in Alberta which opened in 1909. It remains the longest (1624 m) and highest (96 m) steel viaduct in Canada. Both of these bridges were built under the direction of the CPR Bridge Engineer C.N. Monsarrat, later to be the Chairman of the Board of Engineers for the Québec Bridge.

Worldwide, the Québec Bridge is probably Canada's best known bridge of the 20th century. The bridge, with a main span length of 549 m, was the longest span ever built when completed in 1917, surpassing the famous Forth Bridge in Scotland. It still holds the record as the world's longest cantilever span. The first attempt to span the St. Lawrence at

Figure 1. Québec Bridge

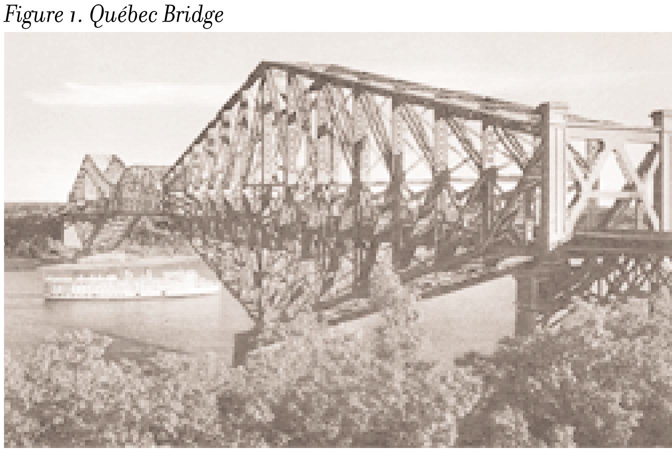
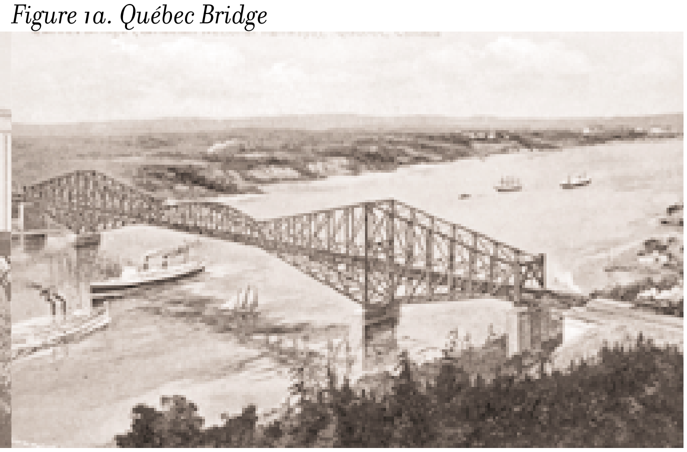


Figure 1a. Québec Bridge



this location ended in disaster, with 75 workers killed when the Phoenix Bridge Company's structure collapsed during construction in 1907. The tragedy was attributed to design errors, inadequate communication during construction, and lack of knowledge of the behaviour of the large compression chord members. Following a lengthy investigation a new contract was awarded to the St. Lawrence Bridge Company in 1911, this company being a joint venture of the two largest Canadian steel construction firms, Dominion Bridge and Canadian Bridge. Extensive studies were carried out on compression members, including large scale model testing, and a distinctive K-shaped system of diagonal members was employed, **Figure 1** and **1a**.

Tragedy was to strike again, however. During the lifting of the central 195 m suspended span in 1916, a failure in the lifting mechanism caused the span to crash into the river with the loss of 13 more lives. A new suspended span was successfully lifted the following year and the completed bridge was recognized internationally as a great achievement in the face of adversity, significantly advancing the knowledge of large compression chords and truss deformations. One of the engineers on loan from Dominion Bridge was P.L. Pratley, who played an important design role under the direction of the Board Chairman, C.N. Monsarrat. In 1921, they formed a partnership and were to become Canada's pre-eminent bridge consulting firm until the death of Monsarrat in 1940.

