PORT MANN BRIDGE CABLE STAY SNOW AND ICE MANAGEMENT PROGRAM

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1. Introduction

The Port Mann Bridge (PMB) is a vital transportation link located along Highway 1 (TransCanada Highway) between the City of Coquitlam and the City of Surrey in the Greater Vancouver area, serving more than 1 Million vehicles per week. It is the second longest cable-stayed bridge in North America and was the widest in the world until the opening of the Bay Bridge in San Francisco, CA[1,2]. The bridge consists of two towers or pylons, 10 traffic lanes, one pedestrian sidewalk, and a total of 288 stay cables. The PMB was built by the Transportation Investment Corporation (TI Corp) and is jointly managed with the BC Ministry of Transportation and Infrastructure (MOTI).

When certain environmental conditions occur during the winter months, snow and ice accretions on the stay cables are possible. When threshold amounts are reached and conditions permit, natural shedding can occur. Though most falling snow and ice accretion drops are harmless, some may have sufficient size and mass to cause a hazard and pose a risk to the travelling public and workers below. The PMB Cable Stay Snow and Ice Management Program strives to mitigate the risk and hazard by minimizing the chance of any significant snow and ice accumulations occurring on the cable stays. In its basic form this is achieved by:

- A weather monitoring and early warning system Dashboard.
- Communication to stakeholders through the “Alert Level Checklist”.
- Pre-event preparedness of onsite resources.
- Effective onsite mobilization for operational control.
- Active traffic management control through the use of proper messaging and;
- Active cable stay control through the use of the Collar Release Devices (CRDs).
- Ensuring program preparedness post event.
- Performing diligent system testing, inspections and maintenance.

Commonly used terms:

Port Mann Bridge (PMB), Alert Level Checklist, Dashboard, Collar Release Devices (CRDs)

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2. Cable Stay Types

As shown in (Figure 1), the PMB has both "inside" and "crossing" stay cables which range from 25 to 77 degrees in terms of their slope angles. There are a total of 152 crossing stays and 136 inside stays. Crossing stays physically pass over Highway 1, while inside stays do not. Although inside stays do not physically pass over traffic, wind currents can transport falling snow and ice from these stays onto traffic lanes below. Therefore, all cables stays on the PMB have been included in its snow and ice management system.

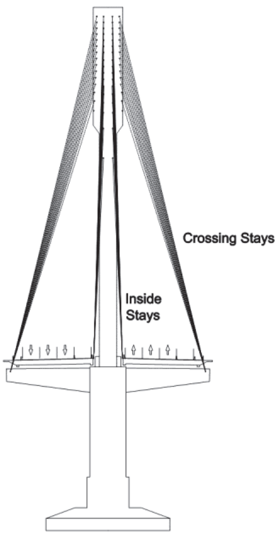

Figure 1: Diagram of Inside and Crossing Stays

3. Collar release device (CRD) System

In conjunction with an installed early weather warning system Dashboard, snow and ice buildup on the stay cables is limited by strategically releasing an array of chain-link collars stored at the top of each stay in a collar release device (CRD). Based on the severity of a given weather event and the associated previously established system response protocol, PMB Snow and Ice technicians release collars strategically, either individually or in groups, from the tops of the stay cables. As the weighted collars travel rapidly down a stay cable, they remove accumulated snow and relatively light levels of ice until they contact the collar attenuator at the base of the stay. The collars essentially free fall with gravity. Dropped collars remain at the stay base until they are collected, inspected for reuse, hoisted back to the appropriate stay cable CRD, and reloaded into the device by a technician skilled in industrial rope access work. They descend from the top of the pylon and install the multiple collars on a particular stay cable and into the CRD. The system is fully functional[3]. It has safely removed snow and prevented ice accumulations during two major weather events on the PMB, one in 2013, one in 2014, and numerous events during the La Nina winters of 2016/17 and 2017/18.

There are a total of up to 8,600 collars on the stay cables, which are made of galvanized steel chain and they vary in weight and length depending on the length, angle of inclination and diameter of the stay cable to which they are installed. The collars are attached to the CRD by saddling a cable tether connected to the collar, over a retractable piston (see Figure 2).

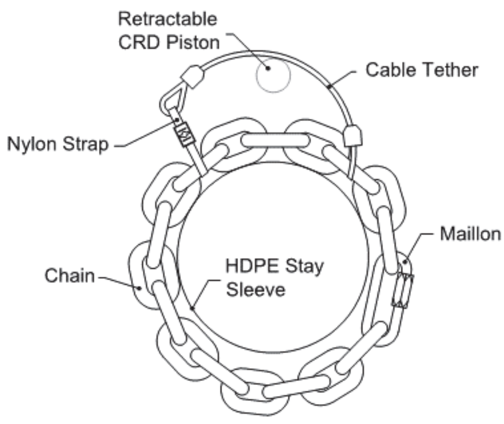

Figure 2: Chain-Link Collar with Cable Tether Connected to Retractable Piston

Collar Release Devices (CRD) are mounted to all four sides of the two bridge pylons. The CRD is located on the stay expansion tube where the top of the stay enters the face of the concrete pylon (see Figure 3). Each CRD contains holding slots for 30 chain-link drop collars. All CRDs are connected electronically in a network to a programmable logic controller (PLC) and can be controlled by a Human Machine Interface (HMI) inside either of the two pylons. Figure 3 shows the CRD support

