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APEGBC PROFESSIONAL PRACTICE GUIDELINES - DEVELOPING CLIMATE CHANGE-RESILIENT DESIGNS FOR HIGHWAY INFRASTRUCTURE IN BRITISH COLUMBIA (INTERIM)

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Abstract: The Association of Professional Engineers and Geoscientists of British Columbia (APEGBC) has developed professional practice guidelines that provide practice guidance and case studies to support engineers in addressing climate change and extreme weather event factors in the designs for BC Ministry of Transportation and Infrastructure (BCMoTI) owned provincial highway infrastructure. These guidelines are developed in response to the BCMoTI Technical Circular (T-06/15), which requires infrastructure design adaptation to climate change including documentation for BCMoTI projects. Highway designs already consider climatic factors, but extreme weather resiliency and climate change adaptation are being increasingly considered by professionals, based on the guidance provided by frameworks established by Engineers Canada and the American Society of Civil Engineers. These guidelines showcase the climate science as it relates to the practice of professional engineering and aims to spark a paradigm shift in engineering by supporting the development of designs based on a comprehensive climate vulnerability risk assessment and consideration of innovative approaches that include robust, flexible and low or no regret designs.

1 INTRODUCTION TO THE GUIDELINES

In response to the demand for engineering services that include the consideration of extreme weather events and climate change from BC Ministry Transportation and Infrastructure expounded in their Technical Circular (T-06/15) titled “Climate Change and Extreme Weather Preparedness and Resilience in Engineering Infrastructure Design” published on June 22, 2015, the Association of Professional Engineers and Geoscientists of BC has developed a set of professional practice guidelines that provides a framework in which BC engineering professionals can provide services while meeting an established standard of practice in addressing climate change. Since these guidelines in response to the BCMoTI Technical Circular, these guidelines will be applicable only to those professionals who submit designs to BCMoTI at this time. These guidelines are issued as interim, as it is expected these guidelines will be reviewed based on the experience gained in their application, and revised as appropriate.

Historically, infrastructure has been designed in accordance with the relevant codes and standards based on assumptions of stationarity in climate i.e., past climate being a good predictor of future climate. But various indications (Fraser 2015, IPCC 2014, Milly et al. 2008) and recent experiences with changes in extreme weather conditions indicate that historical climate cannot be relied upon for designing infrastructure expected to withstand the forces of a climate that is changing significantly. Tools and resources to enable practitioners to incorporate climate change and extreme weather resilience in highway infrastructure design are evolving and improving. To prepare a set of guidelines that addresses these issues, a steering committee was formed consisting of members from the Association of Consulting Engineers of Canada's Subcommittee for Engineering Adaptation for Climate Change (BC Chapter), members of the APEGBC's Climate Change Advisory Group, Engineers Canada, practicing consulting engineers, a climate scientist from Pacific Climate Impacts Consortium (PCIC), and staff from BCMoTI. The steering committee identified that while adaptation to a changing climate is imperative, to address the technical and knowledge gaps, these guidelines must seek to introduce concepts relating to climate change resilience and to provide a structured approach to decision making and record keeping.

The specific objectives of these guidelines are to:

1. Outline the professional services of an Engineer of Record (EOR) carrying out climate change-resilient design of highway infrastructure in BC.
2. Outline the professional services to be provided by a qualified professional (or EOR if they are sufficiently trained) conducting climate vulnerability risk assessments on highway infrastructure in BC.
3. Describe the suggested standard of care to be followed when a qualified professional is providing professional services related to conducting risk assessment of highway infrastructure in BC.
4. Specify the tasks that should be performed by the qualified professional and/or EOR to demonstrate that climate change has been considered in the design of the highway infrastructure and demonstrate that their obligations under the *Engineers and Geoscientists Act* (the *Act*) have been met. These obligations include the duty to protect the safety, health and welfare of the public and the environment.
5. Describe the roles and responsibilities of the various participants/stakeholders involved in carrying out climate change-resilient design of highway infrastructure and risk assessment.
6. Describe the record keeping and other quality management processes to be followed when conducting risk assessments of highway infrastructure.
7. Provide consistency in the approach to risk assessments including the relevant reports and other documents prepared when providing professional services in this field of practice and;
8. Describe the typical knowledge and the responsibilities that professionals take on when providing services related to conducting risk assessments.

