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THE CONFEDERATION BRIDGE, CANADA

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SUMMARY

The Confederation Bridge is located in Atlantic Canada; it provides a fixed link across the Northumberland Strait between Cape Tormentine, New Brunswick, and Borden, Prince Edward Island. The design service life of the structure is 100 years. The 13-km Crossing comprises approaches with 93-m spans in shallow water near shores and a main bridge with 250-m spans in the Strait. Because of the short construction time and the often adverse conditions for work at sea, precasting was used systematically on a large scale for the entire bridge. Precast pier bases were installed and grouted to bedrock at depths down to 38 m below sea level. Precast shafts were erected upon the bases. Typical cantilevers for marine spans weighing 78 MN were precast on shore and set in place with a floating heavy-lift crane, which was also used for placement of 52-m- long precast drop-in spans between cantilevers using a procedure which eliminates excessive erection moments in the piers. Innovative design features and the most advanced construction techniques and skills have been called on to match the challenge presented by such major undertaking.

1. INTRODUCTION

A fixed link between the Provinces of New Brunswick and Prince Edward Island had been considered for nearly a century. It was not until 1988, however, that the idea materialized into a 13-km bridge, the Northumberland Strait Crossing. The bridge would be financed, built, and operated by a private developer for thirty-five years, then turned over to Public Works Canada. In 1992 three international joint ventures were on the final list for consideration. Strait Crossing Joint Venture (SCJV), the successful low bidder, is composed of SCI of Canada, Morrison Knudsen of the United States, GTM of France, and Ballast Nedam of the Netherlands. The bridge design consultant is J. Muller International·Stanley Joint Venture. Construction started in Spring 1994 and lasted until the end of 1996, with opening of the facility in June 1997. Considering the size of the project, the short construction time, and the adverse conditions generally encountered at sea in this region, the realization of this bridge was a monumental work.

2. DESCRIPTION OF THE PROJECT

2.1 General

Deep water in the Strait calls for long spans, whereas shallow water near shores is more suited for shorter spans. The extremely short completion time called for massive use of precasting, large precast elements carried by heavy marine equipment for the long spans and more conventional elements for the shorter spans. These requirements naturally divided the bridge into two different structures: the long marine spans in deep water, and the shorter approach spans in waters not accessible by deep draft vessels.

From Jourimain Island on the New Brunswick side to the village of Borden on the Prince Edward Island side, the bridge comprises:

- The West Approach, 1,320 m long with 93-m spans.
- The Main Bridge across the Strait, 10,990 m long with 250-m spans.
- The East Approach, 600 m long with 93-m spans.

2.2 Main Bridge Substructure

2.2.1 Foundations

The rock sequence across the Strait consists of a series of interbedded sandstones, siltstones, and mudstones. These rocks are believed to have been deposited as sediments in a fluvial or estuarine environment, and a broad correlation can be made across the Strait. However, at a small scale, the rock layers are not very consistent from pier to pier, and each pier location must be fully investigated and evaluated on its own. Thick layers of sandstone are interbedded with layers of relatively soft mudstone varying in thickness from 5 to 500 mm, most being 50 mm thick. Sandstone is competent rock, but mudstone layers underlying sandstone constitute weak planes for transmitting horizontal forces, such as those from ice and wind. Because of the uncertainty in assessment of the real geometry of these layers, it is assumed that they are present over 100 percent of the foundation areas.

The contractor chose to use spread footings for all the prefabricated piers. For the reasons explained above, the founding level must be on sandstone with the next layer of soft mudstone, if any, following at a depth not less than that determined by the geotechnical analysis on a pier-by-pier basis, but in no case less than 1.50 m. The dredging operations consist of first removing the overburden, which is up to 10 m thick, and excavating a trench to the competent sandstone level; a template is used to guide the dredging bucket in the circular pattern.

The prefabricated pier base ring footing is installed in the trench on three hard points about 0.5 m above the bottom. The three points determine a horizontal level on which to set the pier base and leave a space between the ring footing and the trench, which is then filled with a specially formulated tremie concrete, ensuring uniform bearing of the whole pier base on the rock.

