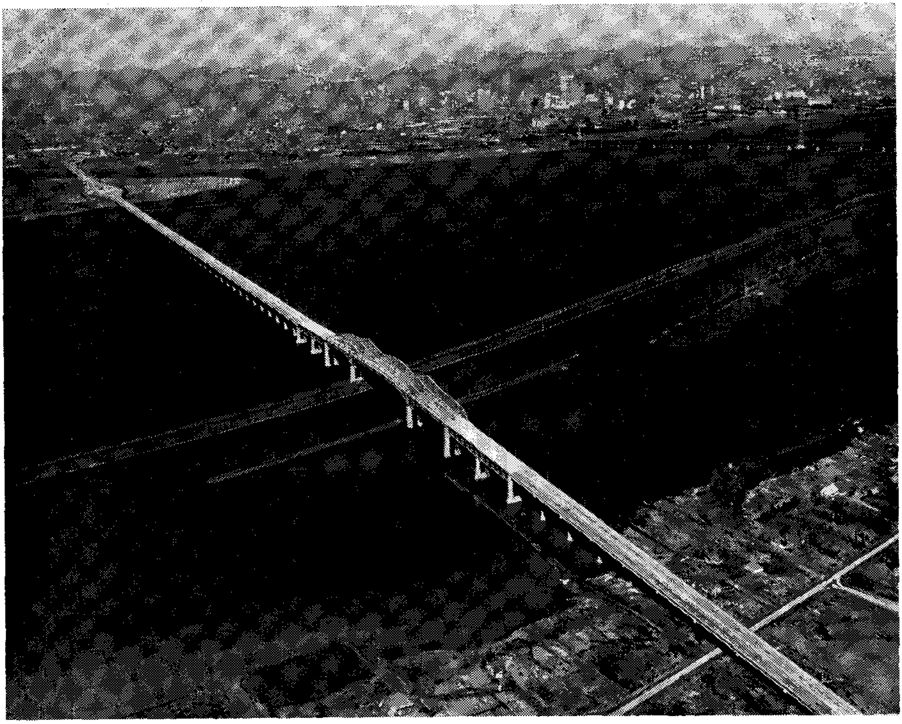


Fig. 1—Champlain Bridge Spanning St. Lawrence River, Montreal, Quebec, Canada

Highways Built with Prestressed Concrete in Montreal

by Bernard Lamarre, Ing., M. Sc.*

Montreal, by reason of its geographical location and its economical importance, is the centre of a highway network which, in the last ten years, has been considerably expanded and, in the last five years, greatly accelerated to be partially completed in time for Expo 67.

Since 1957, 150 miles of toll expressways, 250 miles of limited access rural freeways and 70 miles of urban expressways have been built in the Province of Quebec at a cost of about $850 million.

Lalonde, Valois, Lamarre, Valois & Associés, Montreal, Quebec, Canada.

In this heavy road construction program, prestressed concrete was used extensively in structures as different and as varied as bridges, viaducts, elevated structures and tunnels.

The reasons to use prestressed concrete in highway structures must be the same in Quebec as they are elsewhere: economy, speed of execution, quality of construction, lower maintenance cost, and flexibility of use.

Discussed briefly are four important structures erected in Montreal—Champlain Bridge, Lafontaine Bridge-Tunnel, Bonaventure Autoroute, Nuns' Island Bridge—where prestressed concrete was used with great advantage.

QUEBEC EXPRESSWAYS

The construction of main traffic arteries and autoroutes serving the Metropolitan Region had its beginning around 1957. Constructed were:

1. The Metropolitan Boulevard elevated expressway, crossing the north end of the City from east to west.
2. The Laurentian Autoroute, between Montreal and St.-Jérôme, later completed to Ste.-Adèle.
3. The Eastern Township Autoroute between Montreal and Sherbrooke.
4. The Trans-Canada Highway, between Montreal and Quebec.
5. The Décarie Expressway.
6. The Turcot and De la Vérendrye Expressway.
7. No. 30 Autoroute on the South Shore.
8. The North Shore Autoroute, between Montreal and Berthier.
9. The Montée St.-Léonard Expressway.

This last expressway leads to the Lafontaine Bridge-Tunnel complex, crossing the St. Lawrence River in the eastern sector of the City of Montreal.

Montreal is then surrounded by a rectangle of expressways, where it is possible, without hindrance from intersections and traffic lights, to circle the city at an average speed of 50 mph, at off peak hours.

It is interesting to note the steady growth in the use of prestressed concrete in the construction of these autoroutes:

For the Laurentian Autoroute, first section (1959-60), prestressed concrete was used in 12% of the structures (4 out of 35).

For the Laurentian Autoroute extension (1962-63), prestressed concrete was used in 55% of the structures (10 out of 18).

For the Eastern Township Autoroute (1964-66), prestressed concrete was used in 35% of the structures (18 out of 51).

For the North Shore Autoroute (1966-67), prestressed concrete was used in 40% of the structures (12 out of 30).