2 GUIDELINES FOR PROFESSIONAL PRACTICE FOR HIGHWAY INFRASTRUCTURE CLIMATE CHANGE-RESILIENT DESIGN

Professionals who design highway infrastructure already consider climatic factors – either explicitly or implicitly. It is important to acknowledge that historical climate records will continue to play a vital role in the development of climate design values. Design professionals currently account for uncertainty by establishing design event or threshold criteria, then applying safety factors. From an engineering perspective, future climate projections are considered to carry greater uncertainty than that associated with historical climate records. These factors make it imperative to conduct a risk assessment as part of the highway infrastructure design process.

Future climate projections are considered to carry greater uncertainty than that associated with historical climate records due to the large range of values generated by the full ensemble of Global Climate Models contrasted with the need to select values for design. The fact that climate science is still evolving, especially with respect to projecting extreme precipitation at a sub-daily level, reduces confidence in the projected values. All of this combines to create a perceived increase in risk, which must be acknowledged and managed. Note that there is potential for secondary impacts from climate change, such as changes to resource availability and demographics. These impacts should also be considered, but are not the focus of these guidelines since they may affect the viability of a project rather than the actual design. The following sections, as discussed in these guidelines, provide a framework for professional engineers to have a common approach to consider climate impacts (see Table 1 for the suggested standard of care to be followed) while designing BCMoTI owned highway infrastructure.

2.1 Define the project

It is critical to establish the context within which climate risks can be evaluated, and adaptation measures can be developed and integrated into the design.

2.1.1 Characterizing the Project Location and Identify Infrastructure

Project location encompasses more than just the coordinates of the project extents. It provides the context for determining what infrastructure is to be constructed and what climate-based events are likely to occur. Different location characteristics also contribute to different potential risks. It is essential, therefore, to fully characterize the project location in a way that identifies and communicates climate-related issues that must be addressed through design.

It is also useful to list the key infrastructure components to be designed and constructed. Great detail is not required at this stage of the project, but it should be sufficient for team members to fully understand project elements. Any infrastructure component that has some likelihood of being constructed should be included in the project definition. This will provide a broader context for identifying climate parameters later in the process.

2.1.2 Identify Non-Climate Design Drivers

Depending on the specific project, and especially on its design service life, some non-climate drivers likely have the potential to be impacted by climate change. Identifying these issues as part of the project definition could be useful when determining what, if any, design changes will be incorporated into the project in order to address risks posed by climate change.

2.1.3 Identify General Climate Parameters

It is important to recognize that the general climate parameters that are typically used during design of the subject infrastructure may directly impacts other design values. Identifying all pertinent climate parameters, even those that indirectly impact the design is imperative.

2.1.4 Define the team and Identify Stakeholders

Regardless of project scale and scope, it is essential that all involved are aware of potential impacts of climate change and corresponding potential implications for design. Early in the project, the EOR should list the key team members and stakeholders, as well as their roles. To consider climate change impacts, the team should be expanded to include qualified professionals and specialists with respect to climate projections, risk assessment, climate adaptation, and risk based design.

2.1.5 Define Assessment Time Horizons

Highway infrastructure projects can have relatively long service lives, typically 50, 75, even 100 years. Depending on the climate parameter under consideration, the range of values projected using different GCMs may also increase as the time horizon is extended. The combination of infrastructure longevity and corresponding potential increase in the range of plausible future climate parameter values makes it important to identify the service life of the components and systems that comprise the proposed highway infrastructure.

2.2 Conduct Climate Change Vulnerability Risk Assessment

The risk assessment addresses the first part of risk management: identifying and evaluating the risks. The qualified professional should have a reasonable level of competence in risk assessment – particularly with respect to the impacts of climate change.

Table 1: Table outlining suggested standard of care as defined in these guidelines for a qualified professional conducting a risk assessment

Project Details	Professional Considerations
Project Scope	• Identify if an owner-defined risk tolerance is available and if not, seek to engage with the owner to establish their risk tolerance • Establish owner-defined time horizon for the infrastructure
Project Team	• Assemble qualified team in collaboration with the owner
Regional Climate Projections	• Could be developed by a climate specialist • A range of Representative Concentration Pathways (RCP) or equivalent Special Report on Emission Scenarios should be used to generate regional climate projections • An ensemble of models should be used to generate regional climate projections. For example, the top 3 climate models for Western North America as indicated by PCIC are CNRM-CM5-r1, CanESM2-r1 and ACCESS1-0-r1 (PCIC 2013) • Design should be based on existing codes and standards, but future climate projections for the time horizon identified should be used in place of climate data referred to in the codes and standards
Background Information	• Sufficient fieldwork should be conducted by the qualified professional and their team • The qualified professional should review available and collect additional background information
Climate Adaptation Method	Explore the following adaptation methods: • Robust design that makes the infrastructure resilient to a wide range of future climate projections is preferable • Flexible design that includes redundant systems or has the capacity for design components to be changed in the future • Status-quo design that recognizes that implementing no explicit adaptation measures is a valid response • If appropriate, revisit adaptation options after a time period agree with the owner
Highway Infrastructure Climate Change-resilient Design Report	• Convey in plain language, the climate change risks associated with status-quo emissions scenarios (for example, RCP 8.5) to the owner to enable decision-making • Address the frequency of re-assessment and monitoring required (also includes collection of climate data appropriate for the location to inform future design)
Project Documentation	• The findings of the risk assessment and any assumptions made need to be fully documented and clearly communicated to the owner to demonstrate compliance with the intent and objectives of these guidelines • Climate model ensemble used • Vulnerability risk assessment tool (and version), if applicable

