



Fredericton, Canada

June 13 – June 16, 2018/ Juin 13 – Juin 16, 2018

REVIEW OF BRIDGE DESIGN PRACTICE FOR WATER LOADS, SCOUR, AND ICE ACTION: OPPORTUNITIES FOR CLIMATE RESILIENCE

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Abstract: An appraisal of historical and recent damage to bridges in Canada and internationally underlines the risks posed by water loads, scour and ice effects. More than 50% of bridge failures in North America are attributed to floods and hydraulic factors, including scour, debris impacts and ice effects. River ice is a unique challenge for bridges in northern climates, with estimates of annual average damages in Canada due to ice jams exceeding \$100 million. The rising costs and damages associated with extreme weather events highlight the vulnerabilities of Canadian infrastructure to climate change. Potential changes in exposure to ice and flood hazards (from riverine, pluvial, and coastal sources) pose a threat to the integrity and sustainability of transportation infrastructure, including bridges and overpasses. The *Canadian Highway Bridge Design Code* contains provisions for evaluating water loads, scour and ice action for new bridges, and refers to the Transportation Association of Canada's (TAC) *Guide to Bridge Hydraulics* for additional guidance. However, there are no provisions for evaluating potential climate change impacts on these loads and actions. A review of the current state of bridge design practice for evaluating, mitigating and adapting to water loads, scour, ice action and related climate change impacts was conducted. This included an appraisal of bridge design codes, standards and guidelines in Canada and other countries. The review identified current gaps, emerging best practices, and possible steps towards improving design guidance and the resilience of Canadian bridges and overpasses to water loads, scour, ice action and climate change.

1 INTRODUCTION

The federal government of Canada, through Infrastructure Canada, has established the Climate Resilient Buildings and Core Public Infrastructure (C-RB&CPI) Project led by the National Research Council. The main objective of the C-RB&CPI Project is to support outcomes that will enable the reduction of fatalities, injuries, illnesses, infrastructure damage and economic losses from climate change and extreme weather events by developing new approaches for the design and rehabilitation of buildings and core public infrastructure (CPI) for improved climate-resilience. This project will support and inform the development of codes, standards and guidelines to better mitigate the risks associated with climate change to new and existing buildings and CPI.

Canada's critical infrastructure is vulnerable to extreme weather events under present day conditions, and the increasing costs of natural disasters highlight potential vulnerabilities to climate change (Lemmen et al. 2008). In addition to changes in average temperature and precipitation; changes in temperature and precipitation extremes, sea level, storm surges, sea ice and other climate-related parameters have been observed and projected. These changes pose a threat to the integrity and sustainability of transportation infrastructure, including bridges and overpasses.

This paper summarizes a review of existing codes, guides and standards that form the current state of design practice for evaluating water loads, scour and ice action at bridges in Canada and internationally. The findings are intended to inform future guidance on how to consider the effects of climate change on water loads, scour and ice action for the design of new highway bridges and overpasses in Canada. A more extensive and detailed review is provided in Murphy et al. (2018).

2 IMPACTS OF WATER LOADS, SCOUR AND ICE ACTION ON BRIDGES

More than half of bridge failures in North America during the latter half of the 20th century have been attributed to floods and hydraulic factors; including scour, debris impacts and ice effects (TAC 2004). A quantitative investigation of bridge collapses in the United States (Cook 2014), from a record of 1,745 events spanning the period 1920-2011, concluded that hydraulic hazards (including flood, scour, debris, ice, drift and dam failure) are the most likely cause of collapse. Although statistics are not readily available for Canada, scour is responsible for the majority of bridge failures in the United States (Lagasse et al. 2007, Lamb et al. 2017, Wright et al. 2012) and New Zealand (Melville and Coleman 2000). A review by Lin et al. (2014) of 36 case studies of historical bridge failures pertaining to scour (20 from New Zealand, 14 from the USA and 2 from Canada) concluded that local scour is the dominant type of scour causing failure (64%), followed by channel migration (14%) and contraction scour (5%). River ice is a particularly relevant hazard for Canadian bridge designers, with most rivers having seasonal ice cover (Beltaos and Burrell 2015). Prowse et al. (2007) estimated the economic costs of river ice in North America at \$250 million per year on average (2006 dollars). In Canada, damages due to ice jams were estimated by Gerard and Davar (1995) at \$90 million annually (in 1990 dollars). This includes damage to bridges.