For the Décarie Expressway (1966-67), prestressed concrete was used in 68% of the structures (17 out of 25).

This progress made in the use of prestressed structures is most impressive, considering that in the U.S.A. the first prestressed concrete structure was installed in 1951, namely the Walnut Lane Bridge in Philadelphia. The first prestressed concrete structure in Canada was the baseball stadium built in Sherbrooke, Quebec, in 1952.

In 1957, at the time of the simultaneous construction of the south approaches, including four underpasses, and the raising of the existing portion of Jacques-Cartier bridge over the proposed St. Lawrence Seaway channel, it was found necessary to substitute and use prestressed concrete for steel spans, for which the underpasses were first designed, due to delay in delivery and in order to maintain a very close schedule. These were the first prestressed concrete highway structure spans in the province of Quebec.

It may not be necessary to demonstrate the versatility of prestressed concrete but, to explain the use of this material in expressway and highway construction, it may be appropriate to reiterate a few reasons why it is being used in this province:

Economy

In Quebec, for spans of between 100 ft. to 200 ft., prestressed concrete is the most economical superstructure that can be used for bridges or viaducts. The economy would vary from 10% to 20% compared to any other types of structures.

Speed of Execution

Prestressed concrete superstructures have the additional advantage of being generally erected in any kind of weather. This was, for the majority of projects that had to be realized in time for the opening of Expo 67, the major governing factor.

Quality of Construction

Because, most of the time, prestressed concrete elements are prefabricated, this allows for a better quality control, and better workmanship.

Stability of the Piers

Since a prestressed concrete superstructure is always heavier than a steel superstructure, it adds to the stability of the supporting piers, with regard to the horizontal forces such as wind action, ice pressure, water-flow velocity, braking forces. Consequently, it ordinarily permits a reduction in the weight of the piers, and a reduction in their cost.

Lower Maintenance Cost

Because there is less shrinkage cracking than in normal reinforced concrete structures, prestressed concrete structures have a better resistance to weathering and to the action of deicing chemical agents. They have almost negligible cost of maintenance as compared to steel structures.

Flexibility

Prestressed concrete elements can also be used readily in irregular or curved structures. By maintaining the same beam cross-section, the same formwork can be re-used, and by careful arrangement of prestressing cables, variable beam lengths can be obtained on a mass and economical production.

CHAMPLAIN BRIDGE

The Champlain Bridge in Montreal is a $35,000,000 toll bridge providing a six-lane, 60-mph artery, crossing the St. Lawrence River and Seaway between Montreal and the South Shore by way of Nuns' Island, at about one mile upstream of Victoria Bridge (Fig. 1).

Its approaches on Montreal Island connect with the Bonaventure, Décarie and Turcot Expressways, and on the south shore with Expressway

No. 30 and the Eastern Township Autoroute.

The bridge superstructure was built entirely of prefabricated, prestressed concrete elements, except for the part spanning the St. Lawrence Seaway channel and dykes, for which steel trusses and deck beams were utilized.

Section between Nuns' Island and the Seaway

This is the principal section of the bridge, crossing the St. Lawrence River proper.

MKD (McNamara-Key-Deschamps) were awarded the contract for this section. The original call for bids for this section covered designs in steel and reinforced concrete, or any other alternative the tenderers would develop in accordance with the norms given in the specifications. Six bids in prestressed concrete were lower than the lowest proposal based on the original design in steel. The total cost of this section came to about $17.00 per square foot, which is a very low price indeed for a bridge of this kind.

Bridge construction was divided into four separate operations: construction of piers, manufacturing of prestressed concrete beams, transportation and launching of beams, construction of deck slab. The coordination of all operations was of great importance, for any delay occurring in one of the operations would have affected the progress of the others.

Pier construction

The bridge pier foundations, of circular shape, were cast in the dry. Even if the cylindrical cofferdams were simple in design, consisting of steel sheet piling driven around floating circular bracing, which acted as templates, the actual procedure proved unreliable, time consuming and costly. Water infiltration was difficult to stop, and even if the contractor used double wall cofferdams, as he did in many instances, it was almost impossible to dry up the excavation. In a case such as this, with a fractured rock and an absence of overburden in many locations, it would have been preferable to proceed with pre-excavation and tremie concreting. This method was followed for the construction of the ice control structure just upstream of Champlain Bridge with conclusive results.

In the case of Champlain Bridge, the foundation work delayed the operation and proved to be very costly to the contractor. In many cases, the water infiltration was serious enough to cause segregation in the concrete, and obliged the contractor to grout later on.

All piers were computed to resist an ice load of 20,000 lb. per linear ft.; they were oblong in shape and were constructed with slip forms.

Superstructure construction

The prestressed concrete superstructure of this section comprises 40 spans of 176 ft. 4 in., each including seven prestressed concrete girders.

