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20 years of monitoring of ice action on the Confederation Bridge piers

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ABSTRACT

Monitoring systems for the measurement of ice action and the observation of attendant ice conditions have been in place on several piers of the Confederation Bridge since it opened in 1997. The ice-structure interaction at two of the piers, P31 and P32 have been continuously monitored and data analyzed by the ice research group at the University of Calgary. The resulting database of ice interactions at these piers is very extensive, amounting to some 26,000 discrete interaction events, many of which have been analyzed in detail. The paper presents summaries of the results of the observations related to the interaction of the ice against the instrumented piers and summarizes the ice load and ice parameter statistics associated with the ice observations.

1. Introduction

Ice actions on offshore structures in Northern latitudes are often the primary design load condition and it is therefore important that they are understood, and can be predicted accurately. During the design of piers of the Confederation Bridge, various design parameters including ice velocity, ice thickness, rubble height, ride up and ridge keel kinematic and mechanical properties were considered in the assessment of ice action. Due to the severe and harsh environmental location and owing to the service life of 100 years- twice that of normal design life of typical structures, there was a need to understand the behavior of the bridge as ice interacts with piers and the forces that result from these interactions to accurately predict and evaluate the bridge's performance in the future. In order to gather full-scale data at the Confederation Bridge, several joint monitoring programmes were initiated as a partnership between Public Works and Government Services Canada (PWGSC), Strait Crossing Development Inc. (SCDI) and Canadian universities. Three consecutive spans, one rigid frame span and two drop-in span and four corresponding piers (P30 to P33) of the Confederation Bridge were instrumented to monitor its short- and long-term performance under different environmental loads and effects, such as ice loads, temperature, vibrations due to traffic, wind, earthquakes, and corrosion (Cheung et al., 1997). The ice force monitoring program was focused on two main piers P31 and P32, which comprise one of the frames (Frame 16) of the bridge. The ice force monitoring program has been collecting data since its initiation in 1997 and has completed its 20 years of continuous data collection in 2017, the main focus of this paper. The other aspects of long-term monitoring program such as fatigue analysis, corrosion analysis are outside the scope of this paper.

1.1. Instrumentation

The Confederation Bridge spans Northumberland Strait between New Brunswick and Prince Edward Island (PEI) in Eastern Canada (Fig. 1). The bridge is 12.9 km long and consists of the main bridge of 44 spans, each 250 m long and approach bridges at either end, of shorter spans. The typical span height is 40 m above water level, except at the navigation span, where it rises to 60 m. The main bridge construction consists of a series of portal frames connected by simply-supported drop-in spans. All piers are provided with ice-breaking conical sections at the water-line. The water depth at these piers is approximately 20 m, although the piers are founded at different depths, P31 at −27 m and P32 at −21 m.

The piers P31 and P32 were initially instrumented with high-precision kinematics sensors like tiltmeters, and accelerometers, pressure panels, imaging (video) cameras, and a wind anemometer. In addition, other instruments have been used for some ice seasons including upward looking sonar and Acoustic Doppler Current Profiler (ADCP) to measure underwater ice profile and ice velocity. Table 1 provides a summary of the instrumentation related to long-term ice force monitoring. For additional description and location of instrumentation on the Bridge and instrumentation related to other monitoring programs, readers are encouraged to refer to earlier papers by Cheung et al. (1997), Brown (2001), Bruce and Brown (2001) and Brown et al. (2010a,b).

With the exception of the ice load panels discussed below, each of the two piers has the same instrumentation installed as shown in Fig. 2. The ice load is derived from the tilt response of the two instrumented piers. The tiltmeters and accelerometers are located at +3.2 m