3 CLIMATE CHANGE IMPACTS ON BRIDGE WATER LOADS, SCOUR AND ICE ACTION

The major climate-driven parameters determining the severity of water loads, scour and ice action on bridges and overpasses in Canada are:

- The magnitude of extreme river flows (which governs exposure to floods, water levels and velocities at bridges and overpasses located in rivers and floodplains);
- The magnitude of run-off from extreme rainfall events in fast-responding and urban areas;
- The magnitude of storm surges, waves and relative sea level rise in coastal and estuarine areas (Fig. 1); and
- The thickness of river or sea ice cover, ice temperature, the size of ice floes, and the timing and intensity of ice break-up.

Understanding climate change impacts on water loads, scour and ice action at bridges and overpasses requires some capacity to predict how the parameters listed above will change over time in response to the changing climate.



Figure 1: The 13-kilometre Confederation Bridge, the world's longest bridge over ice-covered waters (National Research Council Canada 2017)

Region-specific projections of the above parameters under future climate scenarios are not widely available for Canada in a format useful for design applications. For some of the parameters (e.g., river flows), future projections on large regional scales may not be directly useful for design applications, due to inhomogeneity across regions and watersheds caused by important local features. Consequently, there remains a need to rely on projected changes in precipitation and temperature, to support high-level inferences on the potential impacts of climate change on water loads, scour and ice action on Canadian bridges and overpasses. However, meteorological indicators cannot provide a complete or wholly accurate picture of climate change impacts on infrastructure. For example, the use of precipitation as an indicator/proxy for river discharge does not take into account contributory factors related to catchment characteristics and hydrologic processes (e.g., infiltration, groundwater storage, surface water storage, evapotranspiration, snow melt, ice jams). Translating projections of precipitation from global and regional climate models to flood flows and inundation extents, at temporal and spatial scales suitable for determining impacts on bridges and overpasses, is not a trivial task. Considering the current lack of scientific consensus on downscaling methods, practical compromises may be required to derive useful information to support design applications (Khaliq and Attar 2017). Robust approaches to address this data gap will likely involve ensemble-based climate simulations, hydrologic/hydraulic modelling and flood mapping techniques.

Ensemble-based climate model projections show increasing seasonal average precipitation (IPCC 2013, Lemmen et al. 2008), and short- to medium-duration (5-minute to 7-day) extreme precipitation (Masud et al. 2016, Mladjic et al. 2011, Wang et al., 2014) across most Canadian regions in the 21st century. In general, therefore, increases in the exposure and vulnerability of bridges and overpasses to water loads and scour associated with riverine and flash floods are likely. However, the magnitude (and possibly the direction) of changes is expected to vary substantially at regional and sub-watershed spatial scales; so too, therefore, will impacts on bridges and overpasses. Direct derivation of seasonal and extreme streamflow projections from climate models such as the Canadian Regional Climate Model (Huziy et al. 2012, Poitras et al. 2011), at spatial resolutions of 45 km or finer, may provide a better understanding of potential future climate change impacts on water loads and scour at Canadian bridges.

Relative sea level change projections for stations throughout Canada's coastal regions by James et al. (2014) provide a potentially useful basis for supporting assessments of climate change impacts on water loads and scour at coastal and estuarine bridges. The projections exhibit substantial spatial variability, with relative sea level change ranging from a rise of nearly 1 m by 2100 in the Maritimes and the Beaufort coastline, to a fall of around 1 m on Hudson Bay, where the land is rising. Many of the more densely populated coastal regions are projected to experience relative sea level rise, and it is therefore reasonable to assume that most coastal bridges will be exposed to higher water loads and scour hazards. However, there is wide variability in the sea level change projections depending on the climate change emissions scenario and climate models used, and there is no national guidance on how to apply the projections in the context of bridge design. A shortage of available data on projected climate-induced changes in storm surges, waves and sea ice cover in coastal regions is another limiting factor in accounting for climate change impacts on coastal and estuarine bridges.

Based on output from the Canadian Climate Change Scenarios Network ensemble climate models, increases in both summer and winter air temperatures are expected across Canada in the first half of the 21st century. Predictions of expected general trends in river ice conditions under such a warming climate regime are described by Beltaos and Prowse (2001). At lower latitudes and temperate regions (southwestern Ontario, parts of British Columbia and Atlantic Canada), the already brief river ice season may disappear completely or become more intermittent. At mid latitudes (west-central Canada, parts of Ontario and Quebec), winter break-up events may begin to occur in some areas where they did not occur before, or more frequently in areas where they now occur occasionally. Spring break-up hazards may diminish due to a shift in precipitation regime from snow towards rainfall, resulting in smaller snowpack. At high latitudes, reductions in ice thickness may occur. Warmer spring temperatures and more intense snowmelt may exacerbate ice hazards associated with the final spring break-up.

