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ADAPTING CSA MASONRY STANDARDS TO CLIMATE CHANGE: PART 2 - CONCLUSIONS AND RECOMMENDATIONS

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ABSTRACT

The CSA Group has collaborated with the Canada Masonry Design Centre and York University to review current Canadian masonry standards for adaptation to climate change. An extensive and comprehensive review of current, formative research literature, best practice guides and international standards was conducted. Consultations with masonry industry stakeholders and academics provided guidance in the development of recommendations to standards committee members in view of the next cycle of updates to standards. Part 1 of this two-part paper discusses various avenues by which climate change is expected to affect the way in which masonry structures are designed and built. In this Part 2 paper, several proposed changes to current Canadian masonry standards are discussed, highlighting their potential impacts on design and construction practices, as well as on the masonry industry. Proposed changes include new methods for assessing requirements for corrosion protection for masonry connectors, and guidance on achieving the energy efficiency targets outlined in the National Energy Code for Buildings. Research needs are also identified in view of providing better guidance to designers on the quantification of expected durability and service life of masonry materials and related elements.

KEYWORDS: c*limate change, durability, building science, CSA standards, freeze-thaw, moisture index, concrete*

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INTRODUCTION

Climate change in Canada is affecting many aspects of our built environment. The financial cost attributed to weather-related disasters in Canada was estimated at $14.5 billion for the period from 2010 to 2019 alone [1], constituting a three-fold increase in the average from the four previous decades. Changes to other climatic conditions such as average temperature and annual rainfall will also have an impact on the long-term durability of certain structures. The various documents that dictate how and where we build (codes, standards, bylaws, etc.) are being modified to adapt to the effects of climate change. Although masonry structures are generally well adapted to severe climate conditions (masonry materials are typically strong, abrasion resistant, and fire-resistant), projected increases in temperature and changes to rain patterns [2] may accelerate the deterioration of certain structures in certain locations. Moves to decrease energy expenditures and carbon emissions to mitigate further climate change are also driving innovation in materials and building sciences. However, detailed research will be needed to ensure these innovations are appropriately integrated into our built systems.

In response to an earlier analysis of its inventory of standards, the CSA Group initiated a project with the Canada Masonry Design Centre and researchers from York University to examine CSA's complement of masonry standards. The resulting report on adapting masonry standards to climate change [3] includes a detailed literature review and a discussion of recommendations; the present 2-part paper summarizes key elements from that report. The report was informed, in part, through consultation with masonry stakeholders and experts. The Part 1 paper [4] provides additional background information and highlights of the literature review on the effects of climate on masonry materials and structures.

DISCUSSION AND RECOMMENDATIONS

Following the review of relevant literature [3], and consultation with key stakeholders, a series of recommendations were developed. These recommendations are based on evidence and practices adopted in other jurisdictions (specifically in the U.S., U.K., and Australia) or for other materials/construction types in Canada.

Corrosion

Requirements for the mitigation of corrosion of steel components and other moisture-related deterioration mechanisms are included in several materials and structures standards; however, the use of the annual Driving Rain Index (aDRI) in CSA A370-14 *Connectors for* masonry [5] as the main criteria for determining corrosion protection requirements appears to be unique. Masonry standards in countries other than Canada specify corrosion protection requirements based on the application or location within a structure without considering climate. For example, the EuroCode 6: *Design of Masonry Structures* [6] defines corrosion protection requirements based on the type of use and exposure of a masonry element. A related approach is in use in Australia and New Zealand, where masonry ties are rated based on the proximity to a coastline. In the U.S., TMS 402 [7] indicates only that wall ties should be galvanized or epoxy-coated or made from stainless steel.

The Brick Industry Association offer additional guidance in a technical note [8], indicating that different levels of protection may be needed depending on whether a metallic element is fully embedded in mortar or grout, exposed to an air space, or exposed in a corrosive environment.