2.2 STEEL HIGHWAY BRIDGES

With the completion of most of the country's railroads by the outbreak of the First World War, the focus of major bridge construction shifted to highway structures to address the rapid growth in cars and trucks. The historic Edward Serrell suspension bridge in Saint John, New Brunswick was replaced in 1915 with a steel arch for highway traffic spanning 172 m. The bridge was built by Dominion Bridge, and the relatively flat arch was erected by cantilevering over the river and changed from a three pinned arch to a two pinned type after arch closure. The various bridges over the Reversing Falls in Saint John have been commemorated by the CSCE in designating the location a National Historic Site.

The Prince Edward Viaduct crossing the Don River in Toronto has been similarly designated by the CSCE. The multiple span three pinned arch structure was opened in 1918, and has become the city's landmark bridge, although now more commonly known as the Bloor Street Viaduct. Having been designed for both highway and transit loading, the cost of a separate bridge was saved when the subway was built after the Second World War and operates with the tracks on a second level beneath the roadway deck.

The first major bridge designed by Monsarrat and Pratley was the Jacques-Cartier Bridge linking Montréal to the South Shore of the St. Lawrence River by way of St. Helen's Island, which opened in 1929. This much needed crossing was first proposed as a two level combined railway and road bridge in 1876. The bridge as built was for highway and transit use, but the streetcar tracks were never added, enabling the roadway to be widened to five lanes in the 1950s with ample capacity for current loadings. The main high-level span over the harbour consists of a steel cantilever with a central span of 334 m. The span is quite different in appearance compared to the Québec Bridge cantilever, appearing more like a suspension bridge in outline but keeping the K-braced diagonal system, **Figure 2**. The bridge was fabricated and erected by Dominion Bridge, who also carried out the jacking under traffic of the south shore approach truss spans to provide an extra 24 m clearance over

Figure 2. Jacques-Cartier Bridge

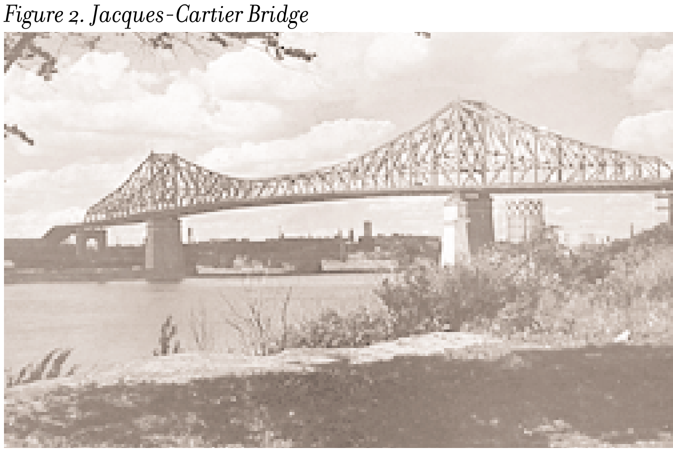
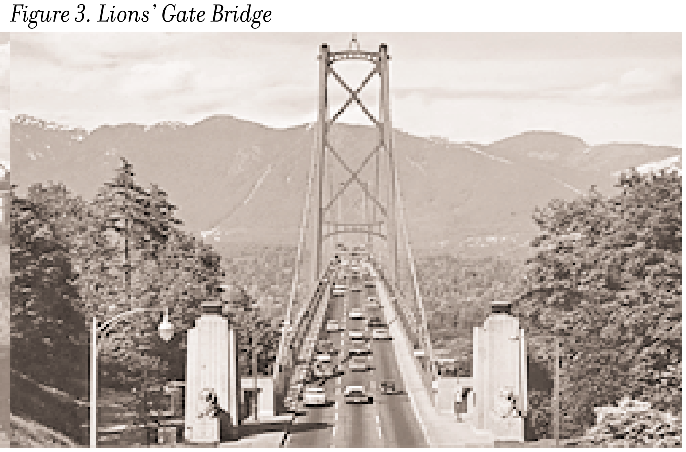


Figure 3. Lions' Gate Bridge



the newly opened St. Lawrence Seaway in 1958.