The T-shaped girders (Fig. 2) were approximately 10 ft. deep, with a top flange 5 ft. 6 in. wide, a bottom flange 2 ft. 3 in. wide, and a 7-in. thick web. They were stressed with 24 cables made up of twelve 0.276-in. diameter wires. The force applied by each cable was about 40 tons after deduction of all losses. Four prestressed concrete diaphragms per span were built between the seven girders.

The deck slab of each span consisted of the 7 flanges of the T-girders and of six cast-in-place intermediate strips. Parts of the diaphragms had been previously cast with the girders. These intermediate portions of slabs and diaphragms were transversely prestressed by means of cables that passed through holes provided when casting the girders. The combined deck slab was prestressed with 54 cables.

Approximately ⅓ of the transversal cables in the deck and ⅔ in the diaphragms were tensioned on the day following the placing of concrete in order to allow for girders of the next spans to be moved across the deck. The remaining transversal cables were tensioned later.

Manufacturing and erection of girders

The manufacturing of the girders took place in a precasting yard on Nuns' Island, which was equipped with eight steel casting beds and four sets of steel side forms.

The yard was equipped with four A-frame dollies rolling on rails and supporting a 180-ft. beam from which hung the assembled reinforcing cages (Fig. 3). Gantry cranes on rails moved the cage to the casting bed. Forms were removed twelve hours after casting. A minimum compressive strength of 3500 psi (after about 48 hours) was necessary before starting the stressing operation.

Using standard Freyssinet equipment and procedures, 14 cables were stressed at this stage. Each girder was then moved by means of straddle trucks on rails to the storage area. After the concrete had reached 4000 psi, six more cables were stressed. First stage of grouting was done at the same time. The last four cables were stressed after the deck had been cast and the concrete had reached 5000 psi.

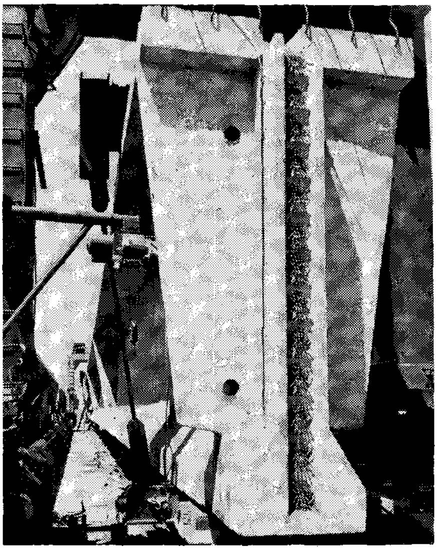


Fig. 2—End View of T-Girders for Champlain Bridge

It was believed that this was the first time that a 5% air-entrained concrete was used for a prestressed concrete project of this magnitude. A series of experiments were conducted at Ecole Polytechnique to determine the short and long term shrinkage and creep of this type of concrete.

The transport distance for the girders was up to 1.5 miles. The placing was done with a mobile launching bridge weighing over 275 tons. The main feature of this launching bridge was a truss of triangular section. Its length was equal to two spans, i.e. 353 ft. It was supported on both ends and in the middle by gantries in such a way that the bottom edge of the steel beam, under which was bolted the monorail for the hoisting carrier, stood about 16 ft. over the deck of the bridge (Fig. 4).

When empty, the launching bridge was balanced on its central gantry. The low-bed trucks passed under the back span of the launching bridge, and the prestressed concrete girder was suspended from the monorail carriers, after having been moved by means of four horizontal 50-tons jacks, with which each carrier was equipped. The monorail carriers brought the girder to the front span and then the launching bridge moved transversely after the back gantry jacks had been removed.

Some trouble was experienced with the suspending jacks. The pressure at maximum capacity was about 10,000 psi. This high pressure caused leaking in the connections which is always difficult to cope with.

Section between Nun's Island and Montreal Island

The superstructure in this portion of Champlain Bridge comprises 12 spans, 128 ft. long, including 132 prestressed concrete girders, with 11 girders per span (Fig. 5). To launch these 128-ft. lighter weight units, a smaller 100-ton capacity launching bridge was used. The general principles were the same although this launching bridge was not quite as flexible as the larger one. Girders could only be moved forward along the axis of the bridge, then lowered from the launching bridge onto dollies which moved them laterally to their final location. The I-shaped girders are 7 ft. 2 in. deep with a top flange 4 ft. 4 in. wide, a heel 2 ft. 2 in. wide and a web 6½ in. thick. These girders were manufactured in a precasting yard located on Nuns' Island and each was prestressed by means of 12 Freyssinet cables of twelve 0.276-in. diameter wires.

Five diaphragms, 8 and 12 in. thick and 5 ft. deep were built between the girders in each span and then prestressed with two cables per diaphragm.