In Canada, other materials standards also refer to usage and exposure categories when specifying corrosion protection requirements. For example, CSA A23.1:19 *Concrete materials and methods of concrete construction* [9] defines exposure classes related to moisture, chlorides, freeze-thaw action, sulphate, or harsh chemicals. CSA S413-14 (R2019) *Parking structures* [10] introduces additional options to help mitigate the risk of corrosion of steel reinforcement such as the introduction of a waterproofing membrane, corrosion inhibiting admixtures, chloride resistant concrete, or a sealer, and the use of other alternatives such as cathodic protection. CSA S6:19 *Canadian highway bridge design code* [11] indicates that reinforced concrete durability may be achieved through the use of concrete covers (the thickness of which is dictated by the type of member), by avoiding alkali aggregate reaction (AAR), and ensuring proper curing. For wood bridge construction, wood preservation techniques are prescribed regardless of member type or local conditions. Corrosion protection requirements for steel fasteners and connector plates are dictated solely by their type and the aggressivity of the wood preservation chemical used. For structural steel bridges and bridge elements, corrosion protection requirements are based on the type of structural element and the exposure to moisture, chlorides, or an industrial atmosphere; the use of weathering steel, coatings, metallizing, galvanizing, or greasing (for rollers and rockers only) are listed in the types of protection requirements. CAN/CSA O80 SERIES-15 (R2020) *Wood Preservation* [12] defines categories for wood products related to exposure to moisture, soil or fresh water, or salt water, and their use.

None of the codes or standards reviewed provide direct guidance for the quantification of expected durability or service life of structural elements based on environmental exposure. However, given the requirements of CSA S478:19 *Durability in buildings* [13], designers will increasingly require such guidance to ensure durability targets are met. Masonry ties and other metallic elements are difficult to inspect in service; therefore, quantification of the durability performance (expected lifespan) is required. Sophisticated methods based on hygrothermal modelling of masonry wall systems, time of wetting analysis, and ISO corrosion models may be needed to achieve this. Special attention will be needed to account for the effects of climate change as regionally applicable practices that account for the uncertainties of climate over the expected service life of masonry buildings are refined.

As shown in Figure 1, the aDRI has increased in Canada's most populous cities over the past 30 years (Historical (1990 – 2020) annual rainfall (mm) and average annual windspeed (km/h) data collected from the Government of Canada (https://climate.weather.gc.ca/) via the website WeatherStats (www.weatherstats.ca)). The increasing trends for Toronto, Montreal, and Calgary, for that period, are all significant at the 5% level (using the t-test). The aDRI values listed in CSA A370 Annex E [5] should therefore be reverified, including considerations for future ongoing changes to aDRI values by region. The latest Government of Canada report on Climate-Resilient

Buildings and Core Public Infrastructure [14] indicates that annual precipitation and windspeed are both projected to increase under multiple climate change scenarios. The list of locations for which an aDRI value is provided should also be revised to ensure adequate guidance is available for major urban centres.

Figure 1: Recent trends in calculated aDRI (adapted from [3])

Given the technical challenges associated with maintaining updated climate data within a CSA standard, other criteria may be considered for establishing minimum levels of corrosion protection. The National Building Code of Canada's (NBCC) Moisture Index (MI) [15] values currently have a reasonable correlation to the aDRI values from CSA A370:14 (R2018), *Connectors for masonry*, as shown in Figure 2, and may be considered for such an application. Further research would, however, be needed to establish a correlation between corrosion rates within masonry wall cavities and MI.

