CHC CENTRE D'HYDRAULIQUE CANADIEN
CANADIAN HYDRAULICS CENTRE

RESPONSE OF CONFEDERATION BRIDGE TO ICE FORCES: WINTER 2008-2010

Lian-Feng Li*, Robert Frederking and Ivana Kubat

* Work-term Student, Memorial University of Newfoundland

TECHNICAL REPORT
CHC-TR-075

OCTOBER 2010

National Research Council Canada   Conseil national de recherches Canada

Canada

RESPONSE OF CONFEDERATION BRIDGE TO ICE FORCES: WINTER 2008-2010

Lian-Feng Li, Robert Frederking and Ivana Kubat
Canadian Hydraulics Centre
National Research Council of Canada
Ottawa, ON K1A 0R6
Canada

Technical Report
CHC-TR-075

October 2010

Abstract

Ice interactions with the Confederation Bridge for the winters 2008, 2009 and 2010 have been studied. Tilt data from piers P23 and P24 in response to ice and wind actions were recorded by a data acquisition system. Video records of ice interactions with pier P23 and overall ice conditions adjacent to piers P23 and P24 allowed ice conditions and interaction processes to be related to tilt measurements. Wind data were also analysed to correct for the tilt caused by wind actions on the bridge. An ice loading scenario of slow build up of ice force on a pier due to the action of current and wind on a large ice floe was identified. In one instance this resulted in a maximum force of about 4 MN being generated on simultaneously on each of piers P23 and P24.

Table of Contents

Table of Figures

List of Tables

RESPONSE OF CONFEDERATION BRIDGE TO ICE FORCES: WINTER 2008-2010

1. Introduction

In order to evaluate the ice impact force acting on offshore structures, two piers of the Confederation Bridge were selected as a test bed for the study of ice interactions. The Confederation Bridge is located in Northumberland Strait. The Strait is usually covered by a large amount of ice in winter, and the ice is continuously drifting back and forth impacting the bridge piers with the result that large ice forces are generated on the piers. Each pier was designed to sustain 30 MN maximum ice impact force, which provides a high safety factor for the bridge. In 1999, National Research Council Canada – Canadian Hydraulics Centre (NRC-CHC) installed tiltmeters in two bridge piers for measuring the force of ice interaction. The measured tilt can be interpreted as an applied force based on the structure response; therefore, an indirect system of determining ice iteration forces was established. The wind force acting on the bridge cannot be neglected, so wind data is required for analyzing any ice event where large wind forces are included. In addition to the analyzed digital data, video recordings were used for observing ice failure behaviour during an ice event. A traffic observation camera on the bridge recorded the behaviour of floating ice in a large field of view, and a time lapse video camera installed under the bridge monitored the area around the pier with tiltmeters installed. The information of ice coverage in the Strait was used to assist and identify ice events. The event data was analyzed by using MATLAB. The data analyzed for this report was from measurements in the winters of 2008, 2009 and 2010.

1.1 Bridge Description

The Confederation Bridge has a length of 12.9 km, and connects the New Brunswick (NB) and the Prince Edward Island (P.E.I). The main section of the bridge is 11km long which contains 44 piers. These piers are numbered from the P.E.I side, as shown in a cross section view of the bridge (Figure 1). Located in the middle of the bridge, a navigation span between the 20th and 21st piers (P21/P22) provides a channel with 60 m height above the water line for ship traffic.

Figure 1: Cross section of the Confederation Bridge

In Figure 2, the water line (GML) is defined as the 0 axis. The green line is the height of pier shaft above the water line, and the purple line is the bridge deck height, which is the sum of the pier's height and girder's depth. The red line is the foundation depth blow the water line, and the blue line represents the water depth. Beside the navigation channel,

the 23rd and 24th piers (P23/P24), which are indicated as two orange lines in Figure 2, were selected as the research object for the project of the response of the Confederation Bridge to ice forces. This project is aimed to study the behaviour of the ice interaction at the navigation span. Large ice floes drifting downstream could accumulate and block the navigation channel. The analyzed ice forces acting on the bridge piers can provide information of ice loading on structures during their operation. However, the instrument could not be installed in P21 and P22 because they were filled with concrete to help the bridge withstand a collision with a ship, so the adjacent piers were chosen as the research object. The heights of P23/P24 are marked in Figure 2; the P23's foundation stiffness is about twice the stiffness of the foundation of P24.
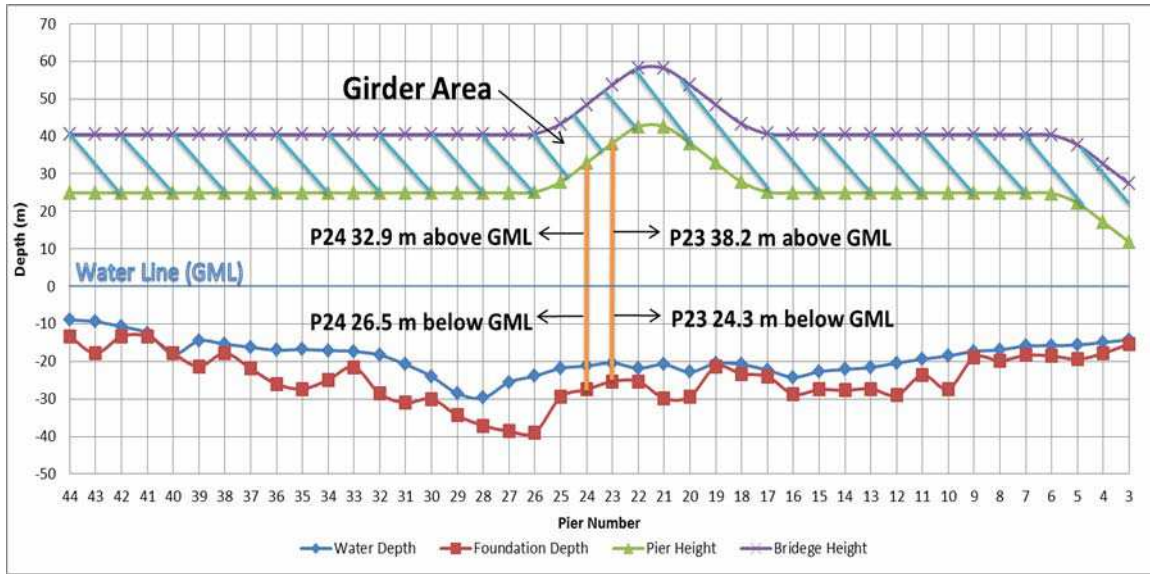
Figure 2: Profile of the Confederation Bridge

1.2 Tiltmeter

Each pier contains two tiltmeters inside its shaft. The locations and sign convention of two tiltmeters are indicated in Figure 3, and both of them are located at the side of water moving from upstream to downstream (Northwest to Southeast). The tiltmeter has an extremely sensitive resolution of 0.1 µrad and a wide range of 7500 µrad in both clockwise and counter clockwise directions. The tiltmeters are connected to a data logger installed inside each pier for storing the measurements. Using an analysis method mentioned by Brown (2006), the tiltmeter measurements are converted to applied force. The data from a tiltmeter is recorded as a voltage signal, which is converted into micro-radian (µrad) by using a calibration factor supplied by the manufacturer.
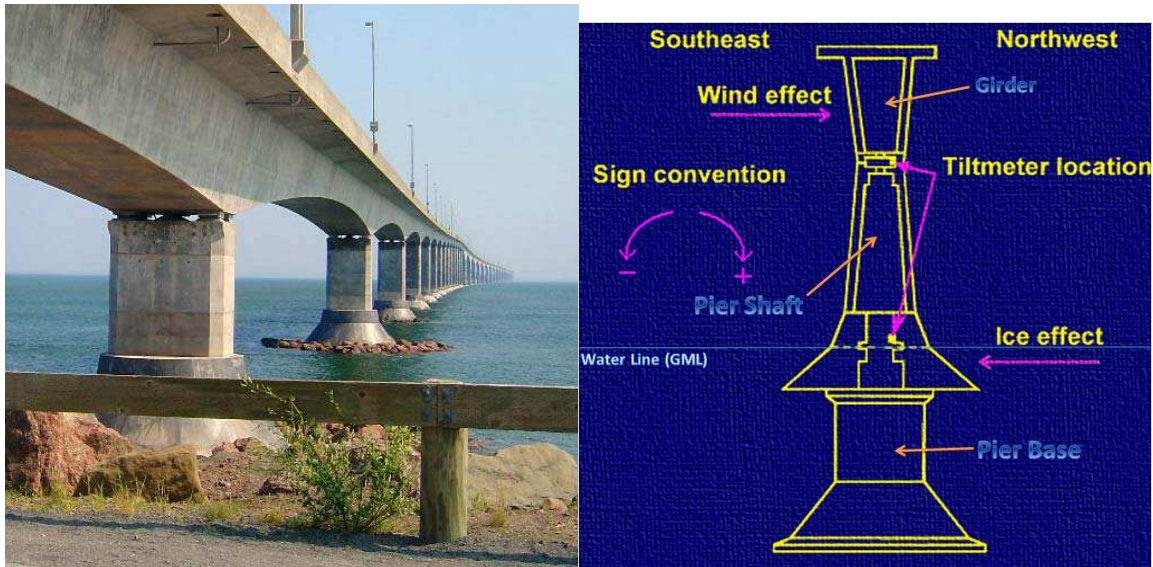
Figure 3: The bridge piers (L) and P23's inner cross section (R)