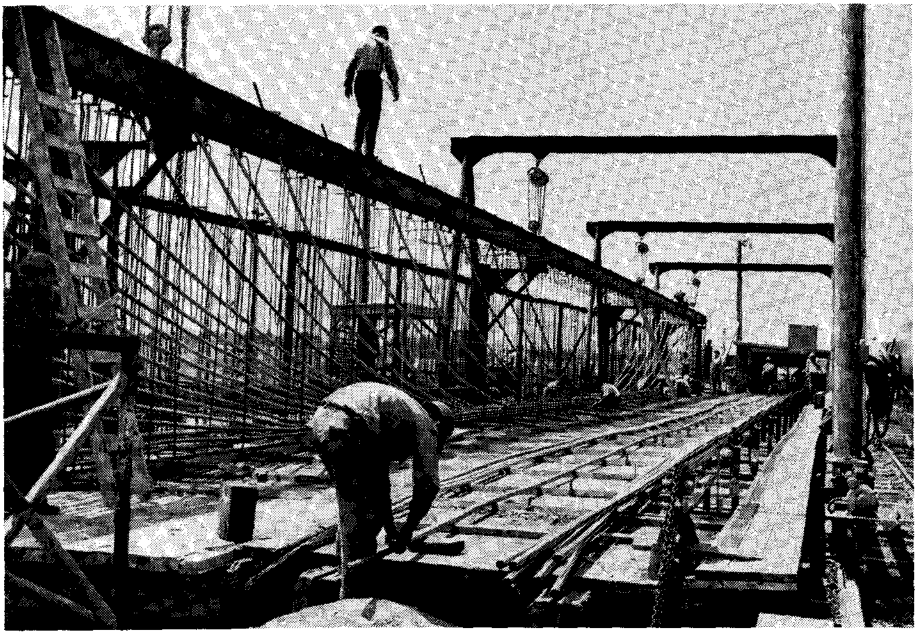
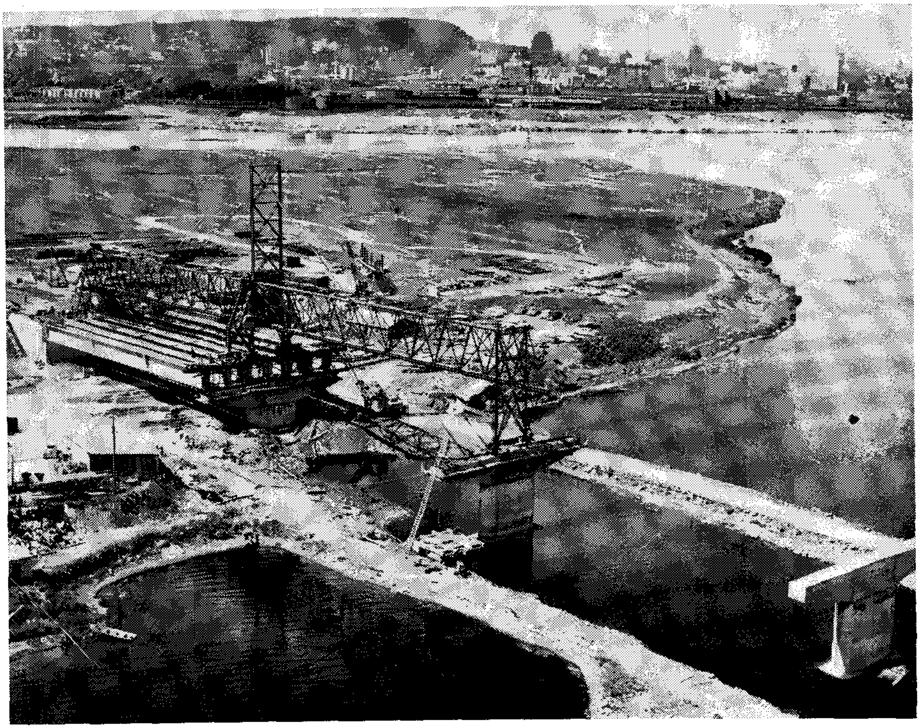


Fig. 3—Preparation of a Cable and Reinforcement Cage for T-Girders



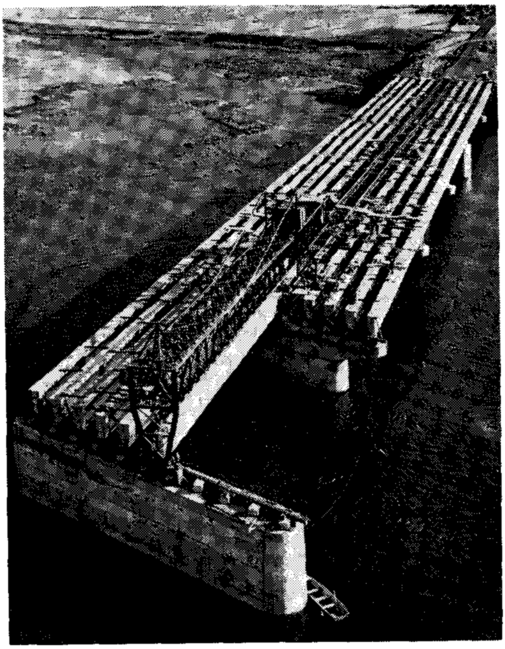


Fig. 4 (Above)—Construction View of Champlain Bridge Showing Launching Bridge for Placing 176-Ft. Spans

Fig. 5 (Right)—For Erection of the 128-Ft. Spans in This Portion of Champlain Bridge a Smaller Launching Bridge Was Used

The girders and diaphragms were topped with a 5½-in. thick reinforced concrete deck slab, with a 6½-in. slab spanning between girders. It is felt that a covering slab, even if it slows down the erection of a prestressed concrete superstructure, is more satisfactory than a deck formed only with the top flanges of adjacent T-beams because it produces a more regular surface and profile.