The 1930s saw the rebirth of suspension bridge construction in Canada, with Monsarrat and Pratley the main consultants. Their first involvement was with the Grand Mère Bridge over the St. Maurice River in Québec, a suspension bridge with a main span of 289 m, in association with the prime consultants Robinson and Steinman of New York. An unusual feature of the construction was the lifting of the rope strand cables and the erection of the stiffening trusses from the ice in the frozen river. This bridge opened in 1929, the same year as the Ambassador Bridge from Detroit to Windsor, Ontario. Monssarat and Pratley were one of the consultants to the design-build contractors, McClintic Marshall of the United States. The bridge featured a record span length of 564 m, slightly longer than the Québec Bridge, making it the longest bridge in the world for a short time until the opening of the George Washington Bridge in 1931.

The first suspension bridge for which Monsarrat and Pratley were the principal designers was the Isle of Orléans Bridge near Québec City, which was also the first suspension bridge built by Dominion Bridge. The bridge opened in 1936, with a main span of 323 m — a length that was to be exceeded two years later by the Lions' Gate Bridge in Vancouver, British Columbia, designed and built by the same two firms. The bridge was built privately to link Vancouver to the north shore to enable the development of West Vancouver. With the attractive setting adjacent to Stanley Park it has become a feature of the Vancouver landscape, **Figure 3**, and was designated by the CSCE in 1991. The span of 472 m enabled the claim to be made for it in 1938 as the longest suspension bridge in the then British Empire.

A number of major bridges linking Canada and the United States were built during this period, including a 1938 suspension bridge at Ivy Lea, Ontario, in the Thousand Islands region. The same year saw the completion of a graceful 265 m arched cantilever truss over the St. Clair River at Sarnia, Ontario. The last international crossing built until after the conclusion of the Second World War was the Rainbow Bridge at Niagara Falls, opened in 1941. Constructed near the site of the old Falls View trussed arch bridge which was demolished by the unexpectedly high river ice in 1938, the new bridge has box girder arch ribs spanning 290 m. At the time of construction, it was the world's longest steel arch bridge, and in 1941 won the American Institute of Steel Construction's award as the most beautiful bridge in America.

2.3 CONCRETE BRIDGES

The first decade of the century saw the introduction of reinforced concrete for the construction of highway bridge superstructures, one of the first being the 1906 arch bridge at Massey, Ontario. It was an earth-filled spandrel type spanning 28 m. Frank Barber designed many concrete bowstring and simple arch bridges, the most outstanding being the Hunter Street Bridge at Peterborough, Ontario. This handsome structure has a clear span of 71 m and was the longest reinforced concrete span in Canada when completed in 1921. The slab arch was designed to be in compression at all times and, surprisingly, is of plain unreinforced concrete. The structure was load tested and rehabilitated in recent years and still carries full highway loading. Its attractive appearance, with arch spandrels, is enhanced by inlaid decorative tiles in the parapet walls, **Figure 4**.

Multi-span arches of the open spandrel type soon became popular and two significant examples can be seen in Saskatoon, Saskatchewan. The longest is the University Bridge over the South Saskatchewan River, consisting of 10 spans, and probably the largest reinforced concrete