Safety against sliding of the foundation is checked at the interface with the rock assuming a shear friction corresponding to 16 degress/18 degrees for the undrained mudstone. The compressive stresses at ultimate limit state are in the range of 1.2 to 1.6 MPa; actual strength of the rock is twice that value or larger, depending upon the pier location.

The modulus of subgrade reaction is in the magnitude of 110 MN/m^3; long-term settlements are minimal. At the ultimate limit state, the eccentricity of the resulting force applied to the footing is limited to 0.33 of its diameter.

2.2.2 Pier Bases and Pier Shafts

All pier bases and pier shafts were prefabricated in the casting yard at Borden. They were prefabricated separately because of height and capacity limitations of the catamaran-type floating heavy-lift equipment, called Svanen, which was upgraded after previous use in Denmark on the Great Belt Project.

There are two types of pier bases: Type B1 for depths down to -27.0 m; and Type B3 for --27.0 to -38.2 m. B1 has a ring footing, 22.0 m in diameter and 4 m wide, that fits exactly between the two hulls of Svanen. B3 has a ring footing 28.0 m in diameter, but with two flat surfaces spaced 22.0 m so that it also fits into Svanen. Above the ring footing, a conical shell transfers the loads from the barrel, which varies in height according to the depth of the foundation. The barrel ends at elevation -4.0 m by a male cone used to connect the pier shaft to the pier base. The maximum weights of B1 and B3 bases are 35 and 52 MN, respectively. The maximum height of B3 is 42.0 m.

Each pier shaft comprises the shaft itself and the ice shield. It is one of the most critical components of the whole structure because it will be in direct contact with the most aggressive and corrosive environment, sea water in the tidal range, salt-laden spray and air, and abrasion from the ice; therefore all exposed cast-in-place joints were eliminated from this element, which is monolithic from the bottom of the ice shield to the top of the pier, with a maximum weight of 40 MN.

The ice shield is conical with a base diameter of 20.0 m, a height of 8.0 m and a 52-degree angle on the horizontal. It is solid except for a central conical void that matches the top of the pier base. The ice shield itself extends between elevations -4.0 and +4.0 m; it is clad with a 10-mm mild steel sheet for abrasion protection.

The pier shaft has a box section, varying from an octagon at the top of the ice shield to a rectangle at the top of the shaft. The walls are 600 mm thick.

The pier shaft is assembled onto the pier base by being lowered until it rests on hydraulic jacks on top of the base; the position of the top of the pier shaft is adjusted by activating those jacks. The space left between the two cones is grouted, creating a continuous structure through the keyed joint, and vertical post-tensioning tendons crossing the joint are then stressed.

The top of the pier shaft is equipped with a template that is matchcast to the soffit of the pier segment. Once the pier shaft is in place, the template (1.0 MN) is grouted in positión so that the future cantilever girder (78 MN) can be placed directly in its final position, thereby avoiding delicate and time-consuming adjustments of a heavy and unstable cantilever.

2.2.3 Superstructure

The superstructure forms a series of frames connected by 60.0-m-long drop-in expansion spans. A frame consists of two cantilevers, integral with the piers and made continuous by inserting a 52.0-m drop-in span between the cantilever tips, pouring closure joints, and stressing post-tensioning tendons to achieve a fully monolithic frame.

3. DESIGN REQUIREMENTS

3.1 Load Combinations and Load Factors

Public Works Canada requires that load combinations and load and resistance factors for ultimate and serviceability limit states be derived specifically for the Project through a full calibration process using probabilistic reliability techniques.

A target safety index β=4.0, applies to each multi-load-path component of the bridge at ultimate limit states, for a 100-year design life. For single-load-path components β=4.25 is imposed. The target safety index is a measure of the accepted risk of failure of a structural member.

As a result of the analysis, load factors, different from those usually recommended in codes, were obtained.

For serviceability limit states, crack widths are related to the change of stress level in the reinforcement or tendon for a given spacing.