Considering that the prestressed concrete sections in Champlain Bridge have a total length of about two miles, at the time of construction it was the longest prestressed concrete structure ever built in this country.

LAFONTAINE BRIDGE-TUNNEL

In 1949 the Government of Canada, by passing the Trans-Canada Highway Act, authorized the construction, with provincial participation, of a national highway across Canada.

The Quebec section comprises approximately 390 miles. Chief among the problems encountered in its construction was the crossing of the St. Lawrence River between the South Shore and Montreal Island.

Following the choosing of the crossing site, the type of crossing remained to be decided, i.e., whether bridge or tunnel.

By reason of subsoil conditions, navigation requirements and town planning exigencies, a tunnel structure was chosen, and estimates indicated it to be 5% to 10% cheaper than a bridge.

The structures included in the river crossing complex comprise the following:

1. The Hochelaga Interchange and north approach within the City of Montreal.
2. The tunnel under the river channel.
3. The south approach on Charron Island.
4. A 1500-ft. bridge spanning the south channel between Charron Island and the Mainland.
5. The south shore approaches.

Description of tunnel

The tunnel has two 42-ft. traffic tubes, separated by a 22-ft. central tube (Fig. 6). The tunnel's cross-section was designed to meet highway standards and requirements (Fig. 7).

The tunnel was formed by seven elements each 25 ft. high, 120 ft. wide, 360 ft. long and weighing 32,000 short tons. Each one had to be calculated as a floating shell with minimum freeboard to reduce towing risks and cost of the sinking ballast.

Also, when in place, each element had to be heavier than the water it displaced. Concrete used to form the roadway replaced the sinking ballast weight after submersion.

The tunnel had to resist an hydrostatic pressure of 8,000 lb. per sq. ft. Comparing the relative merits of reinforced and prestressed concrete, it was found that shear stresses in the former called for thicker slab and roof corner which would require each element to be over 30 ft. high.

Prestressed concrete permitted a reduction of 5 ft. in height, raising the bottom profile as much, and shortening the tunnel length by 225 ft. The density of prestressed concrete and its resistance to cracking provided a structure of higher quality.

Absence of hydrostatic pressure on the elements when in dry dock, was compensated by the temporary use of prestressed steel tendons.

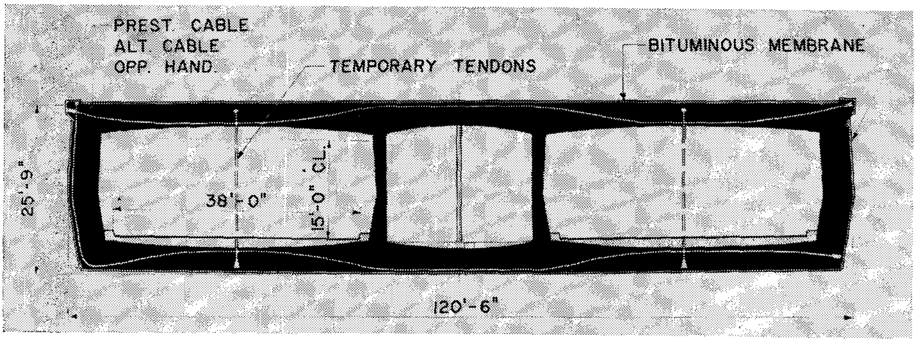


Fig. 6—Cross-Section of Lafontaine Tunnel, St. Lawrence River, Montreal

The seven elements were fabricated in a dry-dock, towed to their ultimate location and weighted down with 10 ft. of sinking ballast. The dry-dock, 2000 ft. long, 1000 ft. wide and 90 ft. deep, was excavated near Charron Island and protected by a dike reaching 2 ft. above high water level (Fig. 8).

The size of the dry-dock and the equipment installed allowed the carrying out of two distinct operations simultaneously: construction in place of 1504-ft. portion of the tunnel and prefabrication of the seven elements.

Exterior walls of the tunnel are 4 ft. 6 in. thick, interior partitions, 2 ft. thick, bottom slab, 4 ft. 3 in. thick, and roof slab, 4 ft. 6 in. thick. The prefabricated elements and cast-in-place tunnel sections were provided with 2 ft. wide construction joints, spaced 50 ft. apart. The joints were fitted with polyvinyl water barriers and were cast after adjacent sections had hardened. Walls and roof were covered with an impervious membrane and the roof was further protected against damage by the appli-

Fig. 7—Interior of Completed Lafontaine Tunnel

cation of a 4-in. concrete layer.