2.2.1 Define Objectives

Specific objectives that must be met by the design with respect to capacity, safety, reliability, and longevity should be identified to ensure that appropriate information is included in the climate risk assessment. These are the elements that contribute to the risk tolerance of the owner.

2.2.2 Select Risk Assessment Method

Several risk assessment methods have been developed by various organizations. At their core, climate risk assessments are comprised of the following:

- A list of infrastructure components
- A list of specific climate parameters
- A matrix showing the combinations of listed infrastructure components and specific climate parameters. The matrix identifies the infrastructure component/climate parameter combinations where there is some potential for the infrastructure component to be negatively impacted by a change in the climate parameter.
- Assignment of a numerical likelihood that each identified matrix interaction will occur
- Assignment of a numerical severity rating to each potential interaction in the matrix, should the interaction occur
- Calculation of risk (product of severity rating and likelihood value) for each matrix interaction (see Figure 1)

Figure 1: Example Risk Matrix

Severity								
7	0	7	14	21	28	35	42	49
6	0	6	12	18	24	30	36	42
5	0	5	10	15	20	25	30	35
4	0	4	8	12	16	20	24	28
3	0	3	6	9	12	15	18	21
2	0	2	4	6	8	10	12	14
1	0	1	2	3	4	5	6	7
0	0	0	0	0	0	0	0	0
	0	1	2	3	4	5	6	7

Probability

Special Case	Low Risk	Medium Risk	High Risk

A well-known climate risk assessment protocol in Canada is the Engineers Canada Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol for Climate Change Infrastructure Vulnerability Assessment (www.pievc.ca). Another tool that is especially applicable to assessing climate change risk for transportation infrastructure is the US Department of Transportation Federal Highway Administration's (FHWA) Vulnerability Assessment Scoring Tool (FHWA 2016) (VAST). It is a "spreadsheet tool that guides the user through conducting a quantitative, indicator-based vulnerability screen." The tool can be downloaded and used without further interaction with FHWA. This ease-of-access makes the tool useful for smaller or less complicated design projects. It can be applied to large or complicated design projects also, but lacks some of the elements of the PIEVC protocol, such as team development and documentation, that might prove useful.

2.2.3 Select Infrastructure Components

The climate risk assessment relies on selecting appropriate infrastructure components. Components may be defined individually, or as a group, or as both if the situation warrants. Listing individual infrastructure components may yield a more detailed risk assessment, but with extra effort and cost. The ability to select and group infrastructure components likely to be sensitive to climate change comes with experience, but it might be useful to review assessment reports based on the PIEVC protocol for examples of how infrastructure components have been defined for similar projects.

2.2.4 Select and Define Specific Climate Parameters

It is useful to list the specific climate parameters that are explicitly and implicitly used in the design process for components. The qualified professional should work with climate experts to determine the appropriate parameters and corresponding values to include in the risk assessment. The qualified professional should also engage climate specialists in discussions of how the climate values will be used to ensure that the information provided is suitable for the intended purpose. Climate specialists may identify climate parameters that previously have not been considered as a design parameter. The key concept to remember is that by working with climate specialists and other experts, the qualified professional is more likely to identify the appropriate specific climate parameters to use for the vulnerability risk assessment, and is also more likely to obtain accurate values that reflect projected climate conditions.

2.2.5 Identify and Characterize Infrastructure/Climate Interactions

For each combination of listed infrastructure component and climate change parameter, the qualified professional and assessment team must determine what type of interactions might occur should the climate event happen. At this point in the climate risk assessment, the only task is to identify potential interactions between each infrastructure component and each climate change parameter. Each risk assessment method specifies the format and process for characterizing and documenting the interactions between each infrastructure component and specific climate parameter.