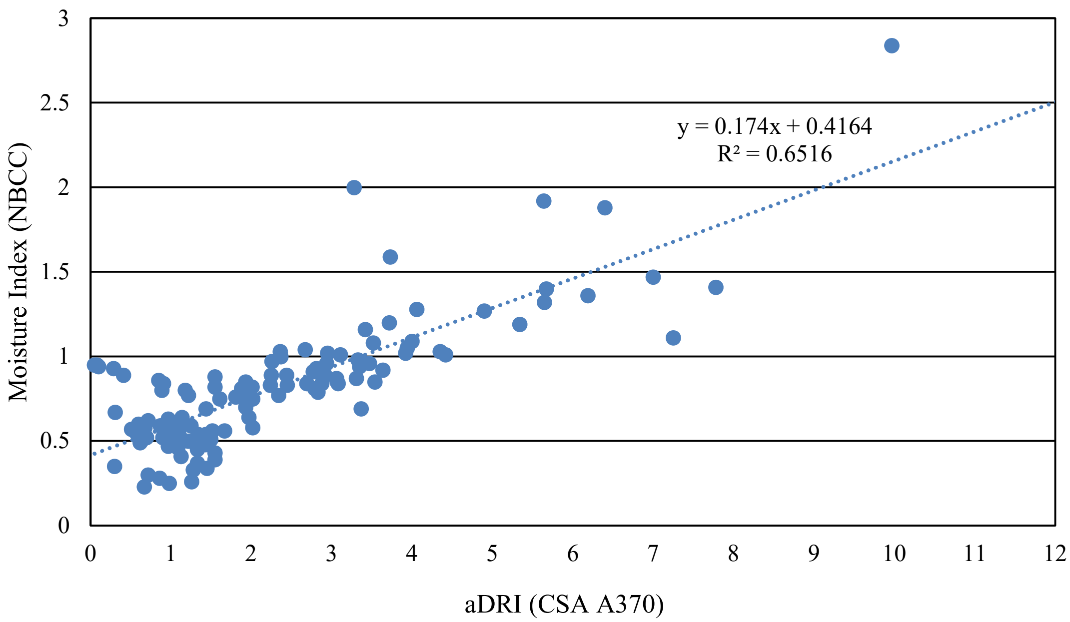

Figure 2: Plot of the MI [15] and aDRI [5] for Canadian cities listed in CSA A370:14 (R2018) (adapted from [3])

Finally, interpretation of the current formulation establishing minimum levels of corrosion protection in CSA A370 is onerous. Delineation of protection requirements related to exposure and those related to climatic conditions could provide better clarity to this section of the standard. If new materials or coatings or additional categories of corrosion protection are added to the standard (e.g., epoxy coatings, ties which include polymer thermal breaks, or ties made entirely or in part from polymers or fibre-reinforced polymers), their recommended use relative to climate and exposure conditions will need to be specified. Similar revisions to the guidance provided for corrosion protection for metallic elements in S304-14 (R2019), *Design of Masonry Structures* will also be needed.

Strength and Spacing of Ties

CSA A370 specifies the minimum strength for masonry ties and wall anchors. In both cases, the designer must ensure that any loads applied to a wall or veneer can be effectively transferred through the tie or anchor to the supporting element. Rather than specifying a minimum strength, the U.S. standard TMS 402 prescribes a minimum gauge (steel wire diameter or sheet thickness) for masonry ties. Other international standards provide a wider variety of strength categories depending on use. In Australia and New Zealand, AS/NZS2699.1 identifies three classifications of masonry ties with different specified minimum characteristic strength (Light duty 0.2 kN, Medium duty 0.4 kN, Heavy duty 1.0 kN). In the UK, seven tie types are available, in conformance with PD6697 or BS 5268-6.1, with different minimum declared compression and tensile load capacities. Limited discussion is available in the literature on a justification for implementing a minimum strength for individual ties or anchors, other than ensuring sufficient capacity exists to transfer loads from the wall to its support.

Similarly, the spacing of ties must also be controlled to ensure they can transfer applied loads to the supporting structure without failure in the veneer spanning between ties. The maximum tie spacing in CSA A370 corresponds closely to that in TMS 402, however other jurisdictions have different restrictions. For example, the Eurocode 6 – *Design of masonry structures* [16] indicates that the combined strength of the ties in a given area should be greater than or equal to the applied loads for that area. However, the UK's National House Building Council (NHBC) specifies a maximum horizontal spacing of 900 mm and maximum vertical spacing of 450 mm [17]. In Australia, technical guidelines indicate that tie spacing should not exceed 600 mm in either orthogonal direction [18], and some manufacturers recommend different tie spacing depending on the grade of the tie (normal- or heavy-duty), and environmental factors, such as windspeed.

As stricter energy targets drive a need to reduce thermal bridging, increasing the spacing between ties may be an effective method for achieving this. Given the performance of connectors in extreme weather events [19] [20] and laboratory testing [21], current standards for minimum strength and maximum spacing of ties appear to be conservative. Additional research is needed to determine if masonry veneers can be permitted to span longer distances between stronger supporting ties.

