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Ice Loading on the Confederation Bridge

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ABSTRACT

Icebergs and ice loading present a number of risks on the design, construction and operation of ocean bridges in harsh environments. In order to design and construct bridges that are structurally stable and safe, it is essential to understand ice-structure interaction and the impact of ice loading. The recent field monitoring of the ice loading on the Confederation Bridge has the potential to improve the design and construction of ocean bridges in harsh environments.

There had long been a desire to connect Prince Edward Island to mainland Canada before the opening of the Confederation Bridge in 1997. A bridge connection served to both increase the flow of traffic and made it far easier to commute, particularly during the winter season. The observation and analysis of ice loads on the bridge serve as an important study for the hazards involved with harsh environment ocean bridges.

The following paper will present a brief project description of the Confederation Bridge and outline the ice-related challenges of bridge construction. The difficulties of the design and construction of the Confederation Bridge will be identified and the implications for other projects based on the research conducted will be highlighted.

1 INTRODUCTION

A fixed link to connect the Maritime provinces along the Trans-Canada Highway had long been desired before the construction of the Confederation Bridge. The bridge serves as a link between the eastern Canadian provinces of New Brunswick and Prince Edward Island. The 12.9 km construction marvel connects Cape Jourimain, NB to Borden-Carleton, PEI [1]. This location of the bridge across the Northumberland Strait can be seen in Figure 1 [2]. It is the longest bridge in the world that crosses ice-covered water and was opened on May 31, 1997 after over four years of construction, and one billion dollars [1].

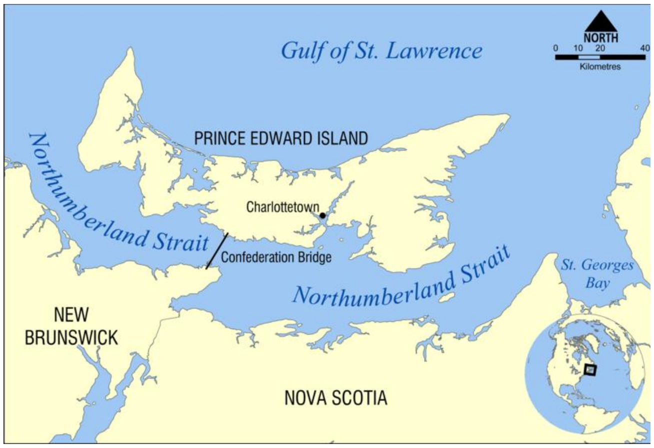

Figure 1 Map of the Maritimes showing the Confederation Bridge [2]

Figure 2 Confederation Bridge Section showing concrete marine piers [3]

A fixed-link connection was decided on to provide a safe, reliable and efficient passage between the Maritime provinces. It was deemed preferable to a ferry service. The long length dictated the use of a multi-span post-tensioned concrete box girder structure [1].

A team led by J. Mueller International and Stantec (previously known as SLG Consulting) completed the design [1]. It was built for a life of 100 years and consists of a west and east approach bridge of 1.3 km and 0.6 km, respectively, as well as a main bridge of 11 km [1]. The final bridge design can be seen in Figure 2 [3].

On average, the daily traffic of the Confederation Bridge is around 4000 vehicles [4], and it has made travel between the provinces significantly easier.

2 PROJECT DESCRIPTION

The successful bid for the Confederation Bridge design was selected in 1993. The design team consisted of the contractor, the prime engineering consultants and the independent engineer. The project was a build-own-operate-transfer (BOOT) type, as it was considered most logical and feasible. The project's main sections included the approach roads, main bridge and associated facilities [5].

The 300 km Northumberland Strait separates the provinces of New Brunswick and Prince Edward Island, and its width ranges from 55 km to 13 km [5]. The bridge was built at the most narrow section of the strait.

The Confederation Bridge is 12.9 km long and consists of both marine and approach spans. The 43 marine spans at a length of 250 m have variable depth box cross sections of 4.5-14 m. Four precast units of up to 7800 t make up each marine span and a heavy crane vessel placed them. The approach spans were erected at either end by balanced cantilever method and are made of 3 m precast segments. A schematic of a typical Confederation Bridge segment can be seen in Figure 3 [6]. A grade of 2.3% from the roadway to the onshore abutment is used at both the New Brunswick and Prince Edward Island sides. A grade of 2.1% is used to bring the deck to the maximum elevation, which allows for marine traffic. A single cell trapezoidal box makes up the 12 m wide bridge cross-section [5].