3.2 Ice Loading

Generally, the ice season in the Northumberland Strait begins in December or early January, and conditions worsen until late March. The maximum thickness of ice floes, i.e. floating pressure ridges formed from large sheets at the surface of the sea, is about 0.30 m. Floes may occasionally extend over 500 m with a mean of 118 m.

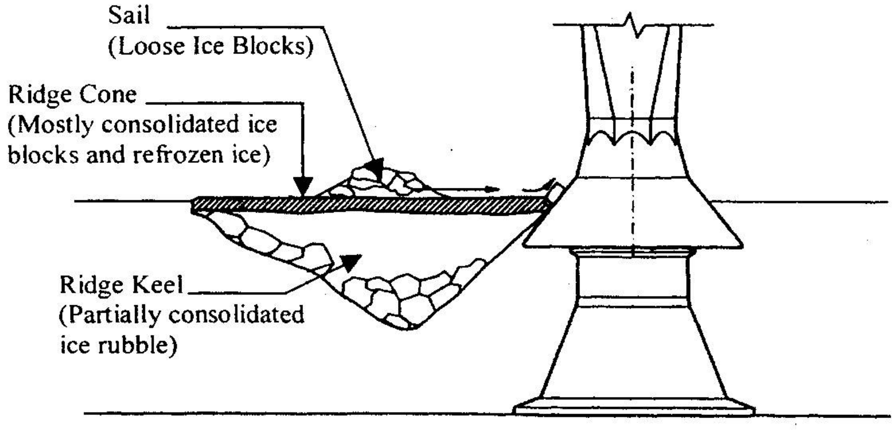

Figure 1: Ice Formations

Currents, waves, and wind induce ice movements, cause floes to break and result in rafting and ridging; ice ridges consist of a consolidated core of refrozen ice at the waterline with loosely bonded blocks of ice forming a small sail on top of the ridge core and a much larger keel below it.

Ridge dimensions can be 50 to 75 m. The ridge keel depths can be evaluated from the number and location of scours seen on the bottom of the Strait; the deepest is at 18 m with an average of 8.5 m. The ridge core thickness may reach 2.5 m.

The critical case for the substructure of the bridge is the consolidated ridge core hitting the pier shaft. To minimize the horizontal force on the pier shaft, a conical ice shield was designed with an angle of 52 degrees to break the ridge core in bending the ice riding up the cone and collapsing under its own weight, rather than crushing directly on a vertical surface, producing a much higher force. The ice shield is clad with ultra high-performance concrete to minimize ice abrasion and reduce friction.

It should be noted that all assessment of ice loads carries a degree of uncertainty as relevant on-site measurements of ice forces are scarce; besides those made at Lighthouse KEMI-1 in the Gulf of Bothnia 1985-1986, practically none have been reported, and laboratory test results can be only a guide.

Another aspect of ice loading is its dynamics. The dynamic response of the bridge allows the assessment of the dynamic loading characteristics of the ice. An analysis was carried out taking into account ice force versus time histories derived from the consideration of all contributing features: ice failure frequencies; ice speed; ridge core characteristics, ridge keel dynamics; rubble surcharge.

Failure of the ridge core is estimated to be the most likely source of dynamic ice loads for frequencies of less than 1.5 Hz; ridge keel dynamics activate frequencies below 1.0 Hz; the combination of ridge core and ridge keel effects is relevant only for frequencies less than 1.0 Hz. The lowest natural frequency considered for the completed bridge is 2.6 Hz, higher than the ice-induced frequencies.

The design of the substructure was based on a transverse static ice force (perpendicular to the bridge) of 17 MN and a longitudinal static ice force (in the direction of the bridge) of 12 MN. For ultimate conditions a factor of 1.8 is applied to the loads, which control the dimensions of the foundations.

4. CONCLUSIONS

The Confederation Bridge is one of the longest deep-water structure in the world. It was designed for 100-years service life in a harsh environment. Unique precasting methods were used for the substructure and superstructure to allow construction of the bridge within a tight schedule. The bridge substructure was designed to resist ice loads up to 30 MN. This unique structure was opened to traffic on schedule in June 1997.