2. Analyzed Data

2.1 Tilt Data

NRC-CHC has been measuring and analysing data from the tiltmeters since 1999. The tiltmeter is able to measure biaxial inclination angles, and the coordinate system defines tilt about the longitudinal axis of the bridge as the x-axis and tilt about a horizontal axis of right angle to the bridge as the y-axis. The coordinate system is also indicated in Figure 4. Since the predominant ice drift direction is from upstream (NW) towards the bridge, the majority of ice impact forces causes the pier to tilt about the y-axis. Consequently, the data from y-axis is used to calculate the ice load.
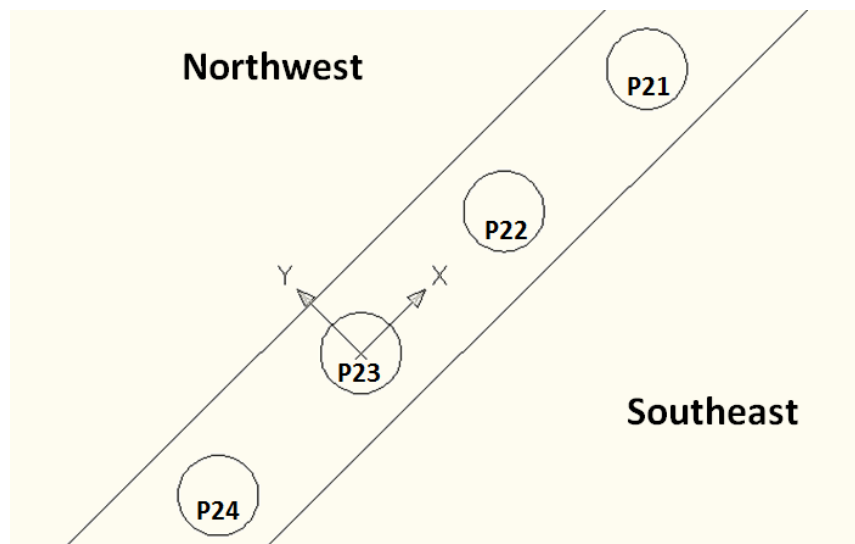
Figure 4: Top view of the bridge

The tiltmeter in 2008 recorded the pier tilt angle relative to the y-axis at one-second intervals, and also measured the temperature and the angle relative to the x-axis every three hours. In 2009 and 2010, the data logger was upgraded and able to record both y-axis data and x-axis data with a frequency of 5 Hz. Although the instrument is able to record the data at a high frequency, the pier needs one second to respond to an applied load. Due to this, the recorded data was averaged at 2-second intervals.

The y-axis data from the three years was extracted and rearranged in the same format. The data were tabulated with a specific time for each reading. The recorded time on the logger was Coordinated Universal Time (UTC), and it was converted into local standard time (LST) by subtracting four hours. The tiltmeter measures the response of all the forces acting on the structure. In addition to ice impact, the wind, traffic, and water current can generate forces on the bridge as well. Based on previous work, Frederking et all (2007) state that the wind creates relatively significant force on the bridge

The bridge girder is 14 m deep at the piers, which provides a large exposure area for wind force to act on. The wind force produces a moment on the bridge pier, and the pier bends in a similar manner to bending of a cantilever beam with an elastic root. The foundation of the pier will rotate in a small amount and the girder area on the top of the pier shaft will have the largest inclination angle. The inclination angle decreases from top to bottom, due to bending of the pier shaft. Thus, comparing to the tiltmeter installed at the lower level of the bridge pier (lower tiltmeter), the pier's tiltmeter at upper level (upper tiltmeter) has a relative larger angle when wind is acting on the bridge.

The lower tiltmeter is closer to the elevation of ice action, and ice is responsible for a proportionally larger part of the tilt change under the combined actions of ice and wind. If ice impact was the only force acting on the bridge pier; the tilt angle change for both upper and lower tiltmeters would be the same. On the other hand, high wind acting to the bridge girder will affect the measured angle at both levels, an have a larger effect on at the upper level.. The tilt angle is added to if the wind has the same direction as the ice drift, and vice versa.
In order to account for the wind effect during analysis of an ice event, the portion of the tilt angle at lower tiltmeter due to wind can be corrected for by using moment equilibrium. The wind force acting on the girder produces a moment at the pier's base, which can be translated to a tilt at the lower tiltmeter proportional to the foundation depth. Since the dimensions of the bridge are given, measurements from lower tiltmeter can be corrected to remove wind force affects. Thus, data from upper tiltmeter is used to determine the wind effect, and the lower tiltmeter result can be used to determine ice force by correcting for wind force.

2.2 Wind Data

The wind effect is the lateral force caused by wind acting on the bridge girder and deck. The wind force is related to the wind speed normal to the bridge. The wind speed and its direction are measured by anemometers at various locations. Since P23 and P24 had no instrument to measure the wind, the wind data were obtained from anemometers, which were installed at other locations on the bridge.

Anemometers are installed at the navigation span and at the middle of P31 and P32. In some years, two gauges have been installed at each location in order to verify wind

data. The data obtained from both locations were provided by the University of Calgary. The wind speed is recorded as a positive value, and measured wind direction varies from 0 to 360 degrees. Wind blowing to north-east, which is the direction perpendicular to the longitudinal bridge axis, is set as 0.

Piers P23 andP24 are adjacent to the navigation channel so that the navigation span wind data should be more reliable than the data from P31/P32. The anemometers installed at P31/P32 recorded data every second and also every 10 minutes, but the navigation span wind data could only be recorded at long time intervals. As a result, the navigation span data is used to analyze the overall wind effect, and the P31/P32 wind data is used for detailed wind analysis. When the navigation span wind data is not reliable, the P31/P32 wind data with the large time interval can be used to replace the navigation span wind data.

In 2008, because of the instrument's limitation, the anemometer at the navigation span recorded the wind direction only in cardinal directions. The measured direction is less precise than measurements in azimuth degree because the wind in cardinal direction is only recorded in four ordinal directions and twelve further divisions, such as N, NW and NNW. The wind direction was thus only recorded in 22.5 degree increments. Moreover, the P31/P32 wind data has many missing data. If an ice event occurred during a time period without detailed wind data, wind data with a large time interval had to be used to analyze the wind effect, which will provide an unreliable result. The navigation span wind data was not obtained in 2009, so the P31/P32 10 minutes time interval's wind data was used to analyze the overall wind effect. Unfortunately, one wind measuring instrument at P31/P32 was damaged due to freezing rain in 2010; hence, data from the other P31/P32 instrument was used to analyze the wind effect. The 17 seconds time interval wind data in 2010 is provided instead of one second time interval wind data at P31/P32, so the detailed analysis of the wind effect will be less reliable.

The data of wind speeds and wind directions is rearranged to the same format as the tilt data. The wind data was recorded in local time, and the time frame is almost the same as the tilt data except the P31/P32's anemometer has one extra hour of wind data after switching to daylight saving day. The time change is always at 2 AM on daylight saving day, and the one extra hour's wind data may be recorded from 2 AM to 3 AM. Rather than adding one hour of tilt data, it is preferred to delete one hour of wind data from 2 AM to 3 AM on daylight saving day. Fortunately, most ice events happened before changing the time, so the time change will not affect the analysis results. The tilt data and wind data both have the same time frame in local standard time (LST) which will match with the recorded video time.