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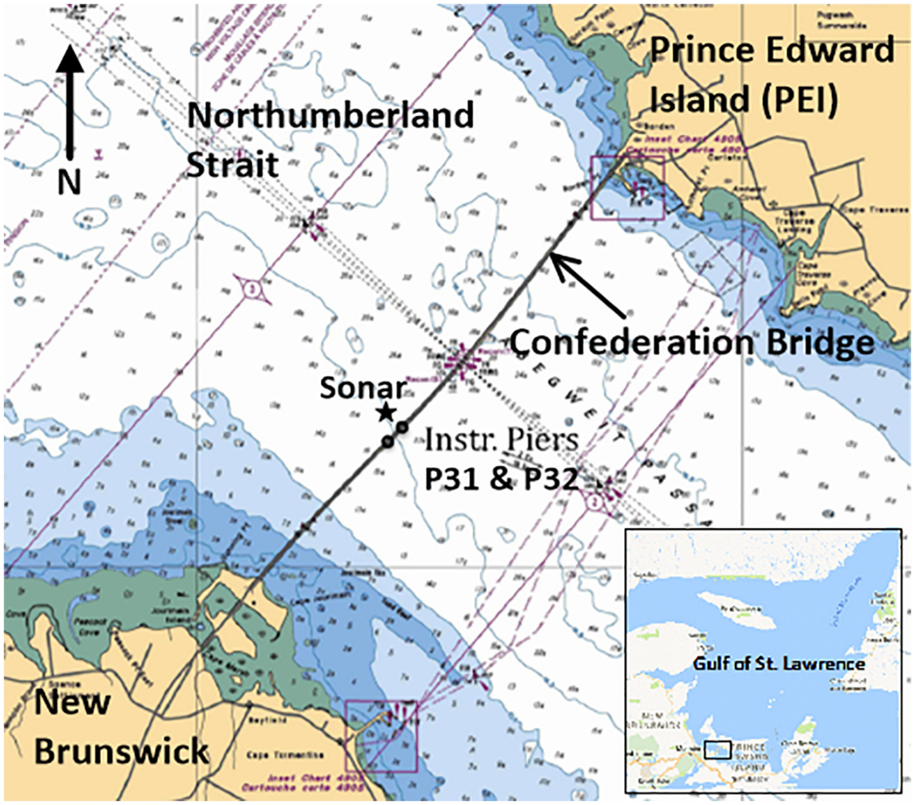

Fig. 1. Map showing location of the Confederation Bridge and instrumented piers, P31 and P32.

Table 1
Summary of the ice force monitoring instrument.

SN.	Instrument	Description	Location	Year active
1	Tiltmeters – Group 3 (G3) & Spare (Sp)	Applied Geo-mechanics Model 716 biaxial tiltmeters: Measure tilts/ rotation of piers	+ 3.2 m above MSL, opposite each other at NW and SE side of piers	1997–2017
2	Tiltmeter – Group 4 (G4)		+ 24.6 m above MSL, at NW side of piers	1997–2017
3	Accelerometer – Group 3 (G3)	Sundstrand QA1200 accelerometers: Measure the lateral and longitudinal accelerations of the tilts	+ 3.2 m above MSL, at NW side of piers	1997–2017
4	Accelerometer – Group 4 (G4)		+ 24.6 m above MSL, at NW side of piers	1997–2017
5	Four video cameras (P31 NW, P31 SE, P32 & far NW)	Monitor and record ice-pier interactions	Below Bridge deck between piers P31 & P32	1997–2017
6	Pressure Panel	Measure ice pressure	Conical section at waterline and bottom shaft of pier P31 at NW face	1998–2003
7	Wind anemometer	Measure wind speed and direction	On Bridge deck midway between piers P31 & P32	1997–2017
8	Datasonics PA900 sonar Ice Profiler sonar (IPS) Ice Profiler sonar (IPS)	Measure keel profile	~40 m NW and SE off pier P31 ~100 m NW off pier P31	1997–1998 1999–2001 2007–2008
9	Acoustic Doppler Current Profiler (ADCP)	Measure ice's speed and heading	40 m NW off pier P31	1999–2000
10	Campbell Scientific CR9000 data logger (High-speed logger, HSL)	Programmed to fed and stored data from different instruments: tiltmeter, accelerometer, wind anemometer and pressure panel	Control room inside the bridge box girder	1997–2017
11	Campbell Scientific CR10X data logger (Slow-speed logger, SSL)	Programmed to fed and stored data from wind anemometer	Control room inside the bridge box girder	1997–2017

and + 24.6 m above mean sea level. The tiltmeter data used for ice load determinations are collected in two modes: average data mode and trigger data mode. For example: for pier P31, the data are acquired at 0.034 s interval, but high-speed logger (HSL) only stores averages of 500 data points (i.e. every 17 s averages). Similarly, for pier P32 data are sampled at 0.008 s interval and an average of 1875 data points are stored at an interval of every 15 s. This means the average data files provide daily load files which are composed of data collected every 17 s and every 15 s for piers P31 and P32 respectively. For pier P31, when the logger is triggered at a preset trigger threshold, currently set at ice load of 0.75 MN, the data are gathered at the high sampling rate of 0.034 s. The high-speed logger for pier P32 is set to trigger for wind and traffic vibration, not ice, and once the logger is triggered for predefined threshold (for e.g. wind > 15 m/s) data are collected at a high sampling rate of 0.008 s.

In the average daily load plots "ice event" is defined as the peak load greater than a preset threshold load of 0.75 MN within the predetermined time period. This time duration is defined by the number of time steps to either side of the peak load and is currently set to 10 time steps total, or 5 to either side of the peak load, i.e. 170 s for pier P31 and 150 s for pier P32. This time duration is considered to be optimum as it enables peak loads to be emphasized without identifying many