Masonry Cracking and Moisture Penetration

Several potential causes have been identified for masonry cracking; these include differential settlements, expansion/contraction of building elements, overloading of a structural element, etc. [22]. Cracking may also occur due to insufficient stiffness of supporting elements such as back-up walls or ties. Multi-component adjustable ties (e.g., eye and pintle type) are used in Canada and the U.S. to accommodate differential movements between a masonry wall and a back-up structure; however, some of these have been shown to exhibit different stiffness values depending on their position within the range of adjustability. Tests performed on masonry veneer walls indicate that the stiffness of the back-up wall does not have significant influence on the cracking load of the veneer, but that increased stiffness of the support (tie and back-up wall) could play a role in minimizing crack width [23]. The effect of veneer cracking on overall wall permeability and durability remains a subject of contention.

Although very fine cracks are unlikely to increase the permeability of masonry veneers, and large cracks and open joints can lead to excessive ingress of free water, it is not clearly defined how cracks in the range of 0.1 mm to 2 mm impact the durability of ties and other detailing elements of a masonry wall. Further research is required to establish the relation between supporting structure stiffness and masonry veneer crack width, and between crack width and moisture penetration. Such relations will be critical to detailed hygrothermal analyses for lifecycle assessment (corrosion, freeze-thaw deterioration, etc.).

CSA A370:14 (R2018) includes informative annexes on moisture penetration and corrosion (Annexes C and D); however, these could benefit from being updated and expanded. Methods of accurately determining the service lifespan of ties are emerging, and the various influences of climate change on service life are becoming clearer. References to the latest research and literature could be included as important guidance for designers on how to demonstrate that their designs conform to the durability targets specified in CSA S478:19 *Durability in buildings*. For example, stormwater pH, concentration of SO_2, the rate of chloride deposition, and time of wetting (TOW) have been used following ISO methods to accurately estimate the corrosion rate of masonry connectors [24]. Additionally, tools for quantifying moisture ingress through various means (infiltration through porous mortar or masonry units, infiltration through cracks, moisture entering through openings) to assist in hygrothermal modelling are needed. Such determination of expected service life is needed due to the wide range of building-owner expectations, and other requirements for minimum service life for buildings and components. Materials and detailing that may work adequately for a building with an expected service life of 25 years may not be appropriate for structures that are expected to last 50 years. Conversely, it would not be economical to require all buildings to adopt the most stringent available moisture protection and corrosion resistance systems (for example, it would be difficult to justify requiring 50 years of corrosion protection for a building with an expected service life of only 25 years). However, designers must have the tools to accurately assess the service life of the various components of a structure, and determine that the constructions methods and materials are appropriate for the required service life.

Freeze-Thaw Durability

Several resources are available to quantify the durability of concrete materials, including resistance to deterioration due to freeze-thaw cycling. Tests for air content and air-void system parameters are cited in CSA A23.1:19 *Concrete materials and methods of concrete construction* [9]; such tests are not, however, specified in CSA 165 SERIES-14 (R2019) *CSA Standards on concrete masonry units* [25]. Exterior grade (Grade I) differs from interior grade (Grade II) bricks by a modest increase in strength and decrease in water absorption. This is similar to the U.S. grading of bricks for moderate or severe weathering exposure (MW or SW) in ASTM C63, C216, and C652. The only durability testing regimen stated in the CSA A165 standard is ASTM C1262, which is an onerous freeze-thaw test; designers are encouraged to use past field performance as an indicator of durability.

Numerous other resources are described in the literature that assess the freeze-thaw durability of fired clay masonry units. However, Canadian and U.S. standards approve fired clay bricks for freeze-thaw exposure based on strength and absorption characteristics, alone, as a substitute for more time-consuming freeze-thaw testing. Of particular interest are: Mercury Intrusion Porosimetry (MIP), used to determine the pore size distribution in fired clay bricks (higher fractions of larger pore size have a positive correlation with durability); Scanning Electron Microscopy (SEM), used to determine the characteristic shape of pores (bricks with round pores are associated with better durability than bricks with elongated pores); and frost dilatometry, which correlate moisture content of bricks, temperature, and strain to assess the risk of frost damage. Research is however still necessary to address the uncertainty associated with the best freeze-thaw testing regime; these physical tests need calibration.