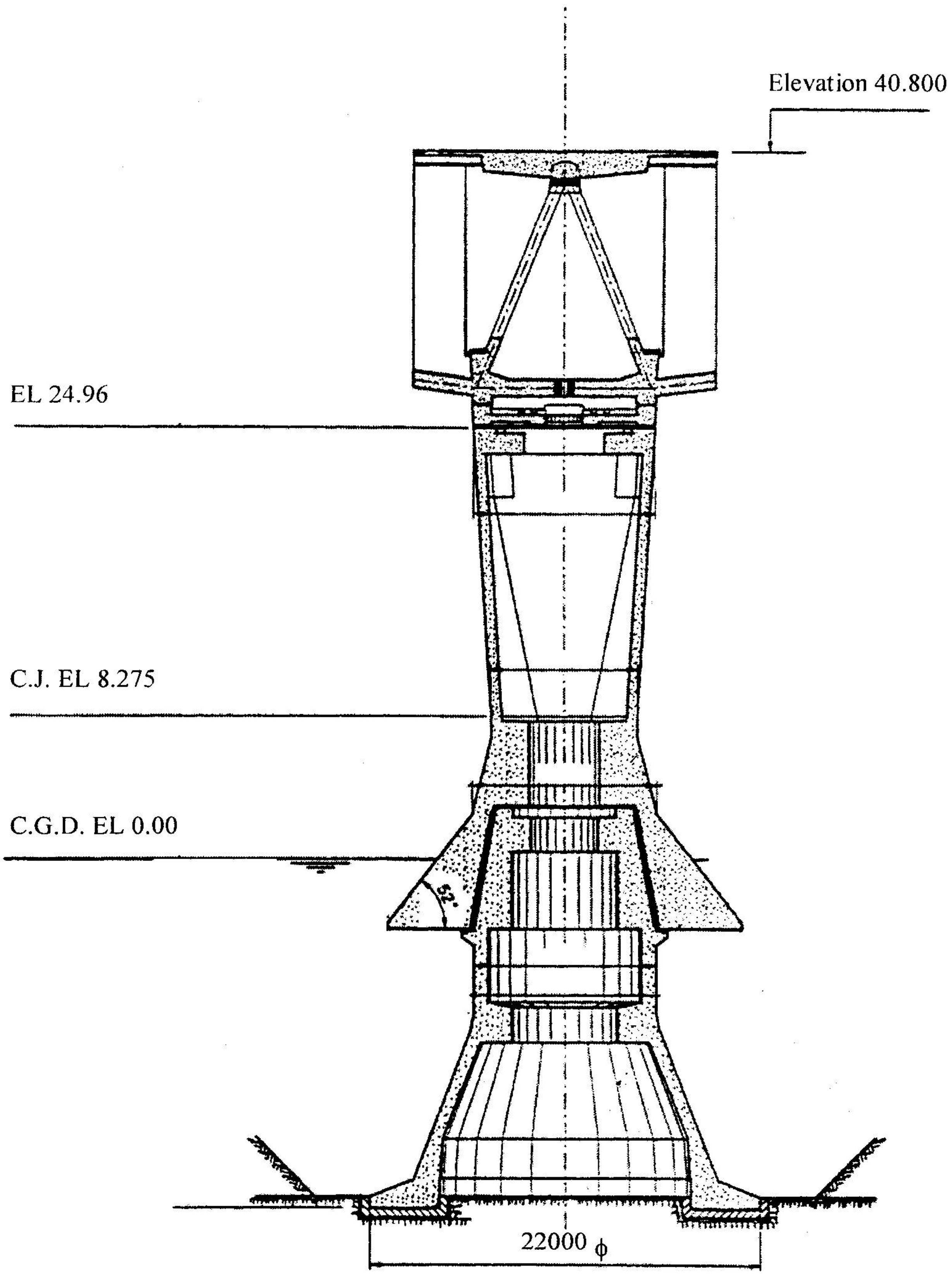

Figure 2: Longitudinal Section