Jean M. Muller: Bridge Engineer

Daniel M. Tassin, P.E.

Daniel M. Tassin is president of International Bridge Technologies Inc., San Diego, Calif. He has 30 years of comprehensive experience in the design and construction of bridges in the United States, Mexico, Canada, Europe, Australia, and Asia. For most of his career, he worked directly with Jean Muller. In 1997, Tassin was awarded the ASBI Leadership Award for Exceptional Contributions to the Development and Application of Segmental Design and Construction Technology in Major Bridge Projects.

The author, who was a close associate of Jean Muller, recounts the career and achievements of this world-renowned bridge designer who transformed segmental concrete bridges into an engineered art form. Muller is credited with the development of the match-cast precast concrete segmental construction method and the first concrete box girder supported by a single plane of cable stays. Largely through his influence, precast concrete segmental construction is today a multi-billion-dollar industry practiced throughout the world.

When Jean M. Muller died in Paris on March 17, 2005, at the age of 80, he left behind a rich legacy of technical achievement that changed the course of bridge construction. His beautiful precast concrete segmental and cable-stayed bridges are today universally admired by bridge designers and the public both for their engineering excellence and aesthetics.

Indeed, Jean Muller was a remarkable engineer whose designs of unique and attractive structures are prominently displayed throughout the world. He excelled in designing elegant and cost-effective bridges, from simple overpasses to long cable-supported spans, using concrete and steel-concrete composite elements (**Fig. 1**).

In addition, he was generous in sharing his knowledge and experience with his colleagues and the engineering community. For example, he was the featured speaker at numerous conferences and symposia throughout the world. His works have been published in a book, many technical publications, and some symposia proceedings.[1–3] This article will focus on Muller's outstanding technical contributions in the field of precast, prestressed concrete structures.

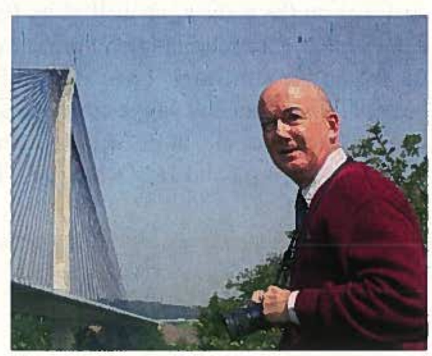


Fig. 1. Pictured is Jean Muller.

With his invention of match-cast segmental construction, Muller was able to extend the span capabilities of precast, prestressed concrete bridges to those previously the domain of steel structures. His concepts have led to the industrialization of the bridge construction process through standardization and large-scale production of box sections in a factory-type controlled environment. Today, segmental construction is a multi-billion-dollar industry.

FORMATIVE YEARS

Muller was born in Levallois-Perret (Seine), France, on May 25, 1925. From an early age, he understood the connection between mathematics and engineering. He received his Master of Science degree in civil engineering from the Ecole Centrale des Arts et Manufactures, Paris, France, in 1947. His area of interest was in the behavior and design of concrete structures—a field that prepared him well for the future.

Muller began his professional career working under the supervision of Eugene Freyssinet, the inventor of modern prestressed concrete (**Fig. 2**). Freyssinet, ever the practitioner, would call prestressed concrete not just another material but a new way to build structures.

During the 1930s, Freyssinet came up with the concept of precast concrete segmental construction but, unfortunately, the onset of World War II in 1939 put any thoughts of implementation to rest. After the war in 1946, however, he got his opportunity to design and construct the Luzancy Bridge across the Marne River; it was the world's first precast, prestressed concrete segmental bridge. This elegant, slender arch bridge was made of precast concrete segments that were erected with temporary masts and cables and then post-tensioned together with mortar in the joints.

Photo courtesy of Freyssinet Co.

Fig. 2. Pictured is Eugene Freyssinet.

Immediately after World War II, Europe's infrastructure had to be rebuilt. Building materials were scarce, and bridges preferably were to be built without falsework or temporary supports. Also, the strength and ductility of prestressing steel and mild reinforcing steel were much lower than they are today. There also was a severe shortage of structural steel in Europe, which made reconstruction of the infrastructure with concrete very attractive.

Shortly after the completion of the Luzancy Bridge, precast concrete segmental construction was applied successfully to five more slender arch bridges with spans of 240 ft (74 m) over the Marne River in France (**Fig. 3**).

In the late 1940s and early 1950s, Muller worked closely with Freyssinet on several major projects, including three prestressed concrete arches along the La Guaira-Caracas Expressway in Venezuela. Working with Freyssinet, he learned some of the main principles that would later guide his career as a bridge engineer, namely thoroughness in establishing continuity between

Photo courtesy of Freyssinet Co.

Fig. 3. Shown is the Esbly Bridge on the Marne River in France.

Photo courtesy of Freyssinet Co.

Fig. 4. Shown is the Shelton Bridge in upstate New York.

Fig. 5. Jean Muller (left) is photographed at the Shelton Bridge site in upstate New York.

structural elements, understanding of load paths, economical use of materials, and necessity to design harmonious structures adapted to their environments.

In 1951, Muller came to the United States, where he was the chief engineer for the Freyssinet Company in New York for four years. He worked directly on several major projects across the country. Some of these projects were the design of a multiple-span bridge over the Garrison Dam on the Missouri River and a precast concrete floating pier for the U.S. Navy.

In 1954, he also participated in the design of the Lake Pontchartrain Causeway near New Orleans, La., a mammoth structure with 2200 identical spans of 56 ft (17 m). It was on this project that he fully realized the potential for mass production on a bridge of such a large scale.

During this same period, he designed the Shelton Bridge in upstate New York, a small single-span structure made of precast reinforced concrete beams divided into three segments to facilitate transportation (**Fig. 4**, **5**). For the first time, the beam segments were match cast with dry joints and assembled at the site with post-tensioning tendons. Eliminating the mortar in the joints significantly improved the speed and quality of construction.

Muller's match-casting innovation for this project is the key technique used today to make precast concrete segmental construction attractive and competitive for a variety of applications in bridge design throughout the world.[4]

CAMPENON BERNARD PROJECTS

In 1955, Muller returned to Paris, France, where he worked as technical director for Campenon Bernard, a general contractor that had acquired the Freyssinet patents. There, he was involved in the design/construction of various large prestressed concrete projects, including dams, nuclear reactor pressure and containment vessels, offshore platforms, and medium- to long-span bridges. He worked in that capacity for the next 20 years.

Choisy-le-Roi Bridge

In 1962, 10 years after the construction of the Shelton Bridge, Muller had the opportunity to extend that experience with the design of the Choisy-le-Roi Bridge over the Seine River in Paris (**Fig. 6**, **7**). For this bridge, he used for the first time precast concrete segmental box-girder technology with match-cast epoxy-coated joints. The box girder section had the advantage of being more efficient than the I-beam section in terms of concrete quantities and structural properties (such as torsion and lateral stability) and lent itself to segmental construction, eliminating the need for a cast-in-place slab.