4 REVIEW OF CURRENT CODES, STANDARDS, AND GUIDELINES

4.1 Canadian Highway Bridge Design Code

In Canada, the authority for establishing design requirements for highway bridges lies with provincial and territorial governments. With the exception of Manitoba, all provinces and territories have mandated the use of the Canadian Highway Bridge Design Code (CSA S6-14), hereafter referred to as the CHBDC, in some cases with amendments or additions. The CHBDC applies to the design, evaluation and structural rehabilitation of highway bridges, and includes provisions for hydraulic design (including floods and scour), water loads, and ice loads. However, the CHBDC does not specify requirements related to coastal effects (e.g., exposure to sea action or icebergs). The main provisions relevant to water loads, scour and ice action are summarized as follows.

4.1.1 General and Hydraulic Design Criteria

The CHBDC specifies a design life for new bridge structures of 75 years, unless otherwise approved by the Regulatory Authority in the relevant jurisdiction. The hydraulic design criteria specified in CSA S6-14 govern requirements for return period-based design floods and other criteria affecting the evaluation of water loads and scour for design. These include requirements for studies and field surveys, and requirements for calculating backwater effects to avoid damages to upstream property and buildings during the design flood. The code stipulates the need for compliance with hydraulic design requirements of the Regulatory Authority (e.g., as set by provincial / territorial government agencies) or, in their absence, the *Guide to Bridge Hydraulics* (TAC 2004).

The two design flood conditions specified in the CHBDC are:

- The *normal design flood*, which has a return period of 50 years, unless otherwise specified by the Regulatory Authority; and
- The *check flood*, which has a return period of at least twice the normal design flood (i.e. 100 years), unless otherwise specified.

The normal design flood and check flood conditions effectively correspond to design conditions for serviceability and ultimate limit states. Bridges must be designed to accommodate the normal design flood without damage to the structure or approach embankments. Bridges must withstand the check flood without endangering the integrity of the structure and without failure of the approach embankments.

Over a design life of 75 years, the 100 year return period has approximately a 53% probability of exceedance. This suggests that check flood (ULS) conditions are more likely than not to be exceeded over the design life of the bridge. By contrast for example, exceedance probabilities based on the design life and return periods specified in the New Zealand Transport Agency's *Bridge Manual* (2016) range from less than 1% to 18%, depending on the importance of the bridge and on whether it is a permanent or temporary structure. The Australian standard for bridge design (AS 5100:2017) targets a 5% probability of exceedance for ultimate limit state actions. In the United States, the 500-year check flood for scour (AASHTO 2014) corresponds to a 14% probability of exceedance over a 75-year design life. On this basis, the minimum standard for the design flood adopted within the CHBDC is substantially lower than for other developed nations.

The CHBDC requires that the soffit elevation of bridge superstructures be determined based on a nominal 1.0 m clearance above the high water level, i.e. the water level associated with the design flood discharge, or the water caused by ice jams with a return period comparable to the design flood. If the difference between water levels associated with the check flood and the design flood exceeds 1.0 m, the implication is that bridge superstructures may be exposed to water loads (and potentially ice loads) during the check flood event. However, the CHBDC does not contain provisions for evaluating hydrodynamic loads on superstructures, only substructure elements. Without evaluating dynamic water loads on superstructures exposed to flood waters, it is unclear how meeting ULS criteria (i.e. integrity of the bridge structure) can be

guaranteed. Updating the CHBDC to include provisions for evaluating dynamic water loads on superstructure elements may therefore be warranted in the future.

Under special circumstances, the CHBDC states that the regulatory flood may be used as the design flood for particular purposes. The regulatory flood standard (i.e. return period) varies by jurisdiction across Canada. Consequently, the use of the regulatory flood for bridge design applications in Canada potentially implies a lack of consistency in the resilience of highway bridges to water loads and scour across provinces and territories.

4.1.2 Water Loads and Scour

Loads and actions categorized as water loads in the CHBDC include hydrostatic pressure, buoyancy, stream pressures, wave action, scour action, and debris torrents.