2.3 Video Record

For the purpose of observing the ice conditions and the ice behaviour during ice impact on the bridge piers, two kinds of video data are provided from the camera monitoring system. The first one is recorded from a camera installed on the top of a light standard on the bridge deck. The main function of this camera to monitor the traffic on the bridge, however it also gives a large field of view of the ice conditions around the bridge, as shown in Figure 5. The traffic camera providing a daily record with one frame every three seconds, but the time in the video is not correct. The time in traffic camera's video data was corrected by adding ten hours to match the LST by comparison with images from the pier video camera.

Figure 5: Ice observation from traffic camera

The other kind of video data is recorded from a video camera installed between P22 and P23, and its view is directed downwards to P23. Figure 6 is an example of this video record. It provides a more detailed picture of ice failure on the pier. The pier video is only recorded from 6 AM to 8 PM in LST (daylight hours), and the taped information is at a rate of four frames per second. As a result, the pier video provides more detailed information of ice behaviour during an ice event.

Figure 6: Ice observation from pier camera

The video data from the pier camera was recorded on a hard drive and the traffic camera on VHS tapes. The hard drive video was converting onto DVDs, as were the VHS tapes. The video information from the DVDs was used to check ice failure mode, weather, ice concentration and ice drift direction, to assist the data analysis.

2.4 Ice Chart

Climate data from Environment Canada is used to provide the information of daily air temperature and weather. The climate data are recorded every hour in local standard time, and the selected location was Summerside in P.E.I., the closest location to the Confederation Bridge, for which such data are available.

The Canadian Ice Service of Environment Canada provides the historical data of ice coverage in the Gulf of St. Lawrence which is plotted in Figure 7. The histograms in the plot represent the last three years' weekly ice coverage, and the red line is the average of the last 40 year's weekly ice coverage before 2008. The pink histogram bars represent the New Ice which has a thickness less than 10 cm. The purple bars are the Young Ice with the thickness of 10 cm to 30 cm, and green bars are the 30 cm to 70 cm thick First-Year Ice. It is obvious that the ice coverage in 2010 is the lowest either comparing to the data from 2008 and 2009 or average data since 1969. Therefore, the number of the ice events and the magnitude of the ice forces in 2010 would be expected to be less than those in 2008 and 2009.
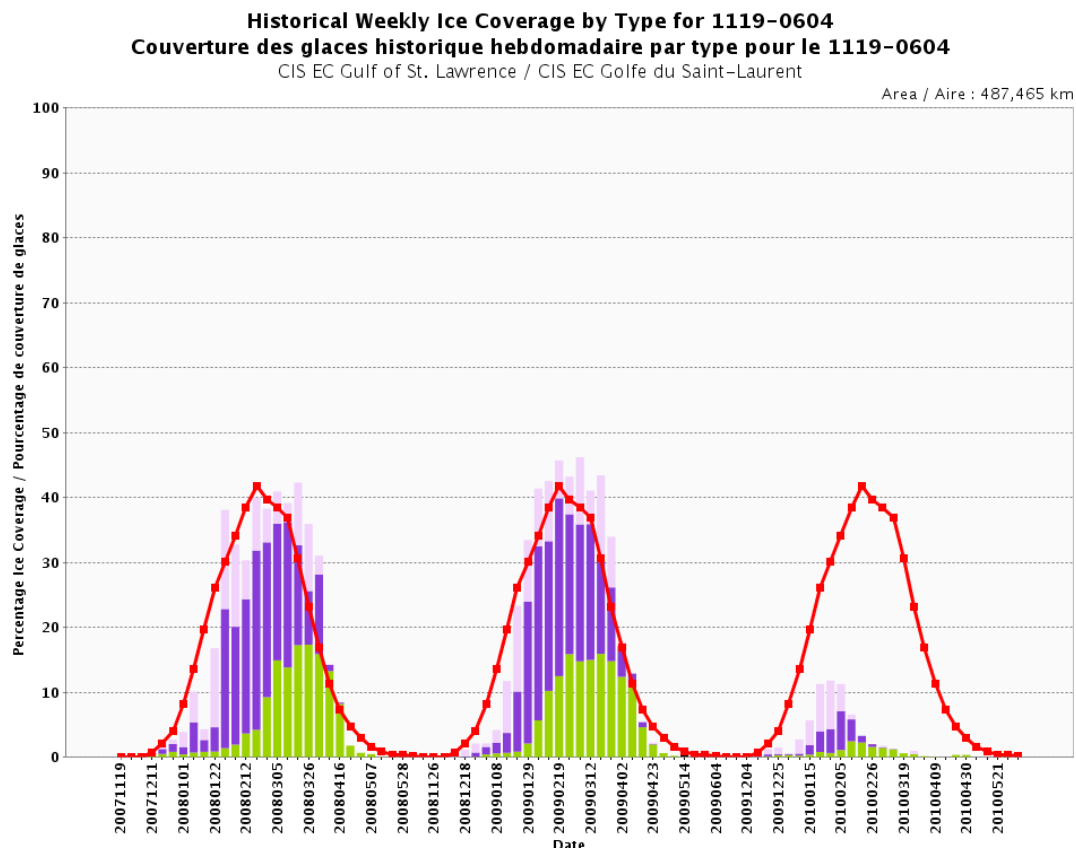
Figure 7: Historical data of weekly ice coverage in Gulf of St. Lawrence

The Canadian Ice Service (CIS) also provides daily ice charts that record the ice concentration, the ice thickness and the floe size of the ice cover in the Gulf of St. Lawrence. Figure 8 shows an ice chart observed on the date of March 12th, 2009. The blue line in the zoomed image is the Confederation Bridge, and the dotted area in the Northumberland Strait represents an area with no ice coverage. The ice conditions near the bridge are described in the area noted as "G", and the egg code of this area is marked in Figure 8. According to the Ice Product Guide (MANICE, 2005) from CIS, the number from the first row in egg code is the total concentration and the second row numbers are partial concentration. The numbers in third row record the stage of development (ice thickness) and the fourth row gives the ice floe size. For this project, the numbers from first three rows are used to identify an approximate ice thickness near the bridge. The total ice concentration in egg code G in Figure 8 is 9+ tenths, which can be viewed in the example picture on the top of the zoomed image. The highest possible ice concentration is 10 tenths so the G area has very close pack ice. The indicated partial ice concentration is 1/10 brash ice, 2/10 medium first-year ice (70-120 cm thick) and 6/10 thin first-year ice (30-70 cm thick), and grey-white ice (15-30 cm thick) present with a concentration of less than 1/10.
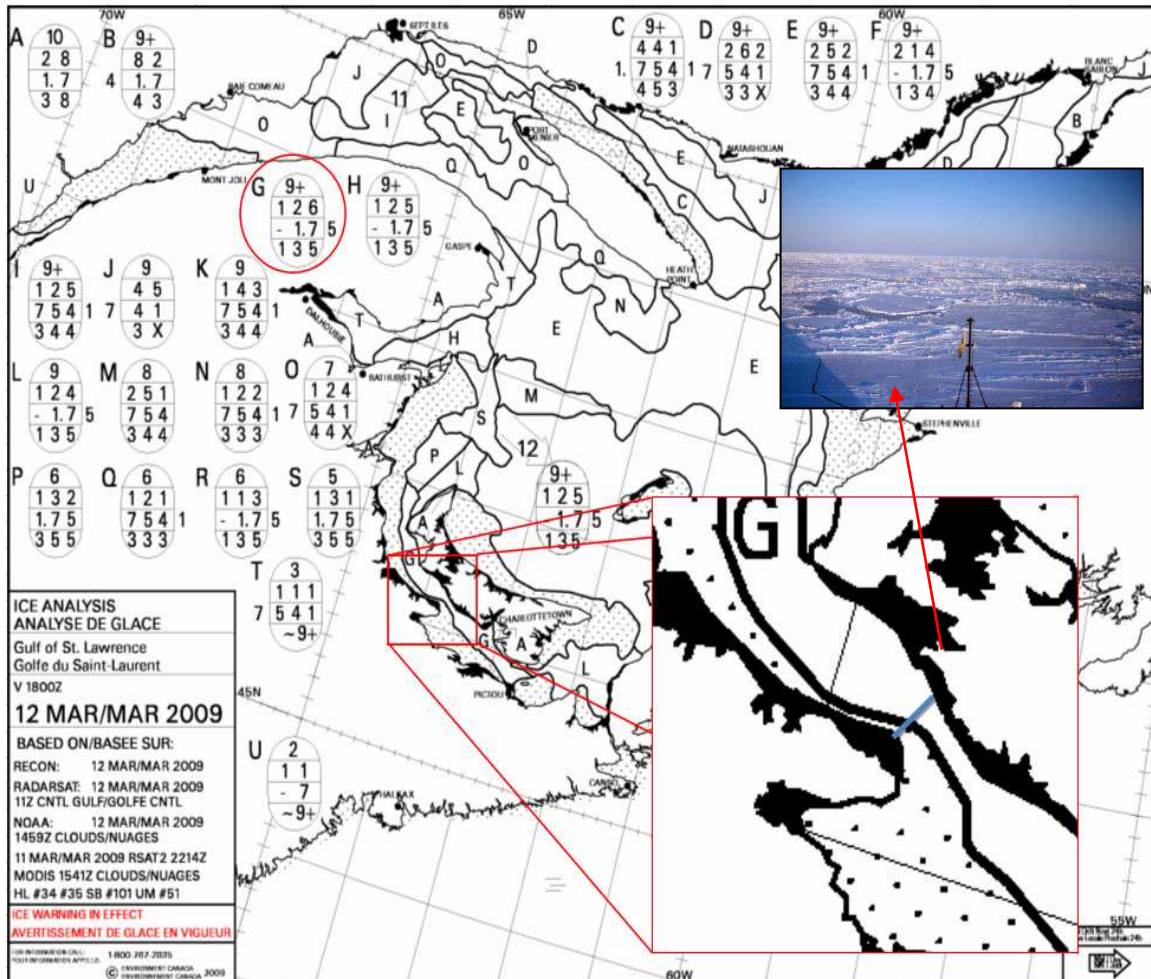
Figure 8: Analyzed Ice chart on March 12th, 2009