The bridge segments were fabricated using the long line method. In other words, the segments were cast in their correct relative position on a casting bed that reproduced exactly the profile of the structure including camber to account for long-term deflections. Two formwork units traveled along this line guided by the pre-adjusted soffit.

Casting started with the pier segment, followed by the symmetrical seg-

Fig. 6. Shown is the Choisy-le-Roi Bridge over the Seine River in Paris, France.

ments on each side of the pier segment. As casting progressed, the initial segments cast could be removed from the bed and sent to storage. This method allowed for easy handling of the segments and control of deck geometry.

The bridge had three continuous spans of 123 ft (37.5 m), 180.4 ft (55 m), and 123 ft (37.5 m), with a total width of 93.2 ft (28.4 m). The structure was divided into two parallel bridges with two single-cell rectangular box girders each. It was erected in balanced cantilever with a floating crane.

Oleron Viaduct

The Oleron Viaduct provides a link between the west coast of France and the resort island of Oleron (**Fig. 8**). The total bridge length is 9390 ft (2860 m), with span lengths up to 260 ft (79 m). For this project, Muller and Campenon Bernard decided to develop new construction methods to accelerate erection. Floating equipment could access the approach spans only at high tide, and crawler cranes could not be used at low tide for environmental reasons.

For the first time, a launching gantry was designed to erect the superstructure in balanced cantilever with segments delivered from the top of the previously built structure. The segments were fabricated by the long line method close to the bridge abutment. The gantry was capable of launching itself with a system of moveable supports. This method of construction was successful, and the bridge was designed and built in record time between 1964 and 1966.

Pierre Benite Bridge

In 1965, new construction methods were also developed for the Pierre Benite Bridge over the Rhone River close to the city of Lyon, France (**Fig. 9**). For the first time, the segments were precast using the short line method; the segments were cast in a stationary position between a fixed bulkhead and the preceding (match-cast) segment with the possibility of following curves in plan and elevation by adjusting the position of the match-cast segment. Compared with the long line method, this system had the advantage of being able to cast bridges with variable geometry and required less space in the precasting yard.

Photo courtesy of Campenon Bernard Construction.

Fig. 7. Shown is the long-bed precasting at the Choisy-le-Roi site in Paris, France.

Photo courtesy of Campenon Bernard Construction.

Fig. 8. The Oleron Bridge connects Oleron Island to mainland France.

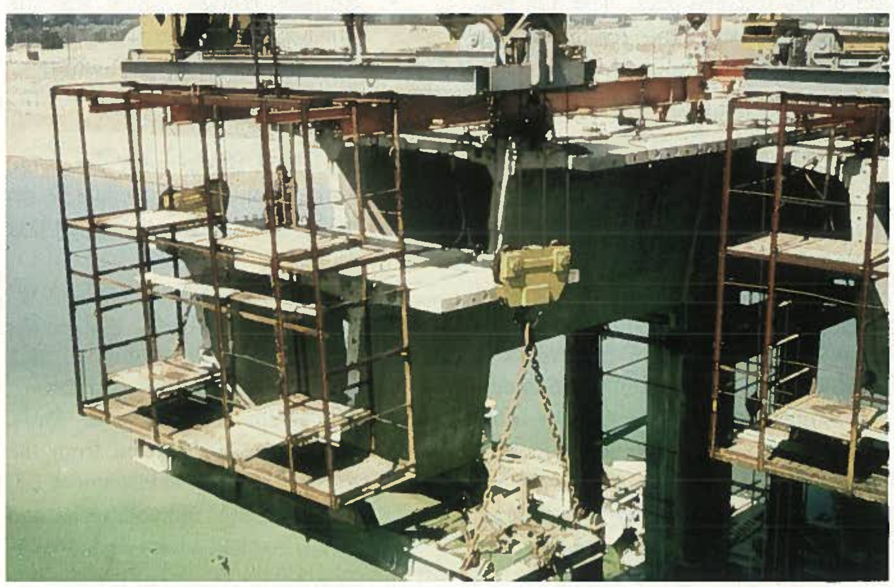


Photo courtesy of Campenon Bernard Construction.

Fig. 9. Shown is the Pierre Benite Bridge over the Rhone River near Lyon, France.

Photo courtesy of Campenon Bernard Construction.

Fig. 10. Pictured is the Chillon Viaduct by Lake Geneva in Switzerland.

The segments were delivered to the site on barges and lifted with a beam-and-winch system cantilevering from the completed part of the deck. Due to the river current, the barges had to be anchored to the piers and the segments had to be moved longitudinally from the barge position to the end of the cantilever. This was accomplished with a special trolley carrying the winches and segment while riding on rails on top of the finished deck. The 528 precast concrete segments for this bridge were erected in 13 months.

Rio-Niteroi Bridge

The Rio-Niteroi Bridge, built in Brazil from 1972 to 1974, was the world's largest precast concrete segmental bridge at the time of its completion. It was made of twin parallel structures with 260 ft (80 m) spans and a total length of 27,000 ft (8230 m). Produced in 10 casting cells, the 3500 segments were transported by barge and lifted in place with 4 cable-stayed launching gantries.

These gantries were two spans long, or 520 ft (160 m), and could be launched from pier to pier without support on the deck. They were also capable of lifting two segments simultaneously. With this system, a cantilever could be built in five days and 180,000 ft^2 (16,720 m^2) of deck were erected each month.

Other Notable Bridges

Muller and Campenon Bernard designed and built several other significant precast concrete segmental structures in France during this period:

- Rombas Bridge, which was the first use of the progressive placing cantilever construction method;
- Paris Ring Road bridges over the Seine River;
- St. Cloud Bridge over the Seine River, with a 67-ft-wide (20 m) deck and three-cell closed-box girder;
- St. André de Cubzac Bridge over the Dordogne River, with a 56-ft-wide (17 m) single-cell box girder and ribbed-top slab;
- B3 South Viaduct near Paris, which was constructed from the top in an urban environment (20 road crossings, railroad tracks, and canal) and had a total deck area of 860,000 ft^2 (80,000 m^2); and
- Three railroad bridges: the Marne la Vallée, Torcy, and Clichy; the first use of precast concrete segmental construction for heavy rail.

Outside of France, Muller worked on several other major projects:

- Chillon Viaduct, Switzerland, which included the first use of a launching gantry on a curved bridge (**Fig. 10**);
- Sallingsund Bridge, Denmark, a bridge over deep water with 300 ft (90 m) spans with precast concrete foundations; and
- F9 Freeway, Melbourne, Australia, an urban viaduct similar to the B3 South Viaduct.