Figure 4. Hunter Street Bridge

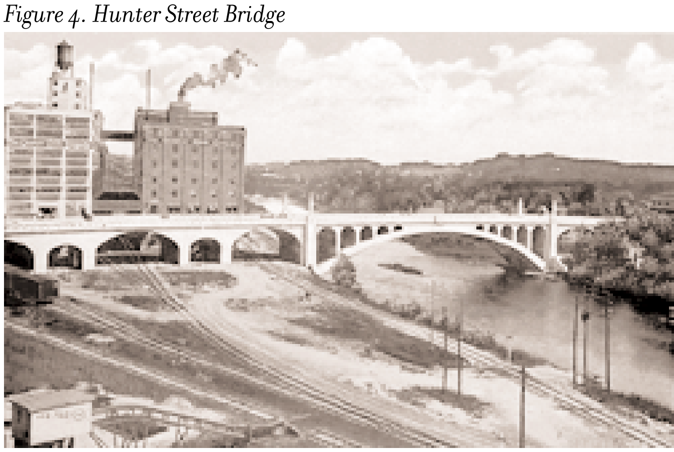
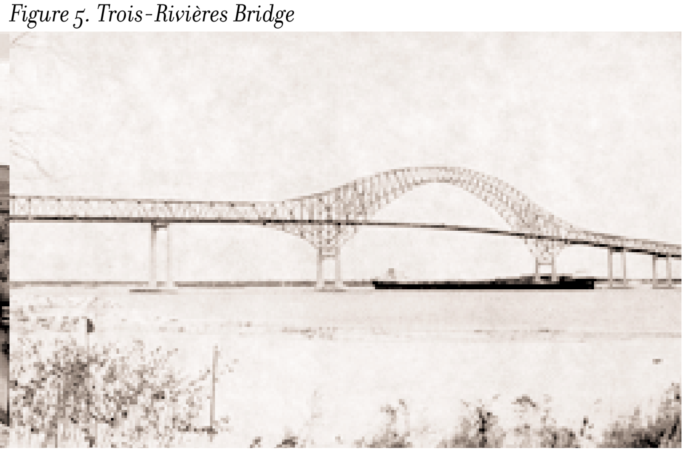


Figure 5. Trois-Rivières Bridge



undertaking in the country at the time of its completion in 1916. The Broadway Bridge is shorter in total length, with five arches of varying length up to 61 m maximum. It was designated as a heritage structure by CSCE in 1985 rather than the older University Bridge, largely because of its social significance at the time of its construction in 1932 during times of depression and high unemployment. Federal relief funds were obtained for its construction, and concrete was preferred to steel as it was more labour intensive, as many as 450 men worked on the project, mostly unskilled and previously unemployed. The bridge was completed in the remarkably short time of 11 months.

Other important arches of a similar type were the Centre Street Bridge in Calgary, Alberta, opened in 1918, and three higher level creek crossings on Ontario's Queen Elizabeth Way between Toronto and Hamilton. The QEW was Canada's first controlled-access expressway, and was commemorated in 1939 by the visiting royal family. Perhaps the most striking looking of the arch bridges built in the first half of the century is the Ahuntsic Bridge, also known as Pont Viau, linking Montréal and Laval across the Rivière-des-Prairies, due in part to the low rise-to-span ratio. Completed in 1930 by Dufresne Construction, the bridge has five arches with a maximum span of 67 m, with each arch being of the three pinned type which is unusual for reinforced concrete construction.

The heyday for reinforced concrete arches was certainly prior to 1950. The emergence of prestressed concrete after that date and its economical application to longer spans, signalled the end of major reinforced concrete arch spans. The last one, completed in 1960, was the elegant Hugh John Fleming Bridge on the Trans-Canada Highway over the St. John River. This multi-span structure is just downstream from the historic covered wooden bridge at Hartland, New Brunswick. Although wood has not been used for many long span bridges in recent decades, a fine example of wood truss construction still exists in Northern Ontario at Sioux Narrows. This 64 m span through truss was completed in 1935, renovated with a stressed laminated wood deck in 1982 and still carries full highway truck loads. It is claimed to be the longest span wooden highway bridge in North America.

3. The Last 50 Years

3.1 STEEL BRIDGES

The war years saw little bridge construction and it was not until the mid-1950s that major steel bridge construction resumed. The steel fabrication techniques were unchanged at that time, but 10 years later would see the replacement of riveted steel work by shop welded fabrication and high strength bolted field connections, and the introduction of orthotropic steel deck construction.