The CHBDC provisions for evaluating loads arising from stream pressures (i.e. hydrodynamic loads) distinguish between longitudinal and lateral force components on bridge piers, defined by the bridge pier orientation. Both longitudinal and lateral loads are calculated using drag-type formulae, which include force coefficients that depend on the upstream shape of the pier and the angle between the direction of flow and the main pier axis, respectively. A limitation of the approach is that the reference areas in the formulae, and the corresponding force coefficients, are defined based on the axis of the pier, not the direction of flowing water. They are therefore only applicable in cases where the longitudinal axis of the bridge substructure element can be easily determined (i.e. not possible for circular piers or complex piers incorporating piles). Furthermore, the lateral load coefficients provided in the CHBDC imply there are no lateral loads on a bridge pier that is oriented parallel to the flow. This contradicts accepted fluid dynamics theory and observations (Apelt and Isaacs 1968, Sumer and Fredsoe 2006, White 2001), which show that time-varying transverse forces occur as a result of turbulence and vortex-shedding at the downstream end of a structure exposed to moving water. These lateral (lift) forces depend on the wake turbulence regime and the dynamic response of the structural element, and can be substantial. The absence of lateral loads in CHBDC provisions for flow parallel to the main axis of the bridge pier, and the possible underestimation of resultant forces (combining longitudinal and lateral components) is therefore a potential concern that should be addressed in future updates of the CHBDC.

The hydraulic design criteria identified in CSA S6-14 require the evaluation of the depth of general scour, local scour, degradation, and anticipated artificial deepening of the channel at all bridge structure sites. According to the code commentary, the competent velocity method is recommended for evaluating general scour on the basis that it "... has been found suitable for calculating average depths of general scour at bridge crossings in most locations." This recommendation contrasts with guidance in the *Guide to Bridge Hydraulics* (TAC 2004) which suggests that two or more methods should be applied and the results compared. Given the uncertainty associated with empirical methods of evaluating scour, and the overly conservative nature of the competent velocity method in rivers with substantial bedload sediment transport, the recommendation given in the *Guide to Bridge Hydraulics* would seem prudent.

4.1.3 Ice Loads

Clause 3.12 of the CHBDC specifies methods for evaluating freshwater ice loads on bridges. Sea ice loads are not covered and the CHBDC cites the need for specialist advice. The CHBDC distinguishes between various types of ice action at bridge piers: dynamic horizontal loading, static horizontal loading, lateral thrust and vertical forces (due to adhesion or accretion) as follows:

- Dynamic horizontal forces due to collision of moving ice sheets or floes carried by the stream current or driven by wind action (both horizontal and vertical components shall be considered);
- Static forces due to thermal movements of continuous stationary ice sheets;
- Lateral thrust due to arching action resulting from ice dams and ice jams; and
- Static or dynamic vertical forces along the substructure element due to the effects of fluctuating water levels or the dynamic effects of colliding ice floes.

Aufeis (ice that forms on top of lake or river ice from groundwater seepage or land surface water run-off) is not explicitly addressed in the CHBDC. *Aufeis* can have significant impacts including blocking of culverts or relief channels, and thickening of ice upstream of bridge piers. The threat of *aufeis* has been considered through amendments of the CHBDC in the Northwest Territories, by increasing the minimum freeboard for superstructures (Barrette et al. 2017).

4.1.4 Climate Change Effects

The potential impacts of climate change on water loads, scour and ice action are not specifically referenced within CSA S6-14. The code refers to TAC (2004), which identifies the need to consider factors such as climate change that might result in "...increased flood flows, increased sediment yield, and morphologic changes to the river", but does not elaborate or provide further guidance.

4.2 Other Canadian Codes, Standards and Guidelines

The *Guide to Bridge Hydraulics* (TAC 2004) is referenced extensively in the CHBDC. It aims to assist bridge designers by outlining factors to be considered in the location, layout and hydraulic design or re-evaluation of bridges, and by suggesting criteria and procedures. By contrast to the more prescriptive approach given in the CHBDC, the *Guide to Bridge Hydraulics* suggests that the design discharge and design high water levels for a bridge should ideally be based on a trade-off between the initial construction cost and life-cycle operation / maintenance costs. It suggests that economics / risk assessment studies may be warranted for very expensive structures or for important transportation routes. This guidance is consistent with the growing appetite and consensus for risk-based approaches to flood management in Canada and internationally (Jakob and Church 2011, Lyle and Mills 2016).

CSA/ISO 19906 (2011) was developed by the international ice engineering community to provide recommendations and guidance for the design and construction of offshore structures in Arctic and cold regions. Although intended for application to offshore structures, it can be adapted for application to bridge piers in rivers and lakes (i.e. fresh water).