Alpine Motorways Bridges

The first full-scale industrial application of precast concrete segmental construction took place with the Alpine Motorways project in 1971 (**Fig. 11, 12**). This project included 220 miles (350 km) of tollways on the western slopes of the Alpine mountain range. The first phase of the project (160 miles [260 km]) required 10 viaducts with spans up to 200 ft (60 m), 200 overpasses, and 50 underpasses.

The design of these structures could be standardized, and the bridge segments were manufactured in a centrally located plant. The overpass superstructure consisted of voided segmental slabs precast vertically. The viaducts' superstructures were standard precast concrete segmental box girders.

For the first time, the single web shear key was replaced with the multiple shear key system so that the joint strength did not have to rely on epoxy. All segments were designed to be delivered to the bridge sites by truck on the existing highway system. The overpasses were typically erected with a combination of cantilever construction and temporary supports in a period of two weeks. The viaducts were erected in balanced cantilever with a light cable-stayed gantry that could place up to 12 segments in one day.

Brotonne Bridge

The Brotonne Bridge over the Seine River, built between 1974 and 1977, established a world record for a cable-stayed prestressed concrete bridge with a main span of 1050 ft (320 m) (**Fig. 13**). The design incorporated a number of innovations, namely, a central plane of stay cables located along the bridge centerline with reinforced concrete center pylons; single-cell box girders stiffened internally with diagonal struts carrying the vertical component of the stay cable forces; precast, prestressed concrete web panels connected to cast-in-place slabs; and the main span supported on elastomeric bearings.

Weight was the main drawback for this long-span bridge, and the design

Photo courtesy of Campenon Bernard Construction.

Fig. 11. Pictured is the Alpine Motorways precasting factory in France.

Photo courtesy of Campenon Bernard Construction.

Fig. 12. Shown is the Alpine Motorways viaduct in France.

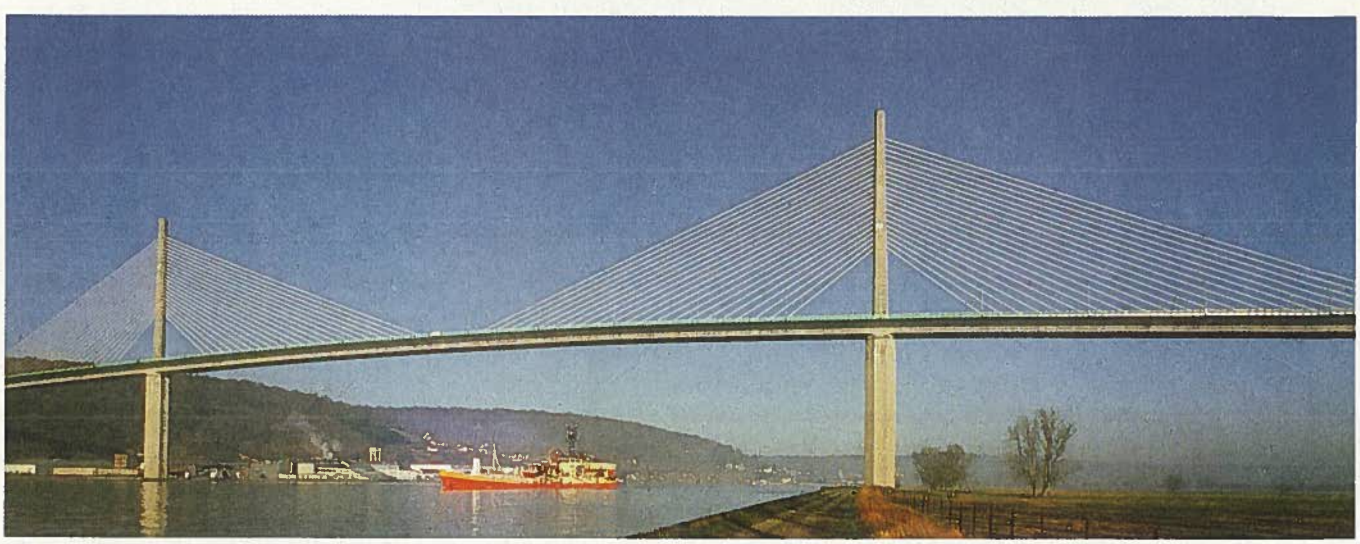


Photo courtesy of Campenon Bernard Construction.

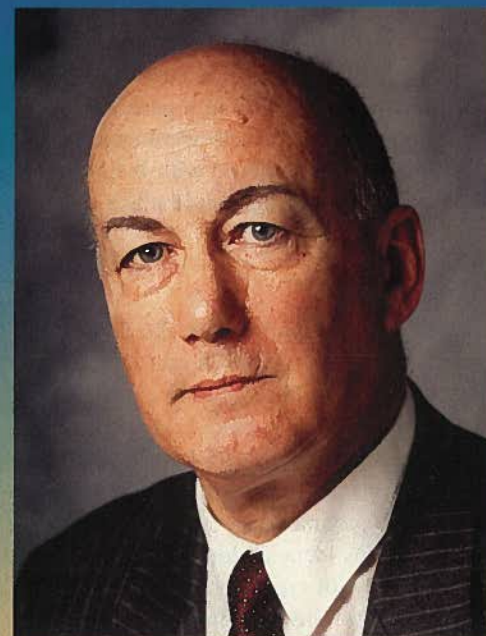
Fig. 13. The Brotonne Bridge is pictured over the Seine River in France.

WORLD RECOGNITION FOR JEAN MULLER

During his 55-year professional career, Jean Muller was widely recognized by national and international societies for his outstanding achievements in segmental bridge design and construction. As a former PCI Professional Member, he gave a number of memorable presentations at PCI Conventions and special seminars, and was a contributing author to the *PCI Journal*. Two of his papers were reprinted and became bestsellers: "Ten Years of Experience in Precast Segmental Construction" and "Design and Construction of Linn Cove Viaduct."

The following are some of the major awards and recognitions bestowed upon him:

- Fritz Schumacher Prize of Stuttgart University, Germany 1976.
- FIP Medal, Fédération Internationale de la Précontrainte, 1978.
- Albert Caquot Prize, Association Francaise de Génie Civil (AFGC), France, 1980 and 1997.
- Doctorate Honoris Causa of Lausanne University, Switzerland, 1983.
- Robert J. Lyman Award for publication of the paper "Design and Construction of Linn Cove Viaduct," September–October 1985 *PCI Journal*; given by Precast/Prestressed Concrete Institute, United States, 1986.
- Golden Eiffel Award, France, 1988.
- French Legion of Honor, France, 1992.
- Medal of the Benjamin Franklin Institute in Philadelphia, United States, 1995.
- FIP Freyssinet Medal, Fédération Internationale de la Précontrainte, 1998.
- Outstanding Structures Award for the Bras de la Plaine Bridge on La Réunion Island, Fédération Internationale du Béton, 2002.