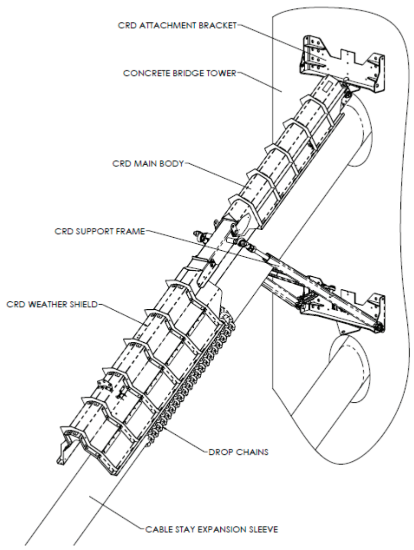

Figure 3: Collar Release Device (CRD) Schematic

frame, weather shield, attachment bracket to the pylon wall and the array of drop collars in-line along the upper portion of the stay cable. Approximately twenty loaded collar drop chains are shown ready for deployment.

4. Weather Monitoring & Early Warning Dashboard System

The early weather warning system includes monitoring of: atmospheric weather changes, on-site video images of cable-stayed bridge snow and ice accumulation, and existing weather prediction models. The early warning system monitors atmospheric conditions and accumulated snow depths at the top of the pylon. This information is combined with other monitored weather prediction models to determine appropriate system response protocol.

The use of various available weather forecasts, weather forecasting and monitoring tools, onsite observations, weather and snow data collection and a good understanding of the factors that influence the bridges geographic location, provides the necessary information for appropriate cable stay snow and ice management. During winter months the PMB Cable Stay Snow and Ice Management Program obtains site specific 24 hours a day, 7 days a week weather forecast information through contracted services. Combined with the early warning Dashboard, technicians are able to acquire a good understanding of possible future meteorological conditions. Current weather condition information is also available through the BC Governments network of roadside and remote weather stations. Specific onsite conditions are obtained through manual observation and the use of several remote weather stations, and various strategically placed cameras specifically assigned to the PMB. To ensure onsite conditions are continuously monitored; weather station alarm notifications are provided through the BC Government's weather information system. The Dashboard application is a unique computer program that allows for quick and efficient access to the vast amount of operational information for operational interpretation and delivery. This allows the technicians to assign one of the six "Port Mann Bridge Snow and Ice Accretion Alert Levels". The PMB Snow and Ice Accretion Alert Level Scale is a six level scale (Alert Levels 0-5) that was developed for the purpose of communicating information about:

- The possibility of a snow and ice event occurring within "X" amount of days of a targeted start date;
- Snow and ice accretion status;
- Control program status and;
- Necessary operational requirements to be performed by the Snow and Ice Technician.

The alert level system provides a pathway to aid in operational planning and success, as well as helps ensure an acceptable level of safety is provided to the travelling public on the Port Mann Bridge.

5. Multi-Level Event System Response Protocols

The Port Mann Bridge Cable Stay Snow and Ice Management Program involves many departments and individuals' working together. The Winter Operations Plan is made up of essentially four independent operational management streams: Bridge Cable Stay Control Program, Traffic Management, Road and Bridge Deck Operations and Communications. Changes in an Alert Level status affect the necessary duties, procedures and requirements needed to be performed by each operational management stream. All actions performed by each stream affect the overall Winter Operation Plan and how it performs. Consistent regular communication is important. Ensuring that all parties are well informed throughout the life of a weather event is necessary.

6. Control Systems

Locally, the PMB Snow and Ice Removal System is comprised of the following major components: Collar Release Devices (CRDs), Programmable Logic Controllers (PLCs), Human Machine Interfaces (HMIs), Uninterrupted Power Supplies (UPSs), Generators, and Auto transfer Switches. The PMB contains 288 stay cables. Each individual stay cable at the top is equipped with one Collar Release Device (CRD) which has the potential to house up to 30 collars to be released to clean snow and ice accumulation from the cable stay as and when required. The CRDs are operated through the use of PLCs and HMIs. There are a total of four PLCs and four HMIs which provide local users the capability to operate the CRDs, view status of the CRDs, and monitor various points in the power generation system. A remote HMI/SCADA workstation is located at the Ministry's Regional Transportation Management Centre providing remote users with the same operational capabilities as local users, with the addition of alarm viewing and data logging capabilities The HMIs use a common interface and therefore each one is capable of controlling all the CRDs. The operator can release collars individually or in pre-programmed groups with various drop patterns available. The specific stays to clean or what sequence to clean is determined by the technicians based on observations, knowledge and experience. The CRD system is connected to utility power and back-up generator power fed through the auto transfer switch and is connected to the power system via uninterruptible power supplies (UPS) isolating the Snow and Ice Removal System from power interruptions.