2.2.6 Define Risk

Risk is a measure of how vulnerable a design component is to negative impacts of climate change. From a design perspective, a negative impact can be considered a failure of the design component– either physically or in terms of performance criteria. Risk is a function of two attributes: the Probability, or likelihood of the failure to occur, and the Severity of the consequences should the failure occur. Each risk assessment method provides specific guidance on how to define the scoring system. For example, scores could range from 0 to 7 for both “zero to high likelihood” and for “no to high severity”.

The Climate Change Vulnerability Risk Assessment has well-defined components that include:

i) Screening of the interaction
ii) Vulnerability Analysis or Assessment
iii) Engineering Analysis

2.2.6.1 Conduct Screening-level Risk Assessment

A screening-level risk assessment (screening risk assessment) is the first step of a climate vulnerability risk assessment conducted to help the qualified professional determine if a more comprehensive climate vulnerability risk assessment is required. This contains a yes/no determination if there is an interaction between infrastructure components and climate and thus potential vulnerability.

2.2.6.2 Conduct Risk Assessment

Once the potential interactions between the selected infrastructure components and defined climate change parameters have been determined, the risk assessment is completed by:

- Assigning a likelihood of each interaction occurring
- Assigning a severity score describing the consequences of the interaction occurring
- Calculating a risk score as the product of the likelihood and severity score

In mathematical terms, risk = likelihood x severity.

It is important to determine the likelihood and severity scores independent of each other. The qualified professional cannot allow perceived severity to influence the assigned likelihood for a given interaction. The reciprocal is true for perceived likelihood influencing the assigned severity score.

2.2.6.3 Evaluate Climate Risk Assessment

Quantifying risk associated with each of the infrastructure component/climate parameter interactions forms the basis for developing strategies to manage these risks. Infrastructure with low risk scores that are the product of low likelihood and low consequence scores can usually be designed without further consideration of climate change. Infrastructure components that garner "medium" risk scores may be candidates for flexible design, or may be evaluated further to determine if additional assessment, such as using engineering analysis, is required to clarify risk and identify appropriate adaptation measures.

2.2.6.4 Conduct Engineering Analysis

A key reason to conduct engineering analysis is to clarify the level of risk associated with a particular infrastructure/climate interaction, particularly when the initial assessment does not yield a clear vulnerability risk score. Typical triggers for an engineering analysis may include a medium risk score that generated significant team debate, interactions that tend to exhibit vulnerability regardless of risk score, or insufficient data to make a definitive assessment.

2.2.6.4.1 Hydrotechnical Analysis

Hydrotechnical analysis is conducted to support the design of bridges and large culverts for highway projects, as well as piers, jetties and erosion protection for ports. Most, if not all, of the climate data required to conduct hydrotechnical analysis are used indirectly. Modeling climate change impacts for every infrastructure design project may not be necessary since some of this work is ongoing and potentially available from many sources.

2.2.6.4.2 Geotechnical Analysis

Geotechnical analysis is conducted to support the design of roads, bridge piers and abutments, retaining walls, and rock-fall protection. Changes in the average and extreme values of precipitation and temperature, including frequency and duration of events, can have a significant impact on geotechnical design. These should be identified and considered as part of any geotechnical analysis in order to support climate change resiliency in infrastructure design.

2.2.6.4.3 Structural Analysis

Structural analysis is conducted to provide design values for a variety of materials and performance objectives. Loads are at least partially a function of wind, precipitation, and temperature (snow and ice).

Durability of the structural components, or at least their protective coatings, may be subject to changes in temperature, solar radiation, and moisture. Many of these climate parameters are applied to structural design implicitly rather than directly, because they are embedded into the various codes that are typically used.

2.3 Identify and Incorporate Adaptation Options

For the purposes of these guidelines, “adaptation” refers to any action that reduces the vulnerability of proposed infrastructure to the impacts of climate change. Infrastructure that is designed and constructed using an adaptation method is considered resilient to climate change for specified requirements.

2.3.1 Apply Professional Judgment

These guidelines should not be interpreted to mean that the professional, specifically the EOR, must become an expert on weather and climate issues. Rather, the expectation is that the professional will, as part of their normal practice, determine where climate information is embedded in codes, standards, and assumptions and evaluate how the information is applied in their professional work.

2.3.2 Identify Adaptation Options

Three categories of adaptation measures that could be applied to the infrastructure design process:

Status-Quo Design: Status-quo design recognizes that implementing no explicit adaptation measures is a valid response, provided that the qualified documents the reason or reasons that this is done.