To prevent shrinkage cracks, specifications were particularly rigid. Temperature of concrete was maintained at between 60°F and 70°F during placing, adding ice to the mixture when warmer temperatures required it. Type II Portland cement was used exclusively to provide slow setting. Coefficient of variation was limited to a maximum of 12.5%.

The fabrication of the elements and construction of the cast-in-place tunnel sections in the dry-dock lasted seven months. 250,000 cu. yd. of concrete were used for the tunnel, out of which 110,000 cu. yd. went into the prefabricated elements. In addition, 6000 tons of prestressing steel were used. It is believed to be one of the largest prestressed concrete jobs undertaken in the world.

Tunnel construction

A trench, 160 ft. wide at the base, 300 ft. wide at the top and 90 ft. deep, was dug through a very dense glacial till by the modified Hydro Quebec dredge, to provide a bed for the elements.

To determine the hydrostatic pressures, and risks to be encountered while towing and sinking the elements, a scale model hydraulic study was first carried out.

Each element was sealed with watertight bulkheads. Following flooding of the dry-dock, the elements floated with approximately 15 in. of freeboard.

Prior to floating each element to its final location, a fitting-out dock

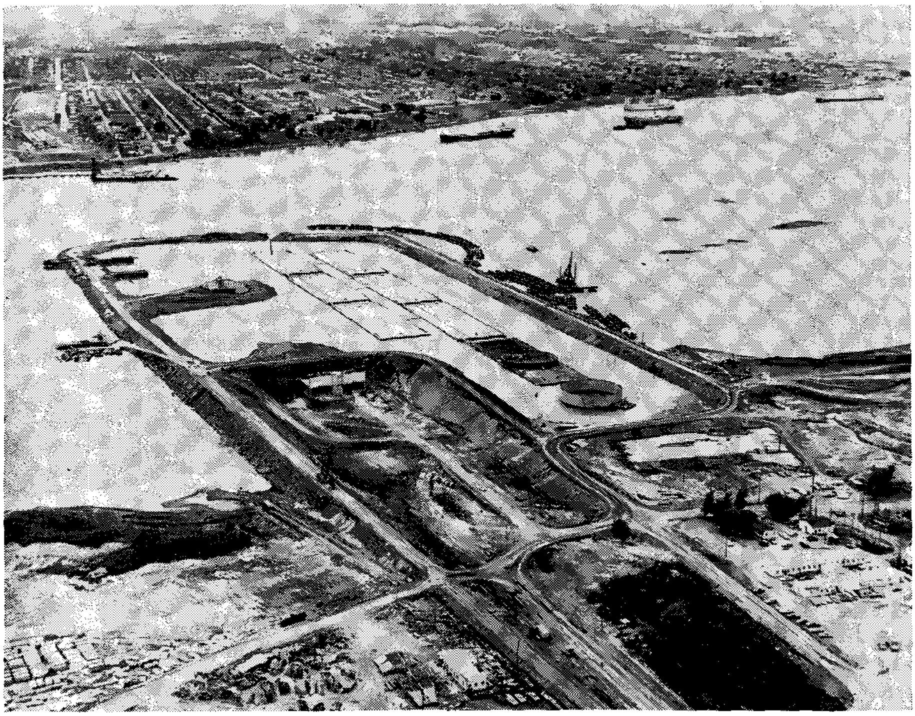


Fig. 8—General View Showing the Seven Prefabricated Tunnel Elements in the Flooded Dry-Dock and the Beginning of the Cast-In-Place Section of Lafontaine Tunnel

had been provided and dolphins driven upstream and downstream of the trench. Preparatory sinking procedures were as follows:

1. Towing each element to the dock by cables.
2. Element suspended between two barges.
3. Installation of inspection stack and alignment apparatus.
4. Ballasting for immersion.

In the meantime, the trench bottom was prepared by installing prefabricated concrete blocks at the required elevation and at the exact locations where the foundation blocks, forming part of the element, will rest.

The elements, straddled by two barges, were moved by means of cables tied to two upstream anchors and two downstream anchors. Jacks lowered the element at the rate of two feet per minute. Correcting jacks counteracted the force of the current. All operations were synchronized in a control room located on one of the barges.

When the elements were within a few inches of the gasket of the adjoining one, four foundation blocks were deposited under the floor slab by divers. Position was verified, levelling jacks were adjusted and pressure applied to support the element at the required elevation.

Coupling jacks at each bulkhead were adjusted and operated, bringing the ends together, compressing the gaskets and temporarily sealing the joints.