3. Data Analysis

3.1 Baseline Definition

Establishing the baseline is a challenge since the tiltmeter is sensitive to various environmental inputs. Air temperature or solar radiation contribute to short and long-term variability of the baseline. As shown in Figure 9, the daily averaged data from the lower tiltmeter in 2008 shows a progressive increase as time proceeds. Because the tilt generally increases linearly, a regression line can be used to define the baseline. The equation of the regression line has an input of a Julian day (x) and an offset value (y) for each day. After the data are processed by subtracting the offset value, a rough corrected data set can be used for subsequent analysis of ice events. The corrected data almost always varies in a same range; ±300 μrad for the upper tiltmeter and ; ±150 μrad for the lower one. Having made the general baseline correction, an accurate baseline for particular ice events is defined by selecting the nearest time when there is no ice and little wind affect.
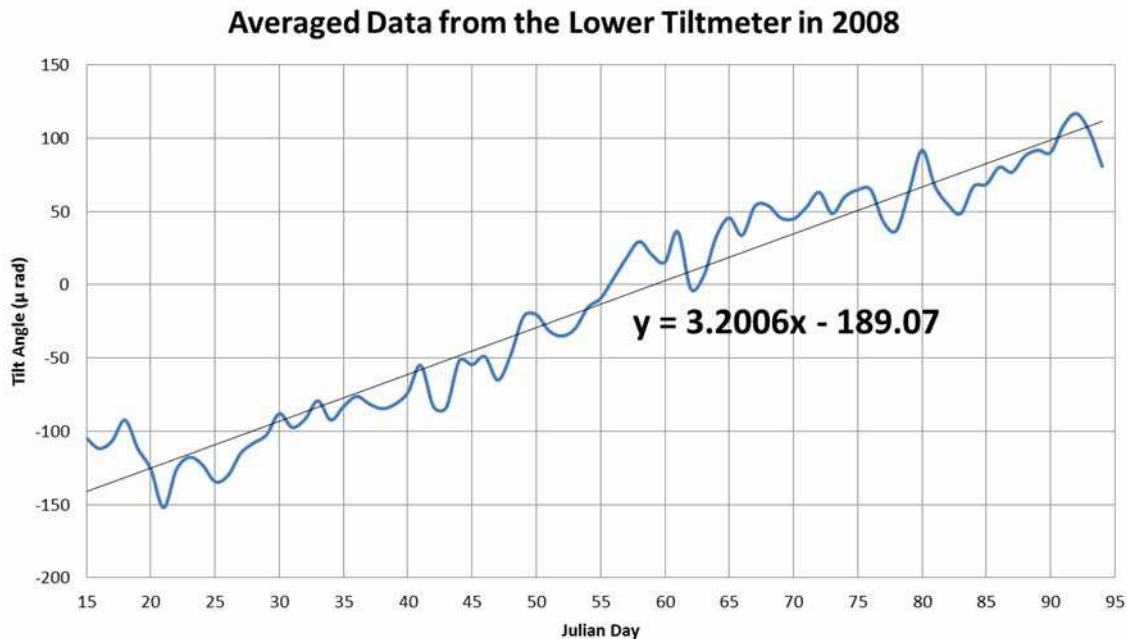
Figure 9: Daily averaged tilt data at lower level of P23, 2008

3.2 Ice Event Identification

In terms of the provided wind data, 2008 is limited, and the amount of ice coverage in 2010 is apparently less than the other two years. The wind data from 2009 provides a complete time series without any missed data. The ice coverage in 2009 is similar to the past several years, and some significant ice events in 2009 happen in daytime so that a number of ice events were captured by the pier camera. To illustrate, a particular ice event in 2009 is analyzed in detail in this report.

After the tilt data is offset with respect to the long-term baseline, the data were averaged every 15 s. Because the amount of raw data is extraordinarily large, a computer with adequate memory is needed. MATLAB is used to plot daily averaged data and create a graph with two y-axes. The y-axis on the left side represents the tilt data and the one on the right indicates the wind speed component normal to the bridge. The wind speed with a longer time interval is selected in order to create a smoothed graph. Plots of the tilt and wind data are made for each day, defined as daily wind-ice plots (see Appendix A).