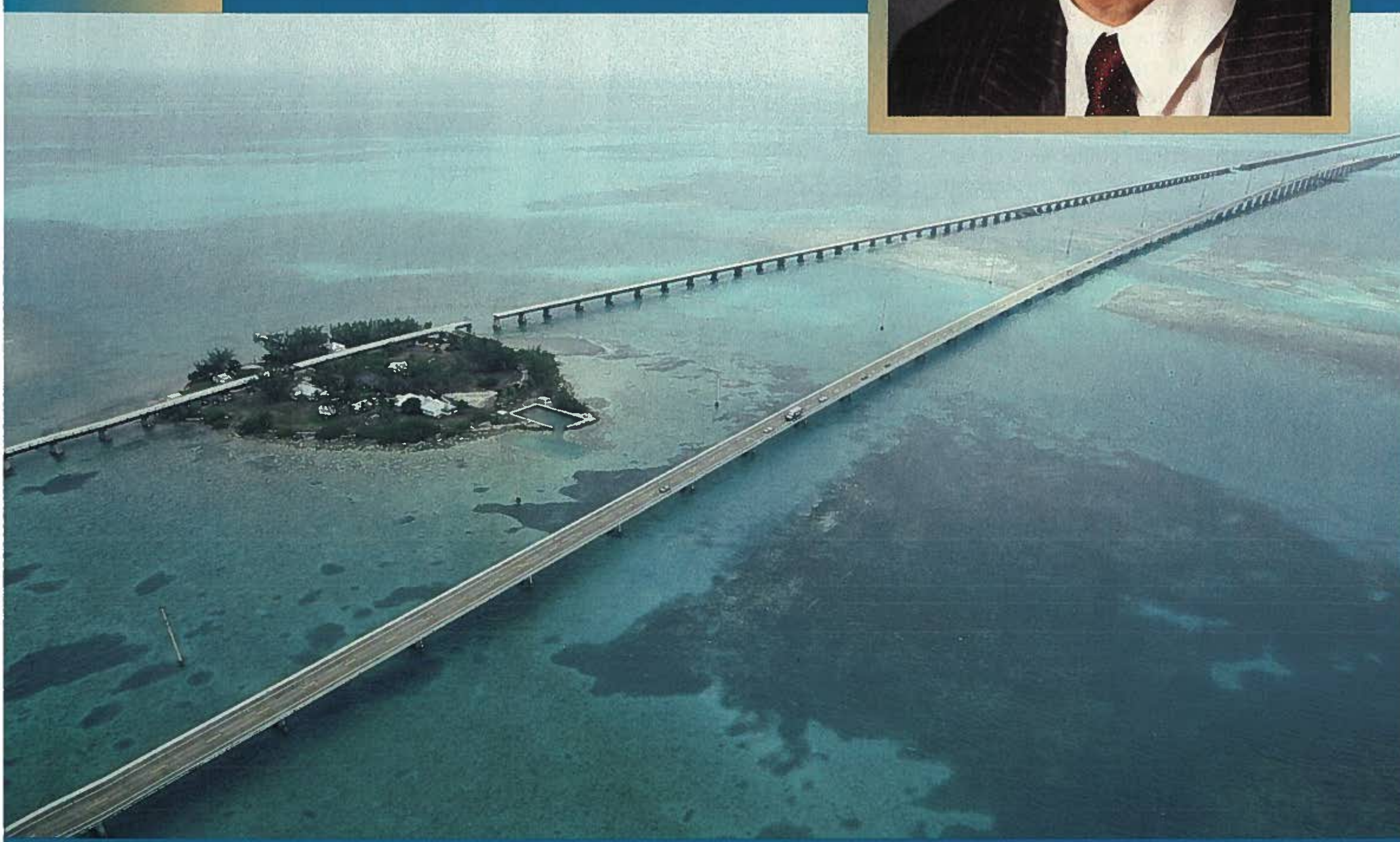


Fig. 14. Shown is the Seven-Mile Bridge in the Florida Keys. Photo courtesy of Figg & Muller Engineers.

of the cross section with precast, prestressed concrete web panels and internal struts was optimum for weight-reduction purposes. Tests were carried out at the job site to verify the capacity of the vertically prestressed concrete webs under a combination of axial and shear forces. These tests proved that the structure could carry these loads satisfactorily.

An excellent survey of most of the mentioned structures is given in Reference 5.

FIGG AND MULLER ENGINEERS PROJECTS

In 1978, Muller joined Eugene Figg and together they formed Figg and Muller Engineers in Tallahassee, Fla. The firm's aim was to develop the precast concrete segmental technology in the United States. As technical director, Muller supervised the designs for a number of innovative structures produced by the firm until 1988.

The projects were usually prepared for government agencies (such as the Federal Highway Administration and the various state departments of transportation) using the design-bid-build method. The fact that two competitive designs were frequently offered to the contractors required special efforts for the development of new concepts aimed at reducing costs while maintaining high quality and good aesthetics.

Florida Keys Bridges

Until 1978, all precast concrete segmental bridges were built by the balanced or progressive cantilever method, with the exception of smaller overpass structures. The first designs produced by Figg and Muller Engineers were for the Florida Keys bridge replacement program and included the Long Key Bridge, Seven-Mile Bridge, Channel Five Bridge, and Niles Channel Bridge (**Fig. 14**).

Several innovative design features were introduced for the Long Key Bridge to simplify the construction compared with the segmental structures of the previous generation. The design called for multiple medium spans of 118 ft (36 m) to 135 ft (41 m) that could be assembled span by span on an erection truss spanning from pier to pier.

In addition, the post-tensioning tendons were placed inside the box girder but outside the concrete, allowing for a reduction of the concrete web's thickness and simplification of the concrete segment's shape and, consequently, the precasting procedure. The number of tendons could be reduced to two or three per side using larger units. Because the spans were continuous, the tendons overlapped within the pier segment diaphragms.

The shear stresses in the webs were reduced through the use of draped tendons. It was possible to eliminate the epoxy in the joints because the segments were aligned on the erection truss without need for lubrication, shear stresses were resisted by the multiple shear keys at the segment joints, and no post-tensioning tendons crossed the match-cast joints. It should be mentioned that because of the chloride-laden environment, corrosion of the prestessing steel was a major concern.

The design included two more innovations, namely, the elimination of tendons anchored in the joints permitted riding on the as-cast top slab surface and the segments were transversely prestressed in the casting beds. The segment lengths could be increased to 18 ft (5.5 m), compared with the standard 10 ft (3 m), for a maximum weight of 60 tons because the segments were delivered by barge.