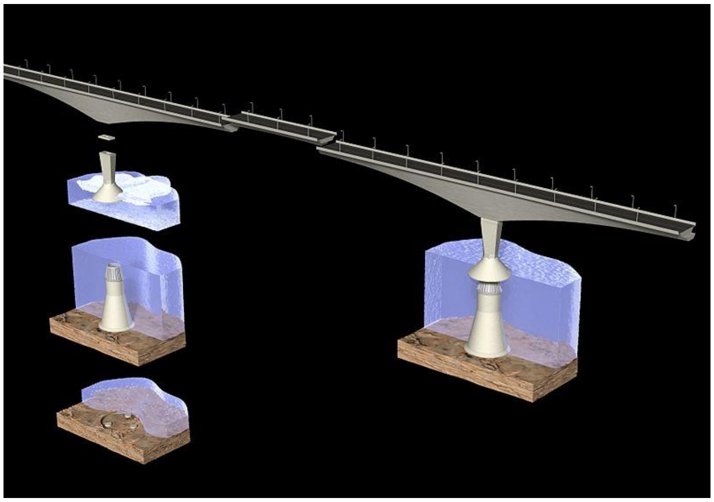

Figure 3: Confederation Bridge segment schematic [6]

To properly and safely design and construct the bridge several codes and standards were used throughout the design process. MacGregor et al. [7] states that CAN/CSA-S6-88 was the primary design code for the structure and it was used along with two highway codes: "Design of Highway Bridges" (CSA 1988) and the Ontario Highway Bridge Design Code, 3rd Edition (MTO 1992a).

Much of the construction work was completed onshore from 1993 onward. The approach bridges were fabricated in New Brunswick, while the main bridge pieces were done in Prince Edward Island. In mid-1995 a gantry crane began placing the precast components, and this work was completed near the end of 1996. From that point until the completion of the bridge in May 1997 the approach roads and toll plaza were constructed [1].

3 PROJECT CHALLENGES

The successful design and construction of the Confederation Bridge faced a number of challenges. In addition to the lengthy distance the bridge must cover, it crossed ice-covered waters. Therefore, the effects of ice loading and forces were a major consideration. Design in ice-covered waters is a field of ongoing research and development. For this reason, the performance of the bridge had to be carefully assessed to implement a safe structure.

The Northumberland Strait is ice-covered a large part of the year from January until late April and sometimes May [8]. It is important to note that this is all very dynamic first-year ice, which results in a lot of first rafted and then ridged ice [8]. Since the strait is somewhat southern, the yearly ice conditions vary wildly; floes are normally several hundred meters in diameter but can be 3-4 km, ice thickness can be 1 m and ridges have keel depths of around 16 m [8]. The ice-covered strait played a large role in the design of the Confederation Bridge and various ice effects are of great concern.

3.1 Design Challenges

The width of the Northumberland Strait at the location of the Confederation Bridge, along with the ice environment, made for a trying design. The length was overcome by the use of a concrete box girder design. In addition to the regular design aspects, challenges such as ice loading and dynamic effects that result from ice had to be investigated. Research was done to make a best estimate of the expected loads so that a safe and economical design could be completed. Typical ice loading and floes can be seen in Figure 4 [9].

Figure 4: Confederation Bridge as it is subject to ice floes and ice loading [9]

3.1.1 Ice Loading Investigation

Brown et al. [8] documents how ice loads on the Confederation Bridge were examined using probabilistic methods to develop a safe design. It is then described how the loads were used in a reliability assessment of the structure and foundation.

The driving force of the ice and the force to cause failure of the ice are both factors of the load on the pier. A deterministic model was used to find the force and the probabilistic method was used to calculate the ice loads. The calculations were done at a level of exceedance of 1% and 1/10,000 per year [8].

The bridge's ice loads were analysed and the safety of structure was examined. The probability of failure of the Confederation Bridge was found to be about $3(10^{-7})$ per year [8].

3.1.2 Exploration of Dynamic Effects of Ice Forces

Dynamic forces occur from the brittle failure of ice floes, which are pushed by wind and current, and contact the piers. These forces are often the governing loads for offshore Arctic structures, so they were greatly considered in the design process of the Confederation Bridge. Consultants completed studies to determine the maximum ice forces on the piers [10].

When ice floes contact the piers at a low speed, a dynamic force that varies in magnitude is produced. The following is an explanation as to why the variation occurs. The pier displacement and ice deformation increases until brittle failure when the structure is instantly unloaded. Then a damped vibration occurs that matches the structure's natural frequency. Models were employed to determine both the dynamic and static effects. The simple model was of an isolated pier and calculated time variation of the displacements and the moment at the base using mode superposition method. A more advanced three-dimensional frame model was utilized as well. This model examined a 1310 m simply supported bridge section and the same values were computed [10].