To determine the tilt due to wind alone, a day in spring when no ice was present, April 7, 2009, as verified from video records, was selected A daily wind-ice plot on that day is shown in Figures 10 and 11. The x-axis is time, and the blue line indicates the tilt data while the green line is the wind speed. The maximum and minimum tilt values are indicated in the plot, and the shape of plotted tilt data, especially in the data from upper tiltmeter, is similar to the wind data. The lower tiltmeter has less wind effect relative to the upper one, so the plot of lower tiltmeter is used to determine wind correction in the ice force analysis.
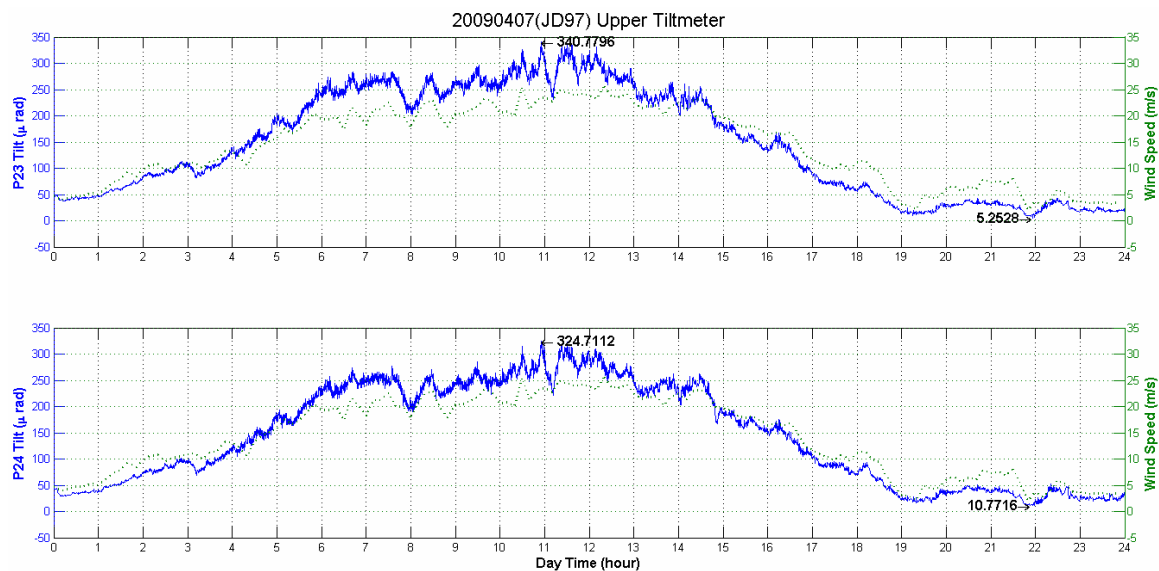
Figure 10: Wind-ice plot for upper tiltmeter, April 7, 2009
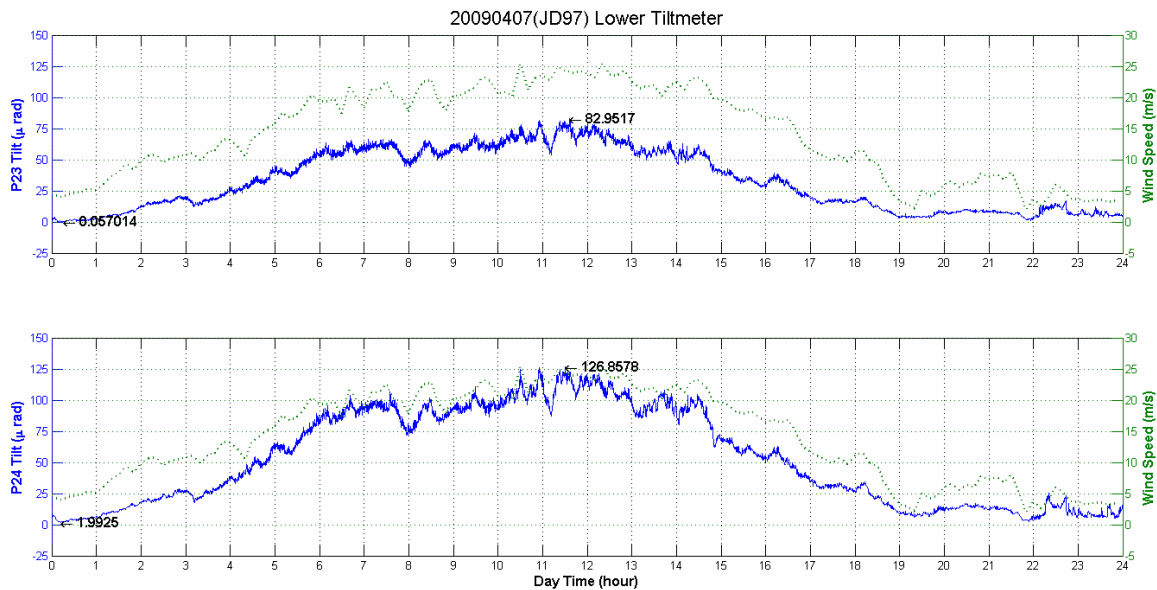
Figure 11: Wind-ice plot for lower tiltmeter, April 7, 2009

An ice event often occurs with a large wind force present. The wind force can persist for a long time while an ice force acting on the pier may only last for a few minutes. The resistance of a bridge pier is much greater than the breaking force of an ice floe, so drifting ice may fail when it hits the pier. The impact happens in a short time, and a peak tilt with a short period will be created in the wind-ice plot. Due to the upper tiltmeter having a larger wind response, the peak caused by the ice in the upper wind-ice plot will be difficult to find. As a result, the daily wind-ice plot for lower tiltmeter is used to search for an ice event which has a short time peak different from the shape of a wind curve.

The largest ice caused peak tilt was found on March 5th, 2009, and its wind-ice plot for the lower tiltmeter is shown in Figure 12. The plotted data is all negative because both ice and wind come from NW which is indicated in the sign convention in Figure 3. The maximum ice force occurred around 8:30 in the morning and the pier camera taped most of the event since 6 AM. The ice chart from that day indicates that the ice coverage near the bridge was 2/10 of 70-120 cm thickness and 5/10 of 30-70 cm thickness, which is able to create a significant ice impact force.
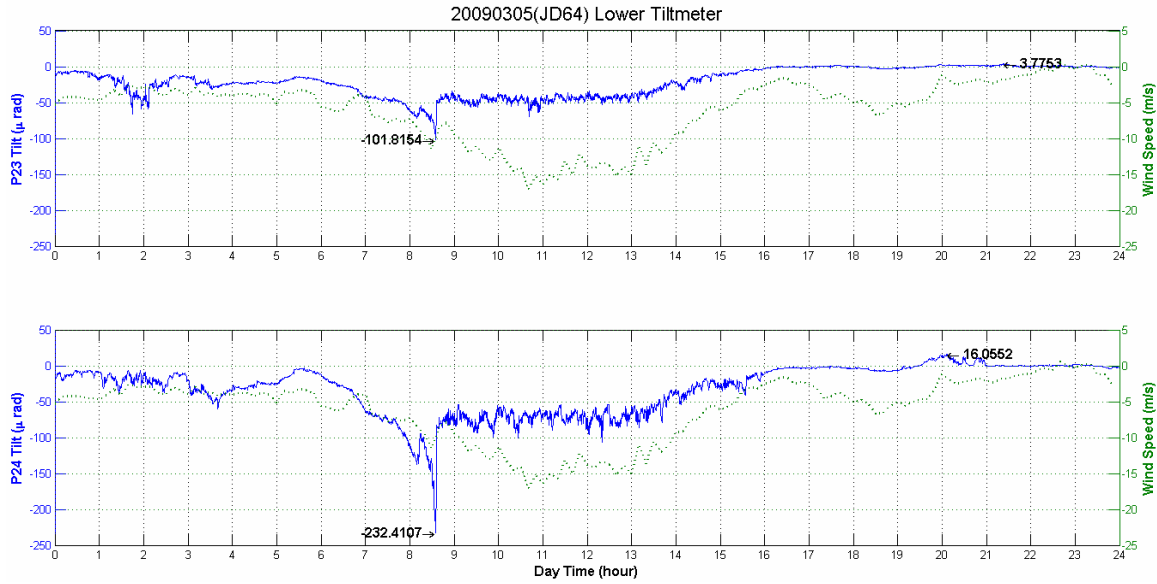
Figure 12: Ice event in wind-ice plot in 2009, March 5

All ice events identified in 2008, 2009 and 2010 are tabulated in **Table 2**. The ice event may occur at an individual pier, so the event duration and pier number are recorded with an approximate tilt angle. The ice drift direction, video record, approximate wind speed and its direction relative to the bridge are also listed in the Table. Due to the limited wind data in 2008, the Table in 2008 has one extra column to record the provided wind data. If the provided data has the required information, it will be marked as a "+" in the table; otherwise it will be recorded as "–". In 2009 and 2010 wind data was obtained from the instruments at P31/P32. As mentioned before, winter in 2010 has the lowest ice coverage in the Strait so that the number of ice events should be less than the other two years'. The maximum tilt angle in each year is analyzed detail to calculate the magnitude of ice force.

3.3 Analysis Method and Example

The following procedure is used to analyse a particular ice event identified from a daily wind-ice plot. Two-second averaged tilt data is prepared, in line with the instrument's response time. The wind data with one second time interval is averaged to two-second intervals to match the tilt data. The wind force acting on the bridge girder tends to overwhelm the ice force, so the first step of calculating ice force is to eliminate the wind effect. According to Kubat and Frederking (2001), the wind affected tilt angle (T_w) is proportional to the square of wind velocity normal to the bridge axis (V_w). Equation (1), shown below, with the coefficient c = 0.19 for P23 and 0.30 for P24, and the unit of c, $\mu rad / (m/s)^2$ can be used to calculate the tilt due to wind at the level of the lower tiltmeter.

$$T_w = c * V_w^2 \tag{1}$$

The wind affected tilt angle correction of the lower tilt depends on the ice drift direction and the wind direction. If the directions are the same, the corrected angle can be

calculated by subtracting the wind affected angle from the measured angle. If not, the corrected angle will equal to the sum of the measured tilt and wind affected tilt angle. The corrected tilt, θ_{lower}, can be calculated from the measured tilt, θ_{MEAS}, and the wind tilt correction, T_w. .

$$\theta_{lower} = \theta_{MEAS} - T_w \qquad\qquad (2)$$

The ice force, F_{ice}, is calculated from the corrected tilt at the lower tiltmeter

$$F_{ice} = b * \theta_{lower} \qquad\qquad (3)$$

where the coefficient b has a value of 0.04 for P23 and 0.02 for P24, with units of $MN/\mu rad$.