Water was pumped out of the

Fig. 9—Bonaventure Autoroute Skirts Expo 67, Montreal

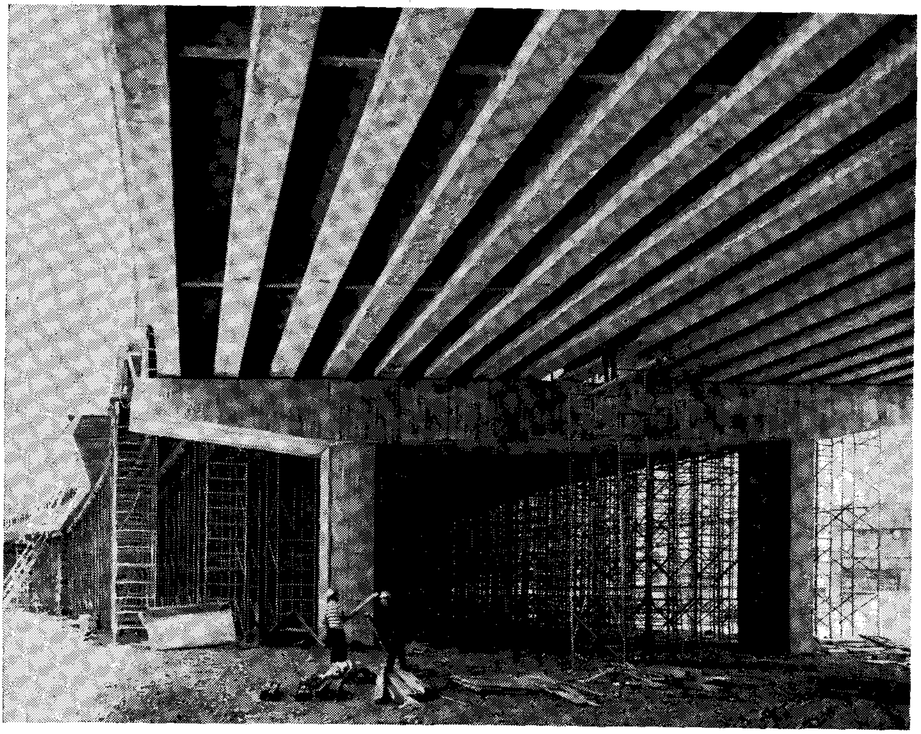


Fig. 10—A Portion of Bonaventure Autoroute Shows Cast-In-Place Box Girders in the Background with Prestressed Girders in the Foreground Span

space between the bulkheads, reducing the pressure in that space to atmospheric pressure. This permitted the hydrostatic force of 8000 tons on the elements to push it very tightly against the previously installed element. The voids under the elements were injected with sand by the Christiani-Nielsen method.

BONAVENTURE AUTOROUTE

The Bonaventure Autoroute may be considered as the third approach to Champlain Bridge, connecting it to the center of Montreal and ultimately to the Trans-Canada Highway which will be built through the Montreal business section (Fig. 9).

Except at three special locations, where continuous box girders had to be built in place, the structure is entirely composed of simply-supported, prefabricated prestressed girders.

The limited time allotted to complete this $4,000,000 project had to be considered in designing the structure. Tenders were opened June 25, 1965, with the project to be completed by December 1, 1966. A section 2000 ft. in length was to be completed by November 12, 1965, barely 4½ months after the award of the contract, to provide an entrance to Expo 67.

Because of the limited time available, the several connecting roadways to be built, and the spanning of heavily travelled railways and streets with the minimum of interference to traffic, the use of prefabricated and prestressed girders was decided upon.

Girders were shop-prefabricated

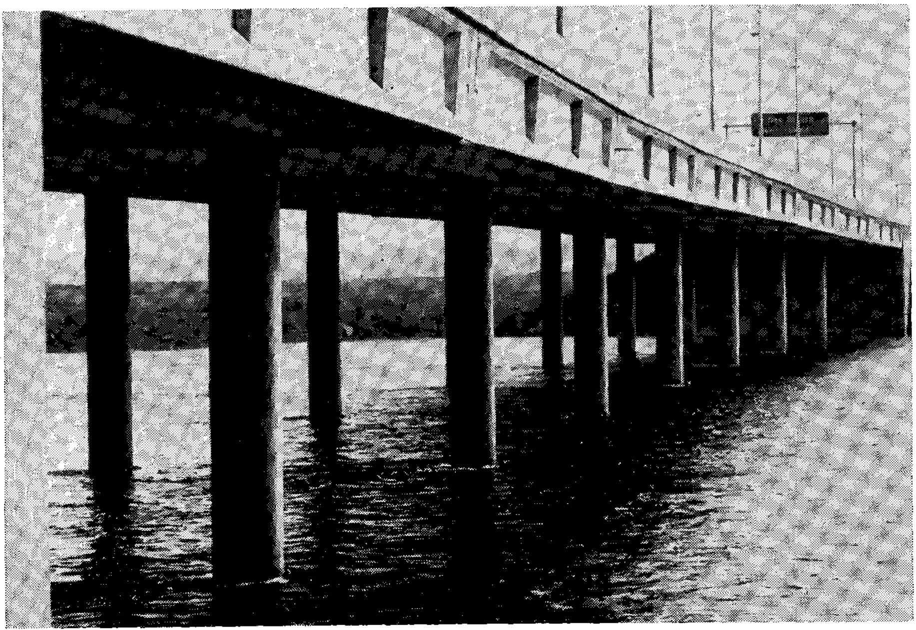


Fig. 11—General View of Nuns' Island Bridge Showing Uniform Depth over Entire Length

while the piers were being constructed. This procedure permitted continuous construction through the winter season to be done efficiently and economically, while reducing to the minimum interference to the public.