Flexible Design: Flexible design is based on the assumption that there will be opportunities to adapt in the future.

Robust Design: Robust design has the objective of ensuring that the proposed infrastructure will perform as expected over a range of possible future climate conditions, including the “worst case” design scenario.

2.3.3 Communicate Effectively

Since language used to communicate concepts and principles can be interpreted differently by practitioners in different disciplines, it is essential that team members are aware of the potential for misunderstanding, and that they take steps to ensure that what is communicated is understood as intended. In addition, highly technical information must be communicated to decision-makers, some of whom have little or no technical knowledge or experience. BCMoTI, along with contributions and support from other organizations, has published a document (BCMoTI, 2014) that addresses this issue within the context of climate and climate projections.

2.3.4 Finalize Adaptation Plan and Resilient Design Measures

Once the resilient design measures have been identified and organized into options, they must be presented to the owner and other appropriate decision makers. The goal of this action is to select the adaptive measures that will be incorporated into the final design. The selected adaptation measures should be documented, along with any discussions that justify their selection.

2.4 Document Process and Decisions

It is critical to document key information associated with incorporating climate change resilience into the highway infrastructure design process. In addition to fulfilling the QA/QC requirements of the APEGBC Quality Management bylaws, For BCMoTI projects, the qualified professional is to complete an assurance statement and submit it with the report. The EOR is to also ensure that the BCMoTI Design Criteria Sheet for Climate Change Resilience is completed and submitted as required by BCMoTI in the Technical Circular.

3 CASE STUDY

While numerous case studies and examples have been provided in an appendix to these guidelines, in a BCMoTI's project to construct a new bridge across the Salmon River near Salmon Arm on Highway #1, a hydrotechnical analysis was conducted in which climate change impacts on the watershed were assessed based on climate change projection data were obtained from PCIC. This project used daily streamflow results projected to year 2098 for 23 different climate change scenarios and they indicated an increased strain on flood protection infrastructure; and reduction in the projected annual maximum freshet streamflow relative to the base scenario for all projections and an increase in extreme events. To account for the uncertainties in the climate change estimates, there was a 10% upward adjustment in the design of the bridge.

4 PROFESSIONAL REGISTRATION; EDUCATION, TRAINING AND EXPERIENCE

4.1 Professional Registration

A professional engineer who is engaged in work related to public infrastructure is typically registered with APEGBC in the discipline of geotechnical, structural, civil, or hydro-technical engineering. Not all professional engineers registered in the disciplines noted above are necessarily appropriately knowledgeable in risk assessments. It is the responsibility of the professional engineer or professional geoscientist to determine whether they are by training or experience able to undertake and accept responsibility for climate change vulnerability risk assessments as a qualified professional or for the climate change-resilient design of highway infrastructure as the EOR.

4.2 Education, Training and Experience

The minimum skill sets and competencies for an APEGBC member to act in the capacity of a qualified professional:

- Should have worked in a multi-stakeholder team in conjunction with the owner to conduct climate vulnerability risk assessments
- Should be able to work with a climate specialist to acquire the appropriate regional climate data projections
- Should be able to use regional climate data projections in a risk assessment
- Should be able to recommend adaptation methods for design of the highway infrastructure based on the risk assessment
- Should be able to clearly document the results of the risk assessment to communicate the risks due to climate change to the owner

5 CONCLUDING REMARKS

To recognize the nature and severity of climate change effects on infrastructure and to address its economic, environmental and social impacts it is imperative that engineers need to be preparing for and responding to climate change. Incorporating climate change data in their decisions and practices will aid in protecting valuable infrastructure assets. Designing highway infrastructure to increase its resilience to the impacts of future climate conditions is one of the ways professionals can contribute to making it more resilient. Specifically tailored to be applicable to provincial highway design projects, these guidelines facilitate the consideration of climate change and other extreme weather event impacts into the Engineering design work by BCMoTI staff and other engineering design consultants working on BCMoTI projects. In addition, it is recognized that the uniform implementation of a suggested standard of care along with an established quality management process providing climate change resilience services would enable clients, stakeholders and various levels of government to work together for the protection of public safety and the environment. APEGBC recognizes that development of this initial version of practice guidelines, which has been endorsed by the APEGBC Council, as the first of many iterations. As more information becomes available and experience with climate change and adaptation is gained, these guidelines will be revised and updated to influence professionals to contribute towards the development of climate resilient infrastructure through their professional practice.

6 ACKNOWLEDGEMENTS

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