The last of the long span riveted cantilevers were completed in this period. The Second Narrows deck type structure spanning 335 m was completed in 1959 in Vancouver, but not without yet another Canadian steel cantilever construction tragedy. On June 17, 1958 two spans collapsed when the grillage beams at the base of the falsework bent supporting the anchor arm failed, resulting in the death of 18 workers. The failure was due to an error in the design of the stiffeners and diaphragms of the grillage. It was the worst bridge accident in Canada since the dropping of the suspended span of the Québec Bridge over 40 years before. P.L. Pratley was at the time working on the design of another cantilever bridge, the Champlain Bridge over the St. Lawrence River in Montréal with a main span length of 215 m. He was called on to investigate the collapse of the Second Narrows Bridge but was to die that year, before the completion of either bridge. His

Figure 6. Port Mann Bridge

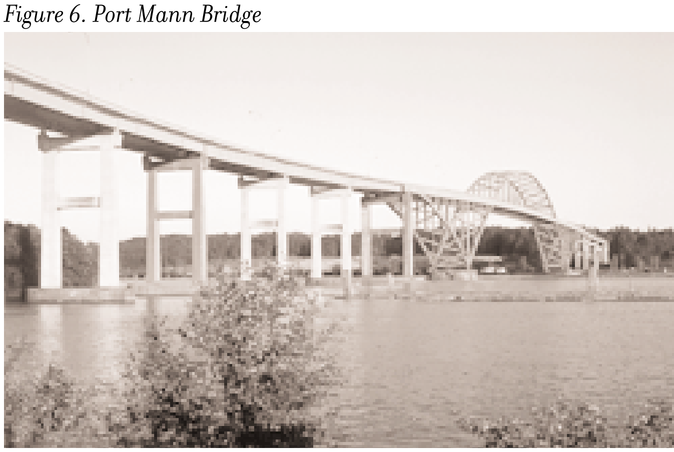


Figure 7. Pierre-Laporte Bridge

last completed project was the lifting of the south approach deck truss spans of the Jacques Cartier Bridge to provide an extra 24 m clearance over the St. Lawrence Seaway. The jacking was carried out under traffic by Dominion Bridge, the bridge being closed for just a few hours when the deck truss over the Seaway channel was slid out laterally onto falsework and replaced by a through truss for additional clearance.

The 1960s brought on a rapid expansion of the highway system, including the construction of the Trans-Canada Highway. A major arch bridge on that highway was the Alexandria Bridge, crossing the Fraser River in British Columbia, designed by A.B. Sanderson and completed in 1961. Another deck arch structure was completed across the Niagara River in 1962. The Queenston to Lewiston international bridge was similar to the earlier Rainbow Bridge a few kilometres upstream, but the span was a little longer at 305 m. A number of through truss arched structures were completed at this time, such as the Burlington Skyway in Ontario in 1958 and the Great Bras d'Or Bridge in Cape Breton, Nova Scotia in 1961. By far the longest of this type, however, was the Trois-Rivières Bridge across the St. Lawrence River midway between Montréal and Québec City, **Figure 5**, designed under the direction of Georges Deiners. Completed in 1967, with a main span of 335 m, it has three approach span through trusses on each side, continuous with the arch anchor spans. The superstructure of these last three bridges were all fabricated and erected by Dominion Bridge. There was another serious accident on this bridge during the construction of the substructure, when 12 workers died from an explosion in one of the caissons.