This increased the speed and efficiency of casting and erection operations. Typically, the speed of construction averaged 2.5 spans per week, with a maximum of 5 spans per week. The simplicity of the design proved to be a success, and the bridge was completed several months ahead of schedule.

All the design innovations first developed for the Long Key Bridge have been used for most of the segmental bridges built today. The design of the Seven-Mile Bridge was similar, and the superstructure segments were prefabricated in Tampa, Fla., and shipped by barge to the bridge site due to the limited material availability and difficult access in the Florida Keys. When completed in 1982, the Seven-Mile Bridge was the longest precast concrete segmental bridge in the world.[6,7]

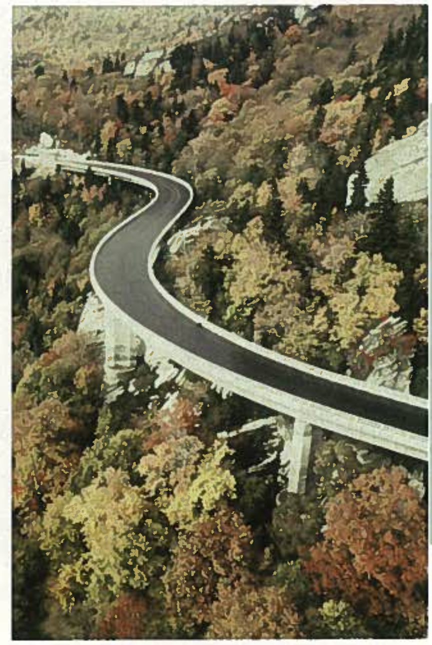


Photo courtesy of Figg & Muller Engineers.

Fig. 15. Linn Cove Viaduct is photographed on the Blue Ridge Parkway in North Carolina.

Linn Cove Viaduct

The Linn Cove Viaduct in the North Carolina Blue Ridge Parkway was completed in 1984 (**Fig. 15**). It was a complex structure with tight curves (250 ft [76 m] radii and variations of cross slopes of +/-10%). In addition, the bridge alignment followed a steeply sloped mountainside with boulders and trees that could not be disturbed.

Several new construction techniques had to be developed for this project. Construction proceeded from the south abutment using the progressive cantilever method. The maximum span length was 180 ft (55 m), and temporary supports were required at midspan to reduce cantilever lengths. Due to the lack of access roads, the foundations consisted of microshafts grouted into the underlying rock formations.

Another innovation was the use of precast concrete segmental piers erected from the top of the completed deck. The piers were post-tensioned vertically to the foundation. Precast concrete segments for piers and the superstructure were delivered from the completed structure and erected with a stiff leg derrick anchored at the tip of the cantilever.

This project proved that precast concrete segmental construction was the right solution for bridges with complex


Photo courtesy of Figg & Muller Engineers.

Fig. 16. Shown is the MARTA light rail viaduct in Atlanta, Ga.

geometry and difficult access. It also showed the adaptability of segmental construction.[8]

MARTA Viaduct

The MARTA Viaduct in Atlanta, Ga., completed in 1983, was the first application of precast concrete segmental construction for a light-rail, mass-transit project (**Fig. 16**). The maximum span length was 140 ft (43 m), and the bridge was erected using the span-by-span method with a new type of erection equipment consisting of twin triangular trusses supporting the segments under the wings. These trusses could be launched easily with a crawler crane and were well adapted for road crossings where the vertical clearance could not be reduced significantly.

Sunshine Skyway Bridge

The Sunshine Skyway Bridge in Tampa was the longest concrete cable-stayed bridge in North America, with a 1200 ft (360 m) main span, when completed in 1987 (**Fig. 17, 18**). The bridge was an extension of the Brotonne Bridge, with a total width of 90 ft (27 m) compared with a width of 63 ft (19 m) for the earlier bridge.

The superstructure consisted of wide single-cell precast concrete segments stiffened by internal struts with a weight reaching 220 tons. Extensive use of precasting was justified by the location of the bridge over water and easy barge access. Superstructure segments for the main bridge and approach spans, approach piers, and underwater foundations were all fabricated by Pomco at the Port Manatee, Fla., casting yard, 5 miles (8 km) away from the bridge site.

James River, C&D Canal, and Neches River Bridges

Other precast concrete segmental cable-stayed bridge designs produced by Figg and Muller Engineers included the James River Bridge in Virginia, the C&D Canal Bridge in Delaware, and the Neches River Bridge in Texas. (**Fig. 19, 20, 21**). For the first time, precast concrete segmental construction was used for the pylons of the James River and Neches bridges.

For the James River Bridge, Muller invented a patented "delta frame" system, which was later used for the C&D Canal Bridge. The delta frame connects two parallel box girders and receives the stay cable anchorages located within the bridge median. With this system, the parallel structures used for the approach spans could be extended through the main cable-stayed span.[9]

The segments for the C&D Canal Bridge were fabricated by Bayshore Products at their plant in Cape Charles, Va., and shipped to the bridge site by barge.

Hanging Lake Viaduct

The Hanging Lake Viaduct, part of the I-70 Glenwood Canyon project in Colorado, was built in balanced cantilever from the top with a self-launching gantry. For this bridge, Muller proposed an innovative solution for the deck expansion joints.

These joints are typically located at the quarter length of the span to avoid angle breaks in the bridge profile under long-term concrete creep. This design, however, requires temporary blocking of the joint and temporary post-ten-


Photo courtesy of Figg & Muller Engineers.

Fig. 17. Shown is the Sunshine Skyway Bridge in Tampa, Fla.

Photo courtesy of Figg & Muller Engineers.

Fig. 18. Shown is the Sunshine Skyway Bridge precasting yard at Port Manatee, Fla.

sioning for cantilever construction, which slows down the erection process. For the Hanging Lake Viaduct, the expansion joints were located at midspan, thereby allowing for typical cantilever erection.

In order to eliminate deflections under live loads and concrete creep, sliding steel beams are placed inside the box girder at the joint. The beams carry the moments due to live loads and concrete creep redistribution. They also can be jacked to correct the bridge profile if necessary.[10]

J. MULLER INTERNATIONAL PROJECTS

From 1989 to 2000, Muller was technical director of J. Muller International, with offices in the United States, France, and Thailand. The firm was involved in a number of large-scale build/operate/transfer projects throughout the world. Segmental construction proved to be well adapted for these projects, especially the ones that required industrialized production and high speed of construction in a dense urban environment with difficult access.