7. Dashboard System

The Dashboard system or Cable Stay Management system (CSMS) is a collaborative effort between the Universities of Cincinnati and Toledo. It is an automated web-based application that collects real time weather data from various sources, processes the information and gives user friendly results from which the user can understand the possibility of accretion or shedding events on the bridge and any given point of time. The Dashboard sends email alerts to the bridge management team during potential snow or ice events on the bridge.

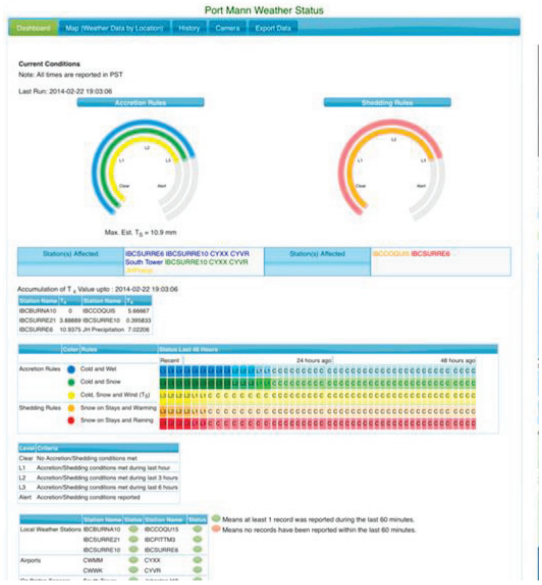

Figure 4: Dashboard Website Screenshot

The Dashboard system for the Port Mann Bridge consists of five Dashboard dials shown in Figure 4. Each dial represents the level of persistence of its corresponding accretion or shedding rule. The Dashboard monitoring system gives information on the status of ice accumulation/ snow accretion or shedding based on last one hour's weather data. To make the Dashboard robust and reliable data from multiple sources, in and around the bridge are collected. There are primarily three data sources used by the dashboard algorithm; METAR data from airports close to the bridge, RWIS (Road Weather Information System) stations and weather sensor suites or stations installed on or close to the bridge to capture the micro climate. From past events it has been observed that because of certain geographical factors and the location of the bridge there is potential for adverse weather just on the bridge and not on the adjacent land. The presence of onsite weather sensors is essential to capture the events on the bridge for post-event analysis and planning for the future. In addition to numerous conventional sensors, a novel sensor for detecting the presence and liquid water content of the snow on the stays will be installed this winter.

The Dashboard has alerted on 16 events between Nov 2013- Mar 2015 and Nov 2017 – Mar 2018 on the Port Mann Bridge when the monitor was in operation, indicating the presence of snow. During all these events the presence of snow on the bridge was visually confirmed.

The availability of weather forecast data from different models and sources, each with their own merits and demerits promise a lot of value in decision making for cable stayed bridges in winter emergencies. The intelligence of the monitor is being increased by incorporating forecast data to alerting operations personnel ahead of time to help them prepare for potential events. The bridge management team uses various forecast sources and models, some specific to the bridge location to make their decisions. The aim of the Dashboard is to present the data from various forecasts in one place, in a user-friendly manner which helps the management team in making decisions. A forecast Dashboard is currently being built, this version of the Dashboard will use forecast data to predict the accumulation of snow and ice on the stays.

Decision analysis has a role in integrating weather forecasts with business operations and planning models. A simple average of the storm track produced by multiple models as the consensus track is used by tropical cyclone forecasters as a decision support system. The purpose of the consensus track is to improve accuracy, not to measure uncertainty. The predictability of a given storm drives the divergence among multiple models. However, no probabilistic information is extracted from multiple forecast sources. There are no automated methods to weight models' forecasts according to indicators of their performance for a given storm, or for past storms[4,5].The forecast Dashboard is an attempt to make such a probabilistic tool using multiple forecasts to accurately predict the possibility of adverse events on the bridge. Based on the events analyzed for one event, from one forecast model tuned to the bridge location, the forecast Dashboard algorithm was able to detect 13 snow events with an average lead time of 26 hours during the winter of 2017-18. There were 2 missed detections and 3 false detections during the same time period. The research team is working on including other forecast sources and models to make the forecast Dashboard system robust.

8. Conclusion

The design of and process for the snow removal and ice management system is the first of its kind based on the research conducted by TI Corp with its partners. Although the construction techniques used to establish the system are not unique, the components of the system have not been implemented previously on a bridge but were customized for this application. All components were professionally designed and manufactured and procedures were developed for their installation, maintenance, and operation. The system and process described in this paper are complete and functioning in a research environment, the development of the system is ongoing with continuous improvements implemented from year to year according to observed performance and maintenance/operational needs.

[1,2] https://en.wikipedia.org/wiki/Port_Mann_Bridge#cite_note-5
[3]https://www.youtube.com/watch?v=AkCG3nK4EM0
[4]http://www.pmh1project.com/Pages/default.aspx

[5]E. Regnier, "Doing something about the weather," Omega, vol. 36, no. 1, pp. 22–32, 2008.