It is noteworthy that modern masonry wall construction, which include water-shedding detailing and an air cavity to promote drying, is significantly less susceptible to freeze-thaw deterioration than historical mass masonry construction. For example, flashing on the top course of brick masonry piers has been shown to greatly decrease the effects of weathering, when compared to piers with a bare top rowlock course [26]. The adoption of refined quantitative durability testing may be useful to justify expected service life and to meet the requirements of CSA S478:19 *Durability in buildings* [13]. Such testing could also assist to determine the durability of bricks exposed to extreme environments (e.g., near horizontal surfaces, or exposed to moisture and salt).

Although the current durability requirements appear to work well for established domestically-produced products, it is uncertain whether they fully characterize the long-term durability of imported products or novel/emerging products, particularly in harsh environments. It is important for designers to consider the performance history of the bricks they specify (if available) and that they become aware of additional tools for assessing the expected durability of bricks. In addition to the absorption and freeze-thaw tests described in the standard, guidance for designers on the assessment and interpretation of properties using more advanced methods should be provided as part of the informative annex on durability. This may be particularly useful as new products with lowered embodied energy and carbon are developed (manufactured from different raw materials, or fired at a lower temperature), or when using reclaimed materials.

Any method for quantifying the expected service life of a brick will necessarily need to include an assessment of the severity of the environment to which it is exposed, including freeze-thaw action. Climate change is expected to have a strong effect on the exposure to freeze-thaw cycling, with increasing severity in some regions and decreasing severity in others. A Canadian regional assessment is needed to determine where the risk of freeze-thaw deterioration is increasing, and where methods and materials for masonry construction that have previously exhibited adequate performance may need to be reassessed.

Mortar and Grout Durability

Performance targets for mortars in the current CAN/CSA-A179-14 (R2019), *Mortar and grout for unit masonry* [27] standard are based on the notion that traditional proportion-specified mortars, which include cement, sand, and lime, provide acceptable performance. In practice, when designers specify performance criteria for mortar, they are limited to criteria that can be measured in the short-term. The Canadian concrete standard CSA A23.1:19, *Concrete materials and methods of concrete construction* [9] outlines a few strategies (performance criteria) to determine the durability which could be applicable to mortar specification. An additional tool which could be of use in the assessment of durability of mortar is the “scratch test” specified in Australia and New Zealand within their AS 3700:2018, *Masonry structures* standard [28].

Current Canadian proportion-specified mortars have characteristics that contribute to their long-term durability (e.g., the inclusion of lime improves freeze-thaw durability, improves the hardened plasticity/deformability, and reduces permeability); methods for assessing these features in performance-specified mortars may be desired. Complete characterization of property-specified mortars will become increasingly important as pressures to reduce the embodied energy and carbon in construction forces the development and adoption of new materials.

Additional guidance on the determination of durability properties of mortar may be beneficial. The development of standardized approaches to determine the freeze-thaw and abrasion resistance and hardened plasticity of property-specified mortars should be considered. As targets for embodied energy and carbon emissions continue to become more stringent, it will also be advantageous to develop a means of quantifying carbon capture through carbonation of mortar and grout over the lifecycle of a building.

Embodied Energy and Operating Energy

Given that CAN/CSA-A371-14 (R2019), *Masonry construction for buildings* [29] is intended to express requirements for masonry components, only limited discussion is included on the integration of damp-proofing, air barrier, and insulating materials. With the increasingly stringent energy targets set out by the NBCC [15] and National Energy Code for Buildings (NECB) [30], additional guidance may be necessary to help constructors achieve these targets. Specifically, additional focus on achieving continuity of insulation materials, and proper sealing of air barrier materials (with explanatory detail drawings) could be beneficial. Guidance on how to account for the dynamic thermal effects (thermal mass contributions) of masonry components to meet NECB Part 8 energy performance requirements would also be useful.