The conclusion based on both models was that the dynamic effects of ice forces were not governing in this case. This is partly due to the conical ice shields on the piers. Furthermore, the amplification factor – resulting from the dynamic effect of the ice forces – for the bridge is not greater than 5% [10].

3.2 Operational Challenges

The successful operation of the Confederation Bridge depends on the accuracy of the original bridge design specifications. Field monitoring and research programs have been carried out on the bridge to assess its performance. These programs are discussed in the next section.

4 LESSONS LEARNED

A number of lessons can be learned from the Confederation Bridge design and construction that can be applied to ocean bridges or structures in harsh environments as a result of several field monitoring and research programs.

These programs provided valuable data and knowledge about the effects of ice on structures. They also will give valuable information for the maintenance of the bridge.

4.1 Performance Monitoring Under Ice Forces

Figure 5: Field monitoring in ice Environments [12]

The field monitoring that has been performed on the Confederation Bridge provides important information. A wide-scale monitoring and research project is being conducted for the bridge, which includes a study of the behaviour and performance under ice forces. It is observed that as floes meet the conical ice shied on the pier, the leading edge rides up the structure slope. A bending moment is caused in the sheet and it fails in flexure. This interaction gets more complicated when embedded ridges hit the pier [11].

The monitoring program has three main parts: global ice force indirect measurement, local ice pressure direct measurement, ice interaction kinematics and prevailing ice conditions observation. The monitoring consists of: tiltmeters to measure structural response; ice load panels to measure local ice pressures; and video cameras, sonars and a laser to observe. The data collected is compared to accepted algorithms with the intention of improving them. It is also used to better manage and maintain the bridge [11].

Figure 5 [12] shows someone performing typical field monitoring tests in a snow and ice environment.

4.2 Extreme Ice Load Assessment

At the time of the bridge design, there was a lot of uncertainty in the design loads. Ice loads were the governing load conditions for the lateral pier design of the Confederation Bridge, for which a 100 yr return period for loads of -16 MN was used for design. Due to the original uncertainty, the bridge has been monitored and extreme ice loads were measured for the Confederation Bridge. The extreme loads recorded were only found to be 50% of the design loads, which shows the piers were well designed to minimize ice forces [13].

4.3 Pier Response to Pack Ice

Another field monitoring program was carried out to study the response of the near-center bridge piers to drifting pack ice. The existence of the piers causes ice to break or lodge against the bridge with the movement of the tides. Tilt was measured from February to April 1999, and pack ice pressure was found. The findings are important for navigational purposes in the ice season [14].

As a result of the program, an important response method was developed. Using the tilt values in addition to wind, current and ice, important pack ice pressure information is obtained. For this study, pressures were determined to be between 600 and 700 N/m, which are fairly low. Greater pressures could result for colder and thicker ice. The findings indicate that the bridge only affects the pack ice pressures over a small area [14].

5 IMPLICATIONS FOR FUTURE PROJECTS

With an increasing number of projects offshore in harsh environments and in the Arctic, it is essential that knowledge gained from past and present projects be applied to new developments. The Confederation Bridge is an excellent case study for the design of bridges in harsh environments and valuable information has been gathered.

The field monitoring and research that has been conducted on the Confederation Bridge is essential to a better understanding of ice loading and effects. The data gathered from the bridge's programs can be used to improve algorithms used to determine ice loads and behaviours [11]. Furthermore, the knowledge gained can be applied to both computer models and similar construction projects [11]. A greater understanding of ice-structure interaction will also help in the development of relevant codes and standards for bridge design in harsh environments.

It is also important to note there can be financial savings for future projects. Designs can become more efficient, while still remaining safe, which saves in both materials and time. This can substantially decrease the overall cost of the project. Such financial savings result from increased knowledge and expertise in an area such as ice loading and effects.

6 CONCLUSIONS

Icebergs and the effects of ice loading have long been a concern to engineers responsible for the design and construction of ocean bridges in harsh environments. It is essential to understand ice-structure interaction and the impact of ice loading. The successful completion and use of the Confederation Bridge, as the world's longest bridge in ice-covered water, can serve as an example for others of its kind.

Several important lessons were learned as a result of this bridge design and construction, and its subsequent field monitoring and research. The effect of ice loading is better understood. Algorithms and models to determine ice loads and behaviours can be improved. Standards and codes can be updated to reflect the newfound knowledge. Also, there can be financial savings for future projects as designs can become more efficient, while remaining safe.

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