Metro of Monterrey

The 11.2-mile-long (17.9 km) elevated line for the Metro of Monterrey, Mexico, was the first large-scale application for a precast concrete segmental light-rail guideway. Over 6500 bridge segments were match cast on 20 long beds and carried by truck to the construction site, where they were erected with 8 sets of steel trusses. Seventeen stations were placed along the alignment with the platforms supported directly from the guideway. The project was completed in 1990, only two and a half years after the notice to proceed for design.[11]

H3 Windward Viaduct

The H3 Windward Viaduct in Hawaii presented some challenges similar to those of the Linn Cove Viaduct in North Carolina (**Fig. 22**). For example, the bridge had to be built in a very sensitive environment along the mountainside in the Haiku Valley on the island of Oahu. The structure consisted of two parallel viaducts with a total length of 6600 ft (2000 m) and span lengths varying from 140 ft (43 m) to 300 ft (90 m).

The superstructure segments were fabricated in a yard located about 7 miles (11 km) from the site. They were delivered from the top of the previously completed structure because of the difficult access to the mountainous site and were erected in balanced cantilever with an overhead erection truss. This truss was specially designed to erect the two parallel bridges and accommodate horizontal curves, cross-slope variations, and differences of elevation between the two structures.

Construction of the viaduct was completed in 1993, seven months ahead of schedule.

Rogerville Viaduct

The Rogerville Viaduct in France was another good example of segmen-

Photo courtesy of Figg & Muller Engineers.

Fig. 19. The C&D Canal Bridge delta frame system photographed in Delaware.

Photo courtesy of Figg & Muller Engineers.

Fig. 20. Pictured is the Neches River Bridge precast concrete pylon in Texas.

Photo courtesy of Figg & Muller Engineers.

Fig. 21. Shown is the Neches River Bridge deck erection in Texas.

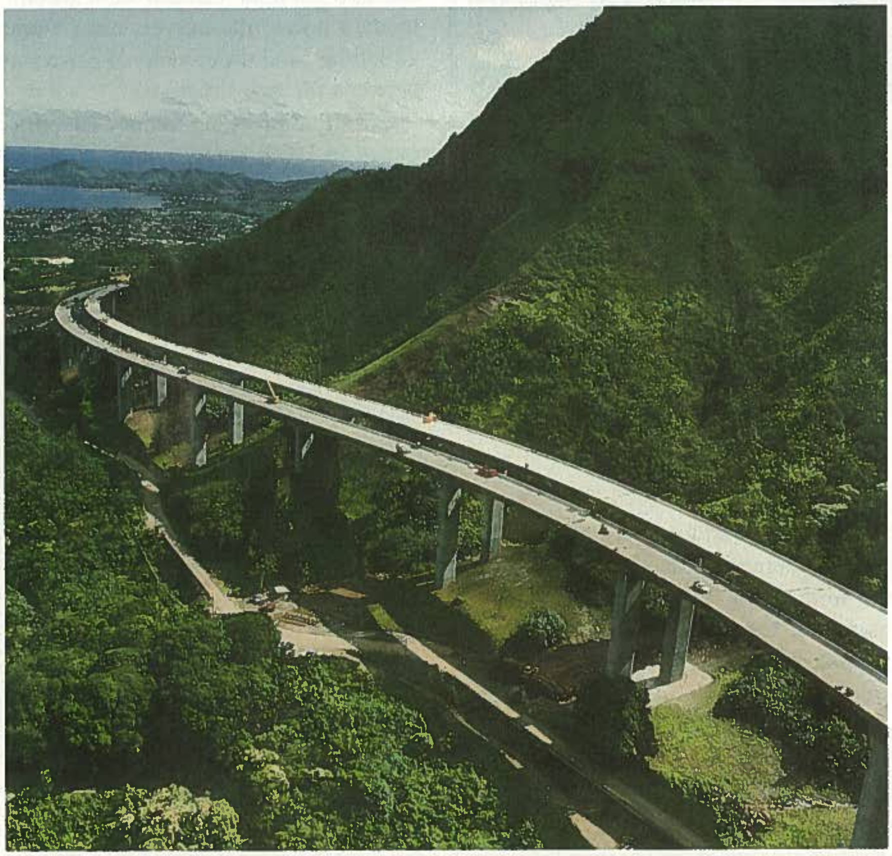


Photo courtesy of Figg & Muller Engineers.

Fig. 22. The H3 Windward Viaduct is photographed in Haiku Valley on Oahu Island, Hawaii.

tal construction in a sensitive environment (**Fig. 23**). For this bridge, Muller developed new V-pier shapes that made the parallel bridges look very attractive and well integrated in the surrounding forest valley.

The superstructure consists of parallel precast concrete segmental box girders with typical spans of 249 ft (76 m). The box girder cantilevers are supported by outside concrete struts, providing a lighter appearance for the structure. The bridge was erected in cantilever from the top with a self-launching truss.[12]

Channel Bridge Section

In 1996, Muller patented his concept for a new "channel" section for bridges.[13] The cross section of such a bridge consists of two edge beams positioned above and on either side of the deck slab. The superstructure is erected by sliding precast concrete segments from the abutment on temporary steel girders and post-tensioning the segments together with tendons running from abutment to abutment. This type of bridge can be used when the available vertical clearance for a crossing is minimal or for replacement of existing bridges that require increased vertical clearance.

Second Stage Expressway

The Second Stage Expressway in Bangkok, Thailand, was the first large-scale precast concrete segmental project for an elevated highway network. The first phase of the project, Sector A, had 29.4 miles (47 km) of elevated structures, including mainline, ramps, and interchanges, such as a three-level interchange over the Makkasan swamp. This part of the project was built within three years. Sectors B, C, and D were built later, adding about 33 miles (53 km) of viaducts.

The superstructure consisted of precast segmental concrete box girders with maximum span lengths of 45 m (150 ft). The spans were simply supported to accommodate differential settlements. All the structures were designed with two types of precast concrete segments, namely, two-lane segments with a maximum width of 39.5 ft (12 m), and three-lane segments with a maximum width of 49.2 ft (15 m).

These sections could be combined with a cast-in-place closure joint in between the wing tips for a maximum width of 197 ft (60 m). The spans were post-tensioned with external tendons placed inside the box girders. The segments were manufactured in an enormous precasting yard with 50 casting machines 50 miles (80 km) north of Bangkok. They were trucked to the site at night and erected with underslung and overhead trusses.

The maximum production reached 1000 segments per month, and the spans were typically erected in less than two days. This method of construction was well adapted to the congested urban environment of Bangkok.

Bangkok Transit System

The Bangkok Transit System was another complex project in downtown Bangkok with 15.2 miles (24.3 km) of elevated guideway and 25 stations. The project included twin-track and single-track structures with two-level single-track structures in some areas. Similar to the Second Stage Expressway, the segments were cast in a yard outside of the city and erected with a combination of underslung and overhead trusses.