The March 5, 2009 event will be used to illustrate the calculation method. Figure 12 shows that the total tilt, θ_{MEAS}, at 08:35 was 102 μrad for P23 and 232 μrad for P24. The calculation of the peak force is presented in Table 1.

Table 1 Calculation of March 5, 2009 maximum ice forces

Pier #	θ_{MEAS}, μrad	Coef c	V_w, m/s	T_w, μrad	θ_{lower} =	Coef b	$F_{ice,}$ N
P23	102	0.19	8	12.2	89.8	0.04	3.6
P24	232	0.30	8	19.2	212.8	0.02	4.3

The calculated ice force for the whole event from 6 AM to 11 AM March 5th, 2009 is shown in Figure 13 and Figure 14. The result with negative values indicates that the ice force is acting from NW to SE.
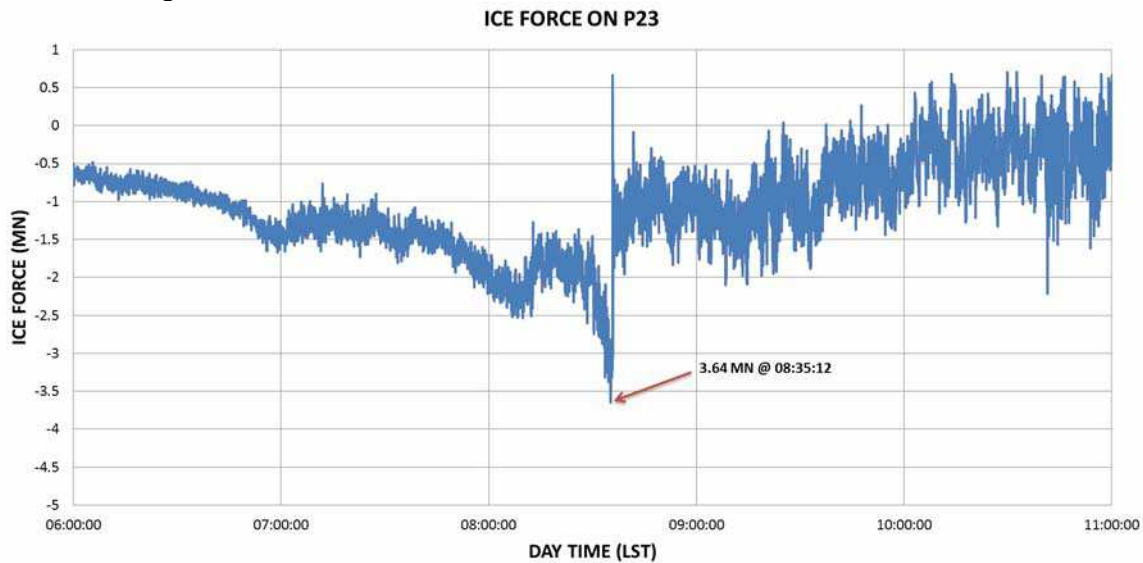
Figure 13: Maximum ice force on P23 in 2009, March 5
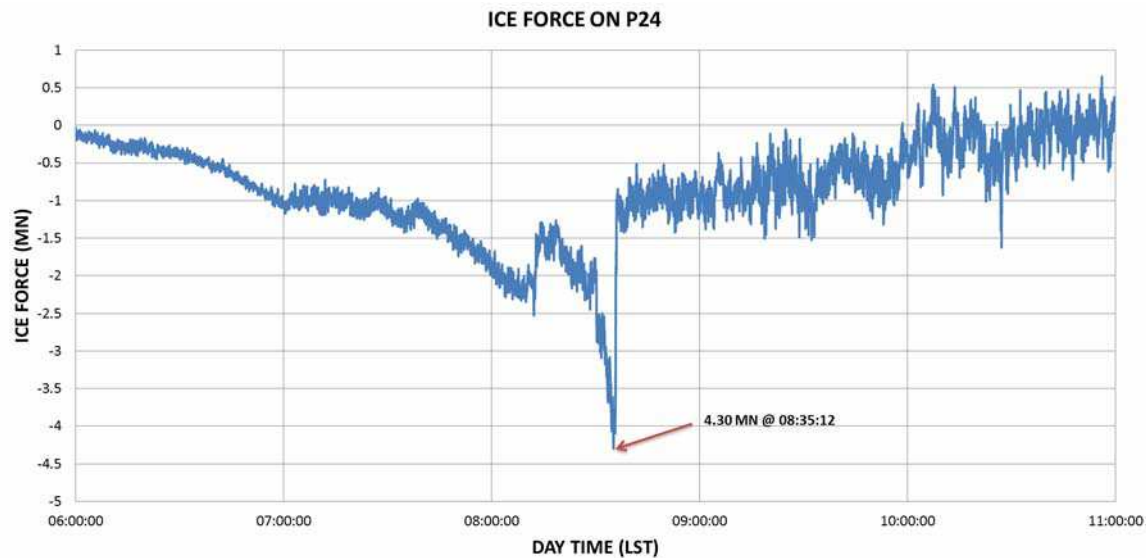
Figure 14: Maximum ice force on P24 in 2009, March 5

3.4 Discussion of Results

The pier video record is used to identify the ice behaviour during an ice event associated with the wind-ice plot. As shown in Figure 15, the wind-ice plot for the P23 lower tiltmeter is limited to day-light hours (0600 to 2000). The tilt angle increases to a peak value and then drops suddenly at 8:35:12 AM. Following the drop, fluctuating tilts occur until 16:00, but they are of much lower magnitude. As observed from video data, the ice was stationary from 06:00 until the time the peak load occurred. The observed ice condition from the P23 video recording just a few seconds after the ice started to move is shown in Figure 16. Note the narrow margin of open water to the left of the pier. After the peak event happened, the ice continues moving to the northwest until about 16:30, when movement stopped.
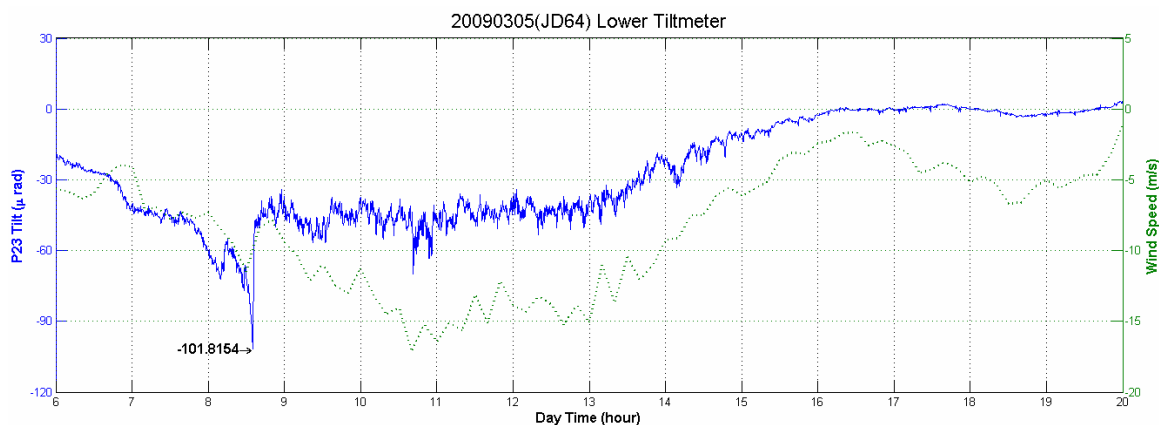
Figure 15: P23 ice event from 6 AM to 8 PM

Figure 16: Pier camera observation at 08:35:12

The loading scenario seems to be one of the ice force on the pier slowly building up, probably under the action of current and wind on a large extent of ice, until it exceeded the strength of the ice cover and it failed against the pier. A similar loading signature was generated on both P23 and P24, so it is likely a large ice floe was located to the northwest of the bridge. It is possible that the rubble accumulation visible in Figure 16 was frozen to the pier and able to smoothly transfer force from the ice floe to the pier. No direct measurements of current are available, but it has generally been observed that the current runs to the southeast in the mornings. The video showed the ice continued to move to the southeast, probably primarily under the action of the wind which reached speeds of 15 m/s, but generating much lower loads. This type of loading scenario was noted several times during the three winters of data analysed, but were of much smaller magnitude. Normally loading events reflect a shorter term loading cycle, lasting a few minutes up to 10 minutes, and representing more of an impact of a thick ice feature or a ridge on a pier.