Some provincial and territorial governments have developed amendments or alternatives to provisions in the CHBDC for evaluating and mitigating water loads, scour and ice action at bridges. Examples include: the *Bridge Conceptual Design Guidelines* (Alberta Transportation 2016); the *Bridge Standards and Procedures Manual* (BC MoTI 2016); *Water Control and Structures – Structures Design Manual* (MIT 2011); *Manuel de conception hydraulique des ponts* ("Handbook on the hydraulic design of bridges") (GDQ 2005); and *Bridge Design Criteria* (SMHI 2016). Many of these documents amend or replace hydraulic design criteria and provisions in the CHBDC, such as return periods for design floods and minimum deck clearances.

4.3 International Codes, Standards and Guidelines

AASHTO (2014) provides specifications for the design, evaluation, and rehabilitation of fixed and movable highway bridges in the US. The Specifications include provisions for considering the location of waterway and floodplain crossings that take into account a variety of hydrologic and hydraulic factors, and the goals and objectives of floodplain management.

Unlike the CHBDC, the AASHTO (2014) does not prescribe minimum deck clearances above a design water level. The deck may be inundated during the design flood condition. However, the commentary recommends setting deck elevations as high as practical to minimize inundation and to reduce vulnerability to damage from scour and hydraulic loads. Recommendations are also provided for measures to mitigate the impacts of inundation (e.g., streamlined decks, relief works, river training devices, approaches for avoiding accumulation of ice/debris). Crucially, AASHTO requires the evaluation of trial combinations of highway profiles, alignments and bridge lengths for sizing the bridge waterway. The commentary recommends that these trial combinations should take into account an evaluation of capital costs and flood

hazards for trial alternatives through risk assessment or risk analysis procedures. This differs significantly from the more prescriptive, standard-based approach in the CHBDC.

US Federal Highway Administration (FHWA) regulations require the use of AASHTO specifications and design standards for bridge design (FHWA 2012). However, the FHWA has published a large number of reports and technical guides relevant to the design of highway bridges to resist or accommodate water loads, scour and ice action. The FHWA's Hydraulic Engineering Circulars – HEC-18, HEC-20 and HEC-23 – are the primary sources of guidance and procedures for incorporating scour and stream instability into safe bridge design in the US (Arneson et al. 2012). HEC-18 includes a risk-based scour design philosophy for new bridges, which recognizes needs to factor in the importance of the structure, to provide safe and reliable waterway crossings, and to consider the economic consequences of failure. Prior to the development of these risk-based approaches, all bridges would be designed for scour using the 100-year return period design flood and checked with the 500-year return period check flood, in line with AASHTO Specifications. HEC-18 introduced recommended minimum scour design and check flood frequencies that depend on the hydraulic design flood frequency. HEC-17 provides a multi-level analysis framework for assessing the vulnerability of transportation facilities (including bridges) to extreme events and climate change in riverine environments. It identifies five levels of analysis, recognizing that the appropriate level of complexity should be selected based on the project risks (considering criticality of the infrastructure, vulnerability and cost).

Other codes, standards and guidelines considered in the review included: ASCE/SEI 7-10, ASCE/SEI 24-14 (United States); *Design Manual for Roads and Bridges* (BA 59/94), BS 5400, *Manual on Scour at Bridges and Other Hydraulic Structures* (United Kingdom); EN 1991-1-6 (Europe); *Hydraulic Guidelines for Bridge Design Projects, Bridge Scour Manual, Bridge Scour*, AS/NZ 5100 (Australia and New Zealand); SP.38.13330.2012 (Russia); and *Specifications for Highway Bridges* (Japan).

5 KEY FINDINGS AND OPPORTUNITIES

A review of existing codes, guides and standards identified potential opportunities to enhance Canadian design guidance for assessing water loads, scour and ice actions and related climate change impacts on bridges. These include opportunities to re-evaluate or re-consider criteria and methods for design of bridges and overpasses in Canada, as described in the following sections.

5.1 General and hydraulic design criteria

The probability of the check flood (with a minimum return period of 100 years) being encountered over the 75-year design life of a bridge, as stipulated in the CHBDC, is substantially higher than probabilities reflected in standards adopted by other developed nations for highway bridges. The high likelihood of the design flood conditions being exceeded over the design life should be considered with respect to the potential consequences. For example, the risk that some bridge integrity may be lost could potentially be acceptable for low-traffic or non-critical rural bridge crossings (provided public safety is preserved), or where there is redundancy in the regional roads network, but is unlikely to be acceptable for critical bridges or heavily trafficked thoroughfares in urban areas. National standardization of return periods for design floods applicable to bridges is highly desirable, to ensure consistent levels of resilience to water loads, scour and ice action across Canada. However, this should not preclude considering varying flood / event return periods for hydraulic design that depend on the type and importance of the bridge.