Bang Na Expressway

The Bang Na–Bang Pli–Bang Pakong Expressway (Bang Na Expressway) in Thailand is the longest elevated expressway in the world, with a total length of 38.8 miles (54 km) (**Fig. 24**).

The expressway carries six lanes of traffic and is located within the median of an existing highway. The main line superstructure consists of a 92-ft-wide (28 m) concrete box girder with a maximum span length of 148 ft (45 m).

Components of this toll highway project include 28 ramp facilities with toll plazas, 14 platforms for toll surveillance buildings, 2 elevated mainline toll plazas, and 2 three-level interchanges. The total area of the elevated portions of the project is over 20.4 million ft^2 (1.9 million m^2).

It was essential to find a way to build the bridge very quickly within the median of the busy highway. Muller had the idea of designing the structure to accommodate an erection girder that could be launched from pier to pier without crane assistance, so the erection girder was designed to fit within the legs of the Y-shaped piers.

The bearings on top of the Y-shaped piers were inclined to eliminate the need of a cross tie, clearing the way for the erection girder. The segments were delivered either from the top of the completed structure or from ground level. They were placed on the erection girder with a swivel crane placed either on the deck or on the nose of the erection beam. In this case, the crane was launched with the erection girder.

The segments were manufactured in the largest casting yard ever built for a precast concrete segmental project with 100 casting cells and a monthly production rate of 1800 segments. The project was opened to traffic in January 2000 with a total design and construction time of only three and a half years.[14]

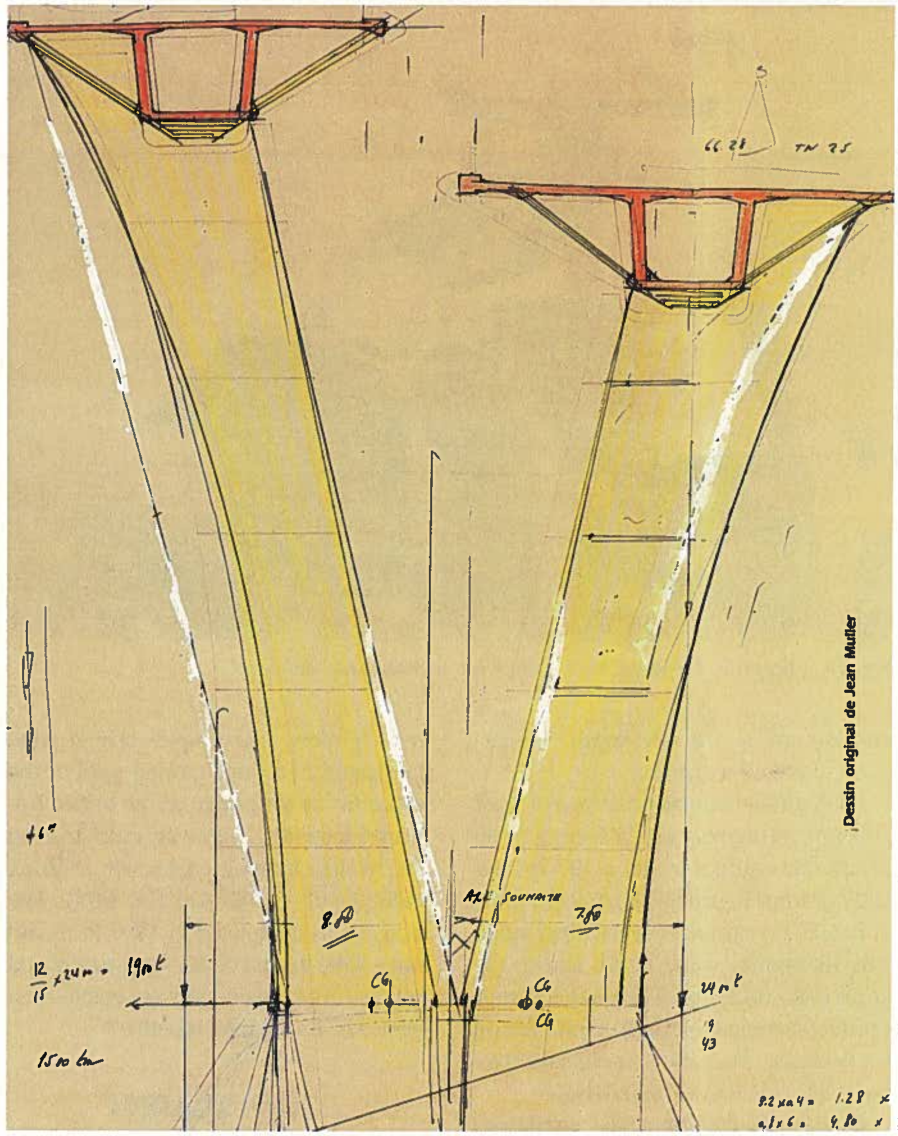


Photo courtesy of J. Muller International.

Fig. 23. This is a design sketch of the Rogerville Viaduct in France.

SEGMENTAL BOX GIRDER STANDARDS

The previously described large projects demonstrate that precast concrete segmental construction allows for the industrialization of the bridge construction process. This type of construction requires an important initial investment for setting up a casting yard and purchasing special forms and erection equipment. This investment was justified for the large projects described in this paper. It is clear, however, that this precast concrete segmental construction method can also be economical for smaller bridges if existing precasting yards could be used and the equipment could be standardized and reused on several projects.

A first step toward standardization was made in the United States at the end of 1997 when the joint committee consisting of the American Association of Highway Transportation Officials, the Precast/Prestressed Concrete Institute, and the American Segmental Bridge Institute published the Segmental Box Girder Standards providing standard dimensions for segmental bridges with different span lengths, widths, and types of construction.[15]

Confederation Bridge

In the field of gigantic bridge projects, the Confederation Bridge was a formidable challenge for design and construction (**Fig. 25, 26**). This 8-mile-long (13 km) bridge crosses Canada's Northumberland Strait between Cape Tormentine, New Brunswick, and Borden, Prince Edward Island.

Ice is present in the Strait for five months every year, preventing any construction at the bridge site. Minimum span lengths of 820 ft (250 m) were required to facilitate the ice clearing process in the spring. Close coordination was required between the design and construction teams to meet the tight construction schedule and find solutions to the unusual project requirements.

The bridge carries a two-lane roadway and two shoulders. The main bridge includes forty-three 820 ft (250 m) spans and two 541 ft (165 m) transition spans. The vertical clearance for the marine spans is typically 92 ft (28 m), except for the navigation channel with a clearance of 161 ft (49 m). The superstructure of the main spans

Photo courtesy of J. Muller International.