4. Summary

The tiltmeters have operated 12 winters since 1999 and produced reliable tilt data from the two bridge piers, P23 and P23, adjacent the navigation span. In this report, data from 2008-2010 were analyzed. The data include the measurement of pier tilt response to ice and wind forces. For the purpose of removing the wind effect, the wind data is analysed to calculate a correction to the ice force. Both wind data and tilt data are adjusted to local standard time (LST) for matching with the time on video recording. The video records provide information on ice condition in the vicinity P23 and P24, and ice failure behaviour around the P23. Daily ice charts provide information on ice thickness and concentration in the vicinity of the bridge. The wind data and ice data are averaged every 15 seconds for creating daily wind-ice plot. By comparing the tilt and wind plots, ice events can be

identified and events with larger peak angle caused by ice interaction selected for calculation of ice forces. Over the three winters, 2008, 2009 and 2010, the largest force occurred on March 5, 2009 and was about 4 MN simultaneously on both P23 and P24. This maximum force was associated with a slow build-up of force on piers P23 and P24, followed by a rapid drop.

5. Acknowledgements

Table 2 Ice Event Recording

Year	Month	Date	Event Pier	Event Time (1 - 24 hours)	Lower Tilt (Mu Rad)	Ice Drifting From	Wind Speed (m/s)	Wind Driection From	Pier Camera Record	Traffic Camera Record	Wind Data Record
2008	Jan	19	24	14 - 15	< 20	T => NW => T	0 - 5	NW	+	-	+
2008	Jan	25	23, 24	14 - 16	25	SE => T	0 - 5	NW	+	+	+
2008	Jan	26	24	1 - 2	25	SE	0 - 5	NW	-	+	+
2008	Jan	26	23, 24	20 - 22.5	< 25	NW	0	-	-	+	+
2008	Jan	28	23, 24	3.5 - 8	20 - 25	SE	0 - 5	SE	+	+	+
2008	Jan	28	24	10 - 11	50	NW	0 - 5	NW	+	+	+
2008	Jan	30	23, 24	1 - 3	20 - 25	NW	0	-	-	+	+
2008	Jan	31	23, 24	5 - 8	25 - 40	SE	5 - 15	NW	-	+	+
2008	Feb	2	23, 24	7 - 8	30 - 40	SE	15	SE	+	+	+
2008	Feb	3	24	22 - 24	20 - 30	SE	0 - 5	NW	-	+	+
2008	Feb	4	24	0 - 2	45	T => NW	0 - 5	NW	-	+	-
2008	Feb	4	23, 24	15 - 19	20 - 25	NW	0 - 10	NW	+	+	-
2008	Feb	4	24	21.5 - 24	**60**	SE	0 - 5	NW	-	+	-
2008	Feb	5	24	0 - 3	50	T => NW	0 - 5	NW	-	+	+
2008	Feb	5	23, 24	21 - 24	15 - 25	SE	5 - 10	SE	-	+	+
2008	Feb	7	24	1 - 3	20 - 25	SE	5 - 10	NW	-	+	+
2008	Feb	8	23, 24	6.5 - 10	10 - 25	NW	0 - 5	NW	+	+	+
2008	Feb	8	24	12 - 14	15 - 25	SE	0 - 5	NW	+	+	+
2008	Feb	9	24	0 - 1	<20	SE	0	-	-	+	-
2008	Feb	10	23, 24	4 - 5	<25	SE	5 - 10	SE	-	+	-
2008	Feb	10	23, 24	14 -18	20 - 40	SE	5 - 10	SE	+	+	-
2008	Feb	12	24	18 - 19.5	25	SE	5 - 10	NW	+	+	-
2008	Feb	14	24	18 - 20	30 - 40	SE	5 - 15	NW	+	+	+
2008	Feb	15	24	10.5 - 15	20 - 50	NW	0 - 15	SE	+	+	+
2008	Feb	15	24	17 - 19	25 - 50	SE	0 - 10	SE	+	+	+
2008	Feb	17	23, 24	3 - 7	**100**	NW => T	0 - 5	NW	-	+	+
2008	Feb	17	23, 24	13 - 17.5	10 - 25	NW	0 - 10	SE	+	+	+

Table 2 Ice Event Recording

Year	Month	Date	Event Pier	Event Time (1 - 24 hours)	Lower Tilt (Mu Rad)	Ice Drifting From	Wind Speed (m/s)	Wind Driection From	Pier Camera Record	Traffic Camera Record	Wind Data Record
2008	Feb	18	24	6 - 9.5	25 - 30	SE	10 - 15	SE	+	-	+
2008	Feb	19	24	19 - 20	40	NW	0	-	+	-	+
2008	Feb	20	24	7 - 10	25 - 50	NW	5 - 10	NW	+	-	+
2008	Feb	21	23, 24	18 - 23	50 - 55	NW	5 - 10	NW	+	-	+
2008	Feb	22	24	0 - 3	25 - 40	-	5 - 10	NW	-	-	-
2008	Feb	22	23, 24	7 - 11	30 - 40	NW	0 - 10	NW	+	-	-
2008	Feb	24	24, 24	21 - 24	<25	-	0	-	-	-	+
2008	Feb	25	24	11 - 12	20	NW	0	-	+	-	+
2008	Feb	28	24	0 - 1	25	-	0 - 5	NW	-	-	+
2008	Feb	28	23, 24	2 - 3	15 - 25	-	0 - 5	NW	-	-	+
2008	Feb	28	23, 24	9 - 14.5	20 - 30	T => NW	0 - 10	NW	+	-	+
2008	Feb	28	24	17 - 18	30	SE	0 - 5	NW	+	-	+
2008	Feb	29	24	0 - 3	20 - 35	-	0 - 5	NW	-	-	-
2008	Feb	29	23, 24	9 - 15	25 - 50	T => NW	0 - 5	NW	+	-	-
2008	Mar	8	24	14 - 15	20	SE	5 - 10	NW	+	-	+
2008	Mar	10	24	16 - 18	30	SE => T => NW	0 - 5	NW	+	-	+
2008	Mar	14	24	4 - 7	25 - 45	SE => T => NW	0 - 5	NW	-	+	-
2008	Mar	14	24	11 - 15	25 - 30	NW	0 - 5	NW	+	+	-
2008	Mar	15	24	6 - 7	20	SE	0 - 5	NW	+	+	-
2008	Mar	21	23, 24	3 - 4	20	NW	0 - 5	NW	-	+	+
2008	Mar	22	23, 24	9 - 10	20 - 30	NW => T	0 - 5	NW	+	+	+
2008	Mar	22	23, 24	19 - 23	20 - 25	NW	5	NW	-	+	+
2008	Mar	23	23, 24	0 - 1	20	SE	5	NW	-	+	+
2008	Mar	23	23, 24	6 - 12	30 - 55	NW	5	NW	+	+	+
2008	Mar	26	24	18 - 19	40	SE	5	SE	+	+	+
2008	Mar	30	23, 24	8.5 - 14	20	SE => T => NW	5 - 10	NW	-	+	+