Minimum deck elevation (clearance) requirements could be re-considered to allow designers to explore potential trade-offs between deck elevations and structural strengthening (or other) measures to achieve economical design and performance standards for bridges of different type and importance. However, this would require careful consideration of the potential implications for the resilience of bridges to ice action.

Guidance on evaluating water loads and effects at bridges in coastal and estuarine regions of Canada (e.g., wave loads, storm surge, tides, tsunamis, scour or sea ice action) is needed, and would benefit from existing international guidance and extensive, ongoing research on these topics. This could be achieved through a

review / update of the *Guide to Bridge Hydraulics* (TAC 2004). A re-visit of methods of hazard identification and assessment is also warranted, e.g., to include pluvial and coastal flood hazards.

5.2 Water loads and scour

Canadian guidance on evaluating hydrodynamic loads on bridge piers could benefit from more generalized approaches used elsewhere, for broader applicability to real bridge pier geometries. Importantly, there is a need for provisions that properly evaluate lateral hydrodynamic forces when flow is parallel to the main axis of the bridge pier. Other work to enhance Canadian guidance could include: the development of empirical force coefficients for common bridge pier types in Canada (e.g., pile-supported piers incorporating pile caps); new provisions for evaluating hydrodynamic loads on partially or completely submerged superstructures; and updating / expanding provisions for scour evaluation and design of countermeasures to align with current international best practices.

5.3 Ice action

An improved scientific understanding of ice cover growth and dynamics is of critical importance for bridge designers, especially in the context of a changing climate. Guidance on how to assess the potential for new bridges to promote ice jams is needed. Canadian design guidance could benefit from alignment with certain provisions for ice action in other codes and standards (e.g., ice strength properties and their influence on loads, dynamics of ice-pier interaction, and thermal cycling).

5.4 Climate change impacts

There are currently no provisions in the Canadian Highway Bridge Design Code for assessing climate change impacts on water loads, scour and / or ice action on bridges and overpasses. Understanding climate change impacts on water loads, scour and ice action at bridges/overpasses requires some capacity to predict how climate-driven parameters will change over time. Unfortunately, region-specific projections of many important design parameters under future climate scenarios are either not widely available for Canada, or are not based on the most recent IPCC future climate scenarios. In the absence of such projections for Canada, there remains a need to rely on projected changes in precipitation and temperature, to support high-level inferences on the potential impacts of climate change on water loads, scour and ice action on Canadian bridges and overpasses. This approach has significant limitations.

One approach that has been taken to support adaptation of infrastructure in other countries and in some parts of Canada is to use an ensemble of climate model predictions as the basis for developing estimates of future water hazards under various climate change scenarios (e.g., Hulme et al. 2002), and a similar approach could be adopted more broadly for Canada (to include ice hazards). Although the scale and variability in regional climatology and flood-generating processes make this a challenging task for Canada, there are clear benefits in terms of supporting cost-effective adaptation measures. An alternative would be to develop a multi-level framework for assessing climate change impacts on Canadian bridges, which could allow for a range of study complexities depending on project risks (criticality of infrastructure, vulnerability and cost).

5.5 Climate change adaptation

Climate change adaptation through design of bridges and overpasses may involve resilience-building and / or measures to reduce vulnerability to extreme events. Many design strategies (e.g., designing bridges to withstand flows greatly exceeding the design flood discharge without catastrophic failure, “perching” of bridges, restraining superstructures to prevent uplift, measures to facilitate speedy return to service following overtopping) are already common practices abroad, and some have been adopted in parts of Canada. However, they are not yet reflected in Canadian design guidance.

Field data on the performance of existing bridges can play a vital role in informing adaptation strategies. The development and maintenance of a national bridge database, similar to existing databases in the US

and other countries, would be a significant step towards improving design guidance and the resilience of Canadian bridges to water loads, scour and ice action in a changing climate.

Acknowledgements

The authors wish to thank the C-RB&CPI Project Manager, Marianne Armstrong, for supporting this research. That authors' appreciation is also extended to Sarah Gagné for providing project co-ordination support, and to Raissa Plechtchenko for assistance in obtaining access to research literature. Infrastructure Canada is also gratefully acknowledged as a C-RB&CPI project partner.

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