The last major crossing on the Trans-Canada Highway in British Columbia was the Port Mann Bridge over the Fraser River 24 km east of Vancouver, opened in 1964, and designed by CBA. This bridge was particularly significant in introducing the European-developed technology of orthotropic decks to North America. Due to its light weight, this type of steel deck proved economical for long spans. The Port Mann Bridge has a main span length of 366 m and upon completion was the longest bridge of its type in the world, a continuous stiffened tied arch. This little-used bridge form, with slender arch ribs, produced a graceful and much admired structure, **Figure 6**. The tie girders were box sections of riveted construction, thus avoiding the lack of redundancy that was to later be of such concern on tie girders of welded box construction. The only other Canadian major span using the continuous tied arch form is the second Blue Water Bridge, opened in 1997 and designed by an international joint venture of Modjeski and Masters of Harrisburg, Pa. and Buckland & Taylor Ltd. of Vancouver, British Columbia. In this case, internal redundancy in the ties was introduced by fabricating the boxes from four corner angles and four plates, connected by high strength bolts. The 281 m main span was erected by the use of temporary towers and cable stays, the fabrication and erection of the Canadian half being carried out by Canron. The Port Mann main span was erected in the same fashion by Dominion Bridge.

Welded orthotropic deck box girder construction was used on several bridges following the completion of the Port Mann Bridge. These included the Concordia Bridge for rail transit at Expo 67 in Montréal, the Saint John Harbour Bridge in New Brunswick in 1968, and the Mission Bridge in British Columbia in 1973.

3.2 CABLE SUPPORTED BRIDGES

The longest span highway bridges have traditionally been suspension bridges. The last 40 years of the

Figure 8. A. Murray MacKay Bridge

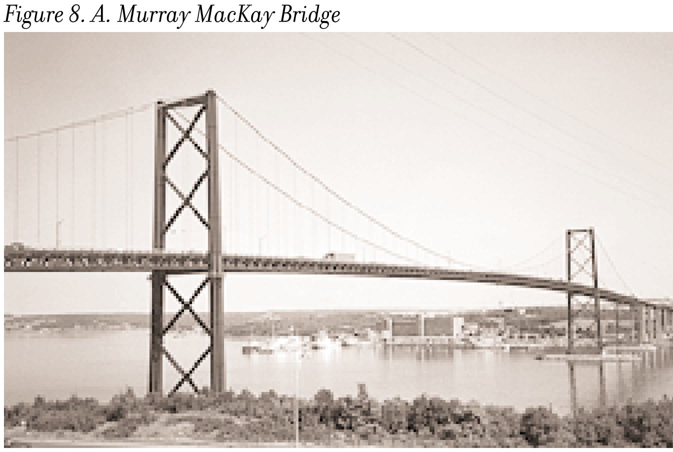


Figure 9. Papineau-Leblanc Bridge

century has seen the development and application of cable stayed bridges to increasingly long spans, previously the domain of suspension bridges. The use of both types of cable supported bridge in Canada will be reviewed in this section, along with the development of wind engineering expertise in this country largely as a response to the aerodynamic susceptibility of these types of bridges.

3.2.1 Suspension Bridges

Monsarrat and Pratley were engaged to carry out studies of a possible high-level highway bridge linking Halifax and Dartmouth N.S. as far back as 1928, but it was not until 1950 that design work was begun by P.L. Pratley, then heading his own firm. The Angus L. Macdonald Bridge crosses the harbour with a main span of 441 m and was opened in 1955. Slightly shorter than the Lions' Gate Bridge, it is otherwise very similar to its 1938 predecessor. P.L. Pratley's son was involved in the site supervision and took over the operation of the consulting firm on the death of his father in 1958.

The Dunvegan Bridge, crossing the Peace River in Alberta was opened in 1960, and has some features that differ from the typical Canadian suspension bridge designs at that time. The bridge has a main span length of 274 m and was designed by T. Lamb, McManus & Associates of Edmonton who carried out static model tests to confirm its behaviour under load. The stiffening trusses are Warren type with double intersecting diagonals with the wind system and deck at mid-depth. The towers are of the portal frame type with three struts above the deck, rather than the more common crossbraced style. In 1961, an international crossing of the St. Lawrence River was opened over the Seaway, linking Ogdensburg, N.Y. and Prescott, Ontario. It has a main span length of 350 m with through type stiffening trusses, but an open steel grid deck was utilized to reduce the dead weight.