In Fig. 10 it is interesting to note the contrast between casting the box-girders in place (background), with their extensive formwork and falsework, and in the foreground the

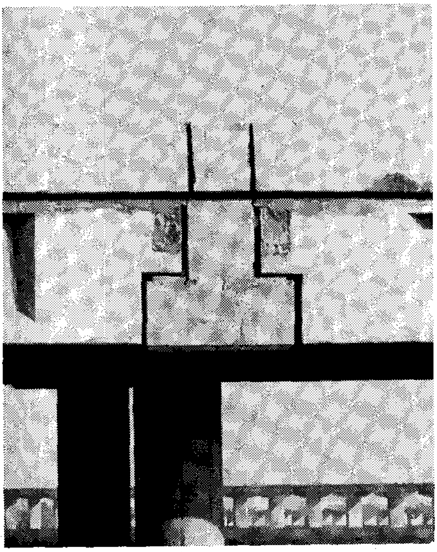


Fig. 12—Nuns' Island Bridge Girder to Pier Cap Connection

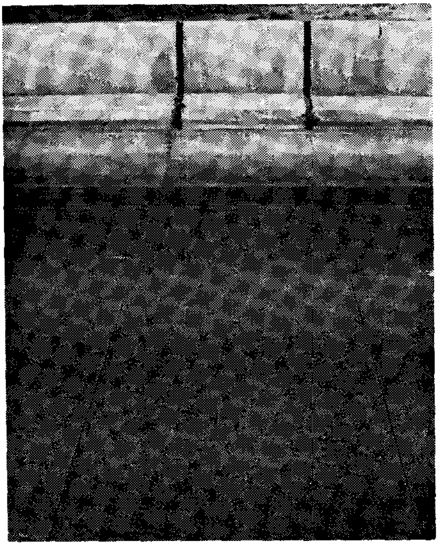


Fig. 13—Narrow Sawed Joints in Pavement over Piers, Nuns' Island Bridge

simplicity of installing prefabricated girders.

Design details

Because of the curvatures encountered and the spanning of a number of streets, railways tracks, etc., piers had to be set up in such a manner as to keep the same beam cross-section. AASHO Type IV sections were used throughout for the interior girders, and a modified AASHO Type IV for the exterior girders.

The number of girder lengths required were kept to a minimum. Only six different lengths were designed for 126 exterior girders and five different lengths for 833 interior girders. Lengths varied between 70 and 100 ft.

The tops of the pier seats were designed not only to receive the girders but also to provide for the drainage system. Furthermore, by abutting the girders to the prestressed diaphragm, and sealing the ½-in. joints with a neoprene seal, the use of metal cover plates over the 1-in. pavement slab joints was eliminated.

NUNS' ISLAND BRIDGE

The bridge forms an integrated part of the Bonaventure Autoroute and provides two-way traffic connections by way of the Champlain Bridge. It joins Montreal Island to Nuns' Island.

The bridge is 1092 ft. long, comprising 8 spans, each approximately 137 ft. long (Fig. 11).

Tenders were opened on April 14, 1966. The girders had to be installed by November 1966 and the job had to be completed by the end of April 1967. Again, owing to the limited time allotted, prefabricated, prestressed concrete girders were used.

Design details

To have the sides of the bridge show a continuous line and to mask the piers' cross beams as much as possible, the prestressed concrete girder ends were notched to rest on the pier cap seats designed for this purpose (Fig. 12). Two 1-in joints, sealed with 1¼-in. neoprene seals, were provided by boxing in the girder ends at the pier cross beam seats. These two joints replaced a larger joint in the asphalt paving, which would have required the use of metal joint covers. Thus, it required only 1-in. deep sawed joints in the asphalt surfacing as shown in Fig. 13.

CONCLUSION

It is evident that, for the last ten years, the use of prestressed and precast concrete for highway structures in and around metropolitan Montreal has known an always progressive popularity. Due to the opening of Expo 67, the Montreal area was faced with a "crash" highway construction program in which precast, prestressed concrete has contributed greatly to meet the very tight schedules, without penalizing in any way the structural and architectural qualities.

The four projects that have been described do not, by any means, cover all the highway work undertaken in prestressed concrete in Montreal. They have been chosen because they represent a good cross-section and are representative of projects with which our office has been associated.

Discussion of this paper is invited. Please forward your discussion to PCI Headquarters by January 1 to permit publication in the April 1968 issue of the PCI JOURNAL.