Masonry products also typically have characteristically high embodied energy and embodied carbon. Firing (vitrification) of clay brick is an energy-intensive process that commonly uses hydrocarbons as a fuel. Clinkering of Portland cement is also an energy intensive process which releases additional CO_2 through the chemical processes involved. However, methods exist to mitigate the embodied energy and carbon associated with the production of masonry products (lower temperature firing of clay brick, decreased cement use in concrete masonry unit production through substitution with supplementary cementing materials such as blast furnace slag or fly ash, etc.). Most recently, accurate methods for quantifying carbon sequestration through carbonation of concrete have been proposed [31]. Consistent procedures to account for these carbon sources and mitigating factors should be developed to allow fair comparisons with competing construction materials.

Additional Recommendations

Through consultation with key stakeholders in masonry design, manufacturing, and construction, it is clear that some of the most severe effects of climate change on masonry construction may be indirect. Steps are therefore necessary to facilitate the calculation of embodied energy and to determine the operating energy inputs for finished buildings. Since standardization is needed across disciplines for multiple construction materials, a focus on coordinating and collaborating with influential organizations in concrete, steel, and wood/timber construction will be required. With the emergence of ties and standoffs with lower thermal conductivity (reduced thermal bridging), there may be a benefit to standardize how the thermal performance of these components is reported. Finally, other benefits of masonry relevant to its lifecycle analysis are currently poorly defined. Masonry facades are more resistant to accidental impacts, abrasions, and vandalism compared to some lighter-weight finishes. Quantifying this type of resistance to wear-and-tear may assist designers and building owners/operators to make informed decisions when selecting exterior finishing.

CONCLUSIONS

Masonry construction has been and will continue to be a durable building material, well adapted to resist extreme weather events associated with a changing climate. However, the updated demands of energy codes with regards to thermal insulation and energy performance, embodied energy, and embodied carbon targets to mitigate carbon emissions and further climate change may make it difficult for masonry construction to remain competitive with other structural systems. A generally warmer climate may make certain regions less susceptible to the adverse effects of freezing and thawing. However, some aspects of climate change may increase the vulnerability of masonry construction to long-term deterioration; increasing rainfall may lead to faster corrosion rates, and changing temperature patterns in colder regions may increase the frequency and severity of freeze-thaw cycling. The following recommendations are intended to keep Canadian masonry standards current on developments for adapting to climate change and mitigating future climate change:

- Develop regionally applicable corrosion protection practices for masonry ties and other metallic elements.
- Reassess the aDRI values listed in CSA A370 to account for climate change or adopt an alternative climatic index to determine corrosion protection requirements.
- Rearrange the formulations for corrosion protection requirements in CSA A370 to distinguish requirements based on usage or exposure from those based on climate.
- Research is required to examine the possibility of increasing the maximum spacing of ties to reduce thermal bridging.
- Additional research is necessary to quantify moisture penetration through veneer crack widths in the range of 0.1 mm to 2 mm.
- Updated information in support of sophisticated analysis for corrosion modeling (accounting for moisture, chlorides, and pollutants) should be included in CSA A370.
- Guidance on the use and interpretation of sophisticated materials testing (such as MIP, SEM, and frost dilatometry) should be included in CSA A165 and CSA A82 in support of quantifying the durability characteristics of masonry units, particularly against freeze-thaw deterioration.
- A regional assessment is needed to determine the locations within Canada that are expected to experience increased or decreased severity in freeze-thaw conditions under various climate change scenarios.

- Adopt additional testing in CSA A179 to assess long-term durability properties of mortar for performance specified mortar.
- Provide additional guidance in CSA A371 on how to achieve continuity in insulation and air-barrier systems, in conformance with NECB targets.
- Industry documents should be developed to assist designers in comparing the lifecycle energy inputs of masonry and other construction materials. Specific guidance on how to account for thermal bridging and the dynamic thermal properties of masonry would be particularly useful.
- Implement accurate methods for the determination of lifecycle embodied energy and carbon from the production of masonry products (clay units, concrete units, mortar, and grout), accounting for carbon capture/sequestration through carbonation of cement products.

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