A most unusual suspension bridge was designed by Phillips, Barratt and Partners to cross the Peace River in a remote area near Hudson Hope, British Columbia. The bridge spans 207 m with concrete portal towers on the riverbanks and unloaded backstays. The deck stiffening system consists of 34 segmental concrete box girder sections, each 6 m long, which were longitudinally post-tensioned together after erection. Each precast unit was erected using a traveller on rubber-covered wheels running on the permanent bridge cable system, and the segments were swung into place, in pendulum fashion, using the permanent suspenders. The design and construction were unique when completed in 1965.

Canada's longest suspension bridge and longest span of any type, is the Pierre-Laporte Bridge beside the famous Québec Bridge which had the record span until the suspension bridge was completed in 1970 spanning 668 m. The consulting engineers, Demers, Vandry, Gronquist, were an association of two Québec firms with the well-known American firm of D.B. Steinman. This six-lane bridge represents the U.S. state-of-the-art of the time, with steel portal towers and deck type stiffening trusses, **Figure 7**.

Also, in 1970, a second suspension bridge across Halifax Harbour was opened, the A. Murray MacKay Bridge at the entrance to Bedford Basin, designed by Pratley and Dorton and erected by Canadian Bridge. This four-lane bridge, with a main span length of 427 m is probably the highest in its span range in North America, **Figure 8**. This is mainly due to the use of a lightweight steel orthotropic deck acting as the top chord of the deck type stiffening trusses. It remains the only suspension bridge on this continent originally built with an orthotropic deck, although this type

Figure 10. Alex Fraser Bridge

Figure 11. ALRT Skytrain Bridge

of deck has since been used in the rehabilitation of older bridges. As the suspended truss sections were to be erected with the orthotropic deck panels in place, there was the potential for aerodynamic instability during erection. Various erection conditions and the finished structure were checked for model testing at the Boundary Layer Wind Tunnel at the University of Western Ontario. In addition to the usual section models, a full aeroelastic model was tested in smooth flow and the more realistic condition of turbulent flow. The bridge test in turbulent flow was a first anywhere and resulted in a significant increase in the critical velocity. This and subsequent work under the direction of Dr. A.G. Davenport helped establish the reputation that Canada enjoys today as a world leader in wind engineering and wind tunnel testing.

3.2.2 Cable Stayed Bridges

The modern use of cable stayed bridges started in post-war Europe in the 1950s but was not introduced to this continent until the mid-1960s. One of the earliest applications was for the Long's Creek Bridge in New Brunswick, with a span of 217 m. Before opening it exhibited undesirable motion in wind. This was corrected by adding fairings to modify the shape of the stiffening girders, following wind tunnel tests at the National Research Council laboratories in Ottawa. A Canadian bridge that made a large impact at that time was the Papineau-Leblanc Bridge in Montréal, built by Dominion Bridge. It utilized the latest European technology, with an orthotropic box girder deck and a single plane of stays supported by single column type pylons located in the median of the four lane stays supported by single column type pylons located in the median of the four-lane bridge, **Figure 9**. The bridge, which has a main span of 241 m, was opened in 1969.

The project that put Canada on the world scene for cable stayed bridge engineering was the Alex Fraser Bridge near Vancouver, British Columbia, designed by CBA-Buckland & Taylor, **Figure 10**. When it opened in 1986 it was the longest cable stayed bridge in the world with a main span of 465 m, a record it held for five years, and it remains the longest on the continent. In addition, it incorporated a number of innovations including the use of a composite steel beam and precast concrete slab deck system now being adopted on projects abroad. It was followed in 1989 by another cable stayed bridge over the Fraser River in nearby New Westminster, designed by Bush, Bohlman-Reid Crowther, **Figure 11**. The ALRT Skytrain Bridge is a narrow structure with a deck system consisting of prestressed precast concrete elements, and provides the world's longest transit-only span of 340 m.