Table 2 Ice Event Recording

Year	Month	Date	Event Pier	Event Time (1 - 24 hours)	Lower Tilt (Mu Rad)	Ice Drifting From	Wind Speed (m/s)	Wind Driection From	Pier Camera Record	Traffic Camera Record	Wind Data Record
2008	Mar	30	24	14.5 - 16.5	**80**	NW => T => SE	0 - 10	NW	-	+	+
2009	Jan	17	23, 24	1 - 2	<25	-	5	NW	-	-	
2009	Jan	17	23, 24	22 - 23.5	<20	-	0 - 5	NW	-	-	
2009	Jan	18	24	12 - 13	<20	SE	5	NW	+	-	
2009	Jan	20	24	1.5 - 4	<25	-	0 - 5	NW	-	-	
2009	Jan	20	24	13.5 - 16.5	25	NW	5	NW	+	-	
2009	Jan	22	23, 24	14 - 18	<20	NW	5	NW	+	-	
2009	Jan	27	23, 24	7 - 8	<20	NW	5 - 10	NW	+	+	
2009	Jan	29	24	14 - 20	30 - 50	NW	5 - 10	NW	+	+	
2009	Jan	30	24	1 - 5.5	25 - 50	SE	5	NW	-	+	
2009	Jan	30	23	10.5 - 11.5	25 - 30	SE	5	NW	+	+	
2009	Jan	30	24	14 - 15	25	SE	0 - 5	NW	+	+	
2009	Jan	31	24	15 - 19	< 25	SE	5 - 10	SE	+	+	
2009	Feb	1	24	10 - 13	25 - 30	NW	5 -10	NW	+	+	
2009	Feb	2	23, 24	3.5 - 7.5	< 25	SE	0	-	-	+	
2009	Feb	2	23, 24	10 - 14	< 20	NW	0	-	+	+	
2009	Feb	2	23, 24	15 - 20	< 20	SE	0 - 5	SE	+	+	
2009	Feb	3	24	14 - 15	25	NW	5	NW	+	+	
2009	Feb	4	24	4 - 6	50	NW	10 - 15	NW	-	+	
2009	Feb	4	24	7 - 10.5	**130**	T	5 - 15	NW	+	+	
2009	Feb	4	24	18.5 - 22	50	SE	0 - 5	NW	-	+	
2009	Feb	5	23, 24	10.5 - 14.5	< 25	NW	5 - 10	NW	+	+	
2009	Feb	6	23, 24	3 - 5	< 25	NW	5	NW	-	+	
2009	Feb	6	23, 24	13.5 - 18.5	25	NW	0 - 5	NW	+	+	
2009	Feb	7	24	2.5 - 7	< 25	NW	5 - 10	NW	-	+	
2009	Feb	7	24	9 -12	20 - 30	SE	0 - 5	NW	+	+	
2009	Feb	7	23, 24	15 - 18.5	< 25	NW	0	-	+	+	
2009	Feb	7	23, 24	20 - 24	< 25	SE	5	SE	-	+	

CHC-TR-075

Table 2 Ice Event Recording

Year	Month	Date	Event Pier	Event Time (1 - 24 hours)	Lower Tilt (Mu Rad)	Ice Drifting From	Wind Speed (m/s)	Wind Driection From	Pier Camera Record	Traffic Camera Record	Wind Data Record
2009	Feb	8	24	12 - 13	25 - 30	SE	0	-	+	+	
2009	Feb	10	24	14 - 15	<20	SE	5	NW	+	+	
2009	Feb	11	23, 24	9 - 11	<20	NW	0 - 5	SE	+	+	
2009	Feb	12	24, 24	15 - 18	~25	SE	0 - 5	SE	+	+	
2009	Feb	22	23, 24	22.5 - 23.5	<20	SE	5 - 10	SE	-	+	
2009	Feb	24	24	13 - 16	50	NW	10 - 15	NW	+	+	
2009	Feb	25	23, 24	4 - 7	20 - 30	NW	5 -10	NW	-	+	
2009	Feb	25	24	19 - 22	25 - 30	NW	0	-	-	+	
2009	Mar	3	23, 24	8.5 - 14.5	25 - 50	NW	5	NW	+	+	
2009	Mar	3	24	16 - 18	50	SE	0 - 5	NW	+	+	
2009	Mar	3	23, 24	18 - 19	25	SE	0 - 5	NW	+	+	
2009	Mar	4	23, 24	8.5 - 13.5	25	NW	5	NW	+	+	
2009	Mar	5	23	1 - 3	40	NW	0 - 5	NW	-	+	
2009	Mar	5	24	3 - 5.5	50	NW	0 - 5	NW	-	+	
2009	Mar	5	23, 24	5.5 - 16	**150 - 250**	T -> NW	5 - 15	NW	+	+	
2009	Mar	6	24	19 - 20	50	SE	10	SE	+	+	
2009	Mar	7	24	20 - 21	25	SE	5	NW	-	+	
2009	Mar	9	23, 24	15.5 - 20	20 -30	NW	0 - 5	NW	+	+	
2009	Mar	14	24	22 - 23	< 20	NW	0	-	-	+	
2009	Mar	20	24	7 - 9	50	NW	5 - 10	NW	+	+	
2009	Mar	20	24	12.5 - 15.5	25	NW	0 - 5	NW	+	+	
2009	Mar	21	23, 24	14 - 17	20 - 30	NW	0 - 5	NW	+	+	
2009	Mar	23	24	5 - 6	40	NW	5 - 10	NW	-	+	
2009	Mar	23	23, 24	7 - 8	25 - 30	NW	5	NW	+	+	
2009	Mar	23	23, 24	13 - 19	25 - 40	NW	5	NW	+	+	
2009	Mar	24	23, 24	4 - 8	35 - 50	NW	0 - 5	NW	-	+	
2009	Mar	24	24	11 - 12	20 - 25	SE	0 - 5	NW	+ LESS ICE	+	
2009	Mar	24	23, 24	16 - 19	25 - 75	NW	0 - 10	NW	+	+	

Table 2 Ice Event Recording

Year	Month	Date	Event Pier	Event Time (1 - 24 hours)	Lower Tilt (Mu Rad)	Ice Drifting From	Wind Speed (m/s)	Wind Driection From	Pier Camera Record	Traffic Camera Record	Wind Data Record
2010	Jan	27	23, 24	12 - 14	20 - 25	T => NW	10 - 15	NW	+	-	
2010	Feb	11	24	15 - 18	30 - 40	NO ICE => NW	10 - 15	NW	+	+	
2010	Feb	11	24	20 - 21	40	T	10 - 15	NW	-	+	
2010	Feb	12	23, 24	9.5 - 10.5	<20	NW	10 - 15	NW	+	+	
2010	Feb	13	24	7 - 11	<25	NW	5 - 10	NW	+	+	
2010	Feb	13	24	17 - 18	25	NW	5 - 10	NW	+	+	
2010	Feb	17	23, 24	19 - 23.5	10 - 25	NW	5 - 10	NW	-	+	
2010	Feb	18	24	3.5 - 5	<20	T	0 - 5	NW	-	+	
2010	Feb	20	23, 24	20 - 24	<25	NW	10	NW	-	+	
2010	Feb	21	23, 24	0 - 2	25	NW => T	5 - 10	NW	-	+	
2010	Feb	21	23, 24	9 - 15	25 - 50	NW	5 - 10	NW	+	+	
2010	Feb	21	24	17.5 - 19.5	25	SE	0 - 5	NW	+	+	
2010	Feb	21	23, 24	23 - 24	<20	NW	0 - 5	NW	-	+	
2010	Feb	22	24	0 - 2.5	**50**	T	0 - 5	SE	-	+	
2010	Feb	22	23, 24	11.5 - 15	<20	NW	0 - 5	NW	+	+	
2010	Feb	23	24	12 - 15.5	25	T	5 - 10	SE	+	+	
2010	Mar	11	24	3 - 5	25	NW	5 - 10	NW	-	+	
2010	Mar	11	24	12.5 - 16	**75**	T => NW	0 - 5	NW	+	+	
2010	Mar	12	24	16 - 17.5	25	NW	0 - 5	NW	+	+	
2010	Mar	15	24	6 - 7	20	T => NW	0 - 5	SE	+	-	
2010	Mar	15	24	14 - 15.5	25	SE	0 - 5	NW	+	-	

6. References

[1] Brown, T.G., 2006, Analysis of ice event loads derived from structural response, *ScienceDirect: Cold Regions Science and Technology 47 (2007) 224-232*, October 23, 2006.

[2] Frederking, R., Kubat, I. and Prinsenberg S., 2007, ICE INTERATION WITH CONFEDERATION BRIDGE – REVIEW OF NRC PROGRAM, *Confederation Bridge Engineering Summit*, Charlottetown, PEI, Canada, August 19-22, 2007.

[3] Kubat, I. and Frederking, R., 2001, RESPONSE OF CONFIDERATION BRIDGE TO ICE FORCES: 2000 WINTER SEASON, *Proceedings of the 16th International Conference on Port and Ocean Engineering under Arctic Conditions (POAC'01)*, Ottawa, Ontario, Canada, August 12-17, 2001.

[4] MANICE, 2005, Manual of Standard Procedures for Observing and Reporting Ice Conditions, June 2005, Revised Ninth Editions, Canadian Ice Service (CIS).