Fig. 24. Shown is the Bang Na Expressway in Bangkok, Thailand.

consists of a variable-depth, single-cell concrete box girder.

Each girder is made up of two precast concrete elements, a 623-ft-long (190 m) double cantilever and a 197-ft-long (60 m) drop-in girder. The drop-in girder is made continuous every other span. The maximum water depth across the strait is 95 ft (29 m). The piers are supported on conical pier bases founded on the bedrock. They had to resist ultimate ice loads of 6700 kip (30 MN).

Due to the environmental conditions and construction schedule, all the main bridge elements (pier bases, pier shafts, main girders, and drop-in spans) were fabricated in a huge casting yard at the extremity of the bridge on the Prince Edward Island side. They were erected using the Svanen floating crane with a lifting capacity of 17,500 kip (78 MN). The bridge was completed in 1997 in record time. Note that all of the substructure and superstructure elements were erected in a period of 12 working months.[16,17]

CONCLUSION

The segmental concrete structures discussed in this article represent some of the most innovative projects from Muller in the field of precast concrete construction. They represent convincing evidence that Muller was blessed with an unusual combination of talents, namely, ingenuity, a thorough understanding of engineering principles, a flair for aesthetics, deep construction knowledge, and enormous enthusiasm.

Like Freyssinet, Muller's legacy continues with the many engineers he has mentored. He always enjoyed working with his staff, and he valued their comments, including those from the most junior engineers. Working with him was an unforgettable experience, in particular when he was developing designs for long-span cable-stayed bridges with only the help of a fountain pen, a hand calculator, and his incredible mind.

In just a few hours, he could sketch the main structural element dimensions, dimension foundations, size cable stays and post-tensioning tendons, check bridge stability and deflections under wind and live loads, and compute the main bridge quantities. His constant quest for new and improved ideas and his ability to create exceptional designs have been and will continue to be a source of inspiration for many bridge designers.

We will let Muller conclude this article in an excerpt from a paper on bridge design that he wrote several years ago:

"What Rudyard Kipling said 90 years ago in his book, the *Bridge Builders*,

Photo courtesy of Alain & Buffie Boily.

Fig. 25. Pictured is the Confederation Bridge over Canada's Northumberland Strait between Cape Tormentine, NB, and Borden, PE.

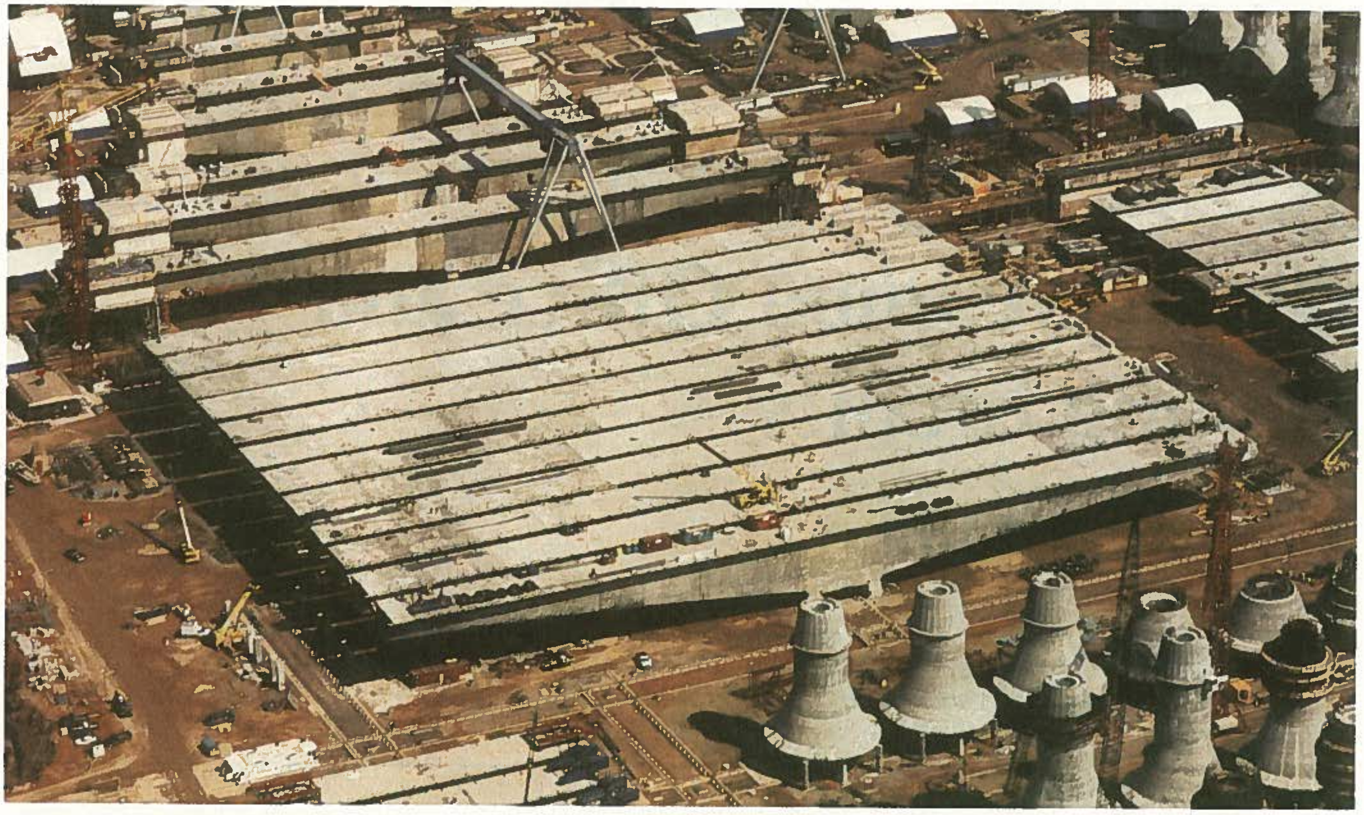


Fig. 26. Shown is the Confederation Bridge precasting yard in Prince Edward Island, Canada.

is amazingly true today: 'At the very moment when he was balancing forces with endless calculations, the river was perhaps digging holes under some of the 80-ft-deep foundations that carried his reputation.' The accumulation of codes and international specifications, and the resulting excessive amount of calculations resemble the river digging holes under our bridge piers. These can never be substituted for experience and common sense to make a bad project good. The most massive structures are rarely the best ones, and unnecessary and sometimes detrimental safety margins are in reality a veil to hide fear of responsibilities. Our profession is not without risks, but these remain limited if we use the experience accumulated through our own or others' mistakes. The only unforgivable thing is to repeat past errors knowingly or by negligence. At the end, only persistence and resolve matter, and nothing can replace energy, moral courage, and intellectual integrity."

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