3.3 Prestressed Concrete Bridges

Prestressed concrete bridges had their start in Europe in the 1930s, but their widespread use followed the end of the Second World War when Europe was rebuilding. The first example in Canada was the single span beam bridge over Mosquito Creek in North Vancouver, British Columbia, in 1952. This was followed in 1954 by the multi-span Chin Coulee Bridge in Alberta. One hundred 18.3 m beams were precast by Con-Force in their Calgary plant. The latest application of prestressed concrete in North America at the time resulted from the alternate design tender call for the 45 approach spans of the Champlain Bridge crossing the St. Lawrence River in Montréal in 1959. The winning bid featured precast beam spans of 54 m erected by a launching truss covering two spans, with beams delivered directly from an on-site precasting plant. This represented the introduction of the latest European prestressed concrete bridge technology to this continent.

Figure 12. Burlington Skyway

Figure 13. Confederation Bridge

The need for spans longer than could be provided by precast beams was the development of segmental construction. This form of construction had its North American introduction on two bridges in Québec, the Lièvre River Bridge for precast segmental and the Sainte-Adèle Bridge on the Laurentian Autoroute for cast-in-place segmental. The latter was designed by Regis Trudeau and Associates, and constructed in just one construction season by Janin Construction Ltd. in 1963. They were followed by longer segmental spans across the country such as the Bear River and Shubenacadie River crossings in Nova Scotia, the Grand-Mère Bridge in Québec, the Islington Avenue and Burnhamthorpe Road bridges in Ontario, and the Knight Street bridge in Vancouver. The new Burlington Skyway in Ontario, **Figure 12**, with a cast-in-place segmental main span of 151 m illustrates the growing competitiveness of prestressed concrete for longer spans in the 1980s. The original Skyway, built in 1958, has a steel arched truss main span, whereas the 1985 structure went to bids on alternative designs in steel and segmental concrete, with prestressed concrete emerging the winner.

The Canadian project that drew recent worldwide attention was the Confederation Bridge linking New Brunswick and Price Edward Island across the Northumberland Strait, which opened in 1997. The overall length of 12.9 km includes 43 spans of 250 m each, making it the longest crossing of open ocean yet constructed anywhere. The project was awarded to Strait Crossing Inc. under a complex agreement with Public Works Canada that covered financing, design, construction and operation for 35 years. Final design was carried out by JMI/Stanley Joint Venture Inc. with Buckland & Taylor Ltd. acting as the Independent Engineer, overseeing the project for the federal government. The design criteria were unusual, requiring evaluation of conditions at the site for items such as ice load, wind load and ship impact and a calibration process to ensure a prescribed safety level using probabilistic methods. The limit states design approach was already well established in Canada, which had been a leader in bridge code development, but the site-specific approach to the development of the design criteria for a 100-year life was unique. All the beam and pier elements were precast on site, and the deep water erection was carried out using the floating crane, *Svanen*, which was brought across the Atlantic from Denmark. Its capacity was increased to handle the beam elements 192 m long and weighing 7500 tonnes each, **Figure 13**. The erection of all the prestressed concrete elements in just two years was a remarkable achievement.

4. Concluding Remarks

Canadian engineers have participated in the design and construction of a number of bridges of world significance during the 20th century, from the tragedies of the Québec Bridge before its final completion to the successful construction of the Confederation Bridge. The number of sites requiring very long spans is limited in the short term in Canada, however, and such projects are more likely to be found overseas.

At the turn of the century, Canada was taking over responsibility for the design and construction of its own major bridges, and becoming less dependent on outside assistance.

The end of the century finds Canadian companies providing design and construction services in the international marketplace. Canada has acknowledged expertise in fields such as wind engineering, effects of extreme environments, rehability-based design and construction management, plus research leadership in advanced composite materials, monitoring methods and high performance concrete. These skills should ensure an important role for Canadian bridge engineering in the 21st century at home and overseas. ■