Optimizing Municipal Structures Inspections

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Abstract

The majority of Ontario's municipal bridges and culverts built in the 1950s and 1960s are quickly approaching the end of their design life. Without the necessary funding, the declining condition of these assets can result in structures with compromised safety and increased maintenance and rehabilitation costs. Municipalities of all sizes are affected by this underinvestment and are required to do more with less to address a $19.1B deficit [1].

In 1985, Ontario emerged as a leader in bridge safety with the introduction of the Ontario Structure Inspection Manual (OSIM), which standardized detailed visual inspections for all structures over three (3) meters in length. The creation of O.Reg. 104/97 *Standards for Bridges* that states the structural integrity, safety and condition of every bridge shall be determined through the performance of at least one (1) inspection every second calendar year under the direction of a professional engineer and in accordance with OSIM.

The paper focuses on advancements in international best practices and decades of insight and knowledge gained through evaluating thousands of structures that can be used to optimize the OSIM process. Key opportunities for improvement include the following:

- Changing the OSIM cycle time inspection frequency based on the structure's configuration, age and condition.
- How the structures are evaluated from cycle to cycle, limiting bias based on a priori knowledge gained from previous inspections.
- Optimizing inspection frequency to focus on elements that have the greatest impact on the Bridge Condition Index (BCI) and overall bridge safety.
- Identifying the factors that give greater insight into the structure's performance and safety.
- Flagging bridge configurations and elements with known inherent vulnerabilities not necessarily connected to the bridge or element condition.
- Modernizing the methods of recording field data to better facilitate data maintenance and post-inspection analysis.
- Opportunities for improvement identified in the Ontario Auditor General's 2021 report.

If adopted in a future OSIM edition, this effort would reform the way OSIM inspections are carried out, reestablish Ontario as a leader in the sector, and provide greater detail and clarity on the condition and safety of structures. This would allow for better asset management planning and safety improvements, saving millions of dollars.

Disclaimer

The views and opinions expressed in this paper are those of the authors and do not necessarily reflect the views or positions of any entities they represent. The purpose is to start a discussion on how the OSIM methodology could be improved to better satisfy asset management planning and safety needs of Ontario municipalities and road users.

Ontario Auditor General Report 2021

In 2021, the Office of the Auditor General of Ontario (OAGO) conducted a Value-for-Money Audit of the Inspection and Maintenance of the Province's Bridges and Culverts [2]. This ensures that infrastructure and programs are financially accountable and well-managed, providing public reporting transparency. This report identified ten (10) recommendations that encompassed twenty-two (22) action items; two (2) of these significantly impact municipal structures.

OAGO Recommendation 1. Quality of Inspection Manual and Standards.
"To improve the guidance given to bridge inspectors and provide a more uniform inspection approach across the province that yields a more accurate assessment of structures, we recommend that the Ministry of Transportation:

- *Update the Ontario Structure Inspection Manual (OSIM) to provide clarity and guidance on how inspectors can quantify the degradation of a structure's material condition from Excellent to Good for the calculation of the overall material condition of a bridge and*
- *Incorporate OSIM inspection tables used in assessing a structure's elements, which can identify and summarize the elements critical to the structure's integrity."*

Authors' Comment
OSIM does not differentiate between elements based on how critical they are to the structure's integrity. The OSIM inspection tables used to assess a structure do not include any way to flag and detail elements considered critical or potentially vulnerable. This is important because, while the OSIM is widely used across Canada for bridge inspection, it does not incorporate all the information relevant to a bridge's safety in calculating the Bridge Condition Index (BCI).

OAGO Recommendation 3. Quality of Inspections.
"So that the bridge inspections are documented and are being performed in accordance with legislation, and so that accurate and thorough bridge inspection data is captured for decision-making, we recommend that the Ministry of Transportation:

- *Implement practices that will enforce the guidance in the OSIM on the length of time an inspection should take, and regularly review the number of inspections completed per day by inspectors to assess their reasonableness and to take corrective action where it is necessary."*

Authors Comment
The Auditor General found that inspection time was often much less than the two (2) to three (3) hours recommended by OSIM to access all the elements of the structure adequately.

Ontario Structures Inspection Manual (OSIM)

OSIM was introduced in Ontario in 1985 to standardize bridge and culvert inspections across the province and ensure consistent ratings. These ratings will be used to plan maintenance and rehabilitation activities to keep the infrastructure in good repair. Since its introduction, the manual has undergone three significant updates: 2003, 2008, and 2018.

Industry-Wide OSIM Inspection Challenges

Inspection of municipal structures is constrained by several key challenges:

Limited Resources – Staffing and Equipment

- There are not enough qualified inspectors to do all the work required to inspect bridges in compliance with OSIM. In Ontario, there is no formal requirement for inspectors to have any training. Some municipalities require that inspectors successfully complete the Good Roads Bridge and Culvert Inspection Course.
- Award of inspection contracts is often based primarily on price, with little to no focus on qualifications or quality. We have seen municipal bridge inspection contracts awarded at a cost of less than $100 per structure. Multi-million-dollar rehabilitation decisions should not be based on a $100 inspection!
- As a result, the time spent inspecting structures is often insufficient. It is not uncommon to see an inspector visiting ten or more municipal bridges in a single day.
- Additionally, recording of inspection observations often takes the form of simple red-lining of the previous inspection notes. In many cases, the previous element notes are used without modification.
- The need for up-close Enhanced inspections far exceeds the availability of specialized access equipment (e.g., Snooper trucks, etc.) required to undertake such inspections.

Focus on All Elements Equally with Little Emphasis on Critical Elements

- OSIM makes mention of Enhanced inspections based on critical elements; however, OSIM does not provide any guidance as to which elements may be considered critical.
- There is no flagging of critical elements whose failure could compromise a bridge or cause it to collapse.
- Critical elements may be small (e.g., tie-down bearing), so they only get inspected briefly.
- There is no overall flag for general vulnerabilities (e.g., tie-down reactions, scour susceptibility, shear susceptibility, cascading or progressive failure mechanisms, etc.).

Unclear Objectives for Enhanced Inspections

- The Enhanced Inspection entered OSIM in the 2008 edition. We believe this was motivated by a reflexive desire to be seen as “doing something” in the wake of a notable bridge collapse in another Canadian jurisdiction. Unfortunately, the defects that led to that collapse were apparently plainly visible for many years before the collapse occurred. There is no evidence that an up-close inspection would have changed anything.
- OSIM inspections are limited to surfaces. They may involve up-close hammer tapping or chain dragging, but they do not provide in-depth knowledge on chloride ion concentration, material strengths, structural demand/capacity ratios, etc.

Archaic Data Recording Methods

- The cumbersome Element Data forms in OSIM may have been appropriate in the 1980s, but they are wholly unacceptable in a data-driven age. More efficient tabular forms of data entry are required. Many consultants (and even some MTO staff) have developed more efficient means of recording the same data.

Misguided Application of the Bridge Condition Index (BCI)

- Many practitioners treat the BCI as a sacred talisman that can foretell the current and future safety of a bridge. In reality, the BCI is simply a measure of the asset's residual value.
- The BCI formulation treats all elements, both critical and non-critical, the same.

- Typically, only 20% of the elements of a bridge will make up 80% of the weighting of the BCI calculation. Critical elements often have very little effect or are not even included in the calculation (e.g., foundations).

Off-loading of Maintenance and Operations Responsibilities

- While OSIM inspections will record the condition of certain elements, such as railings, these elements are susceptible to incidental damage, such as collision damage.
- If a railing, for example, is damaged by vehicle impact, it should not take two (2) years until the next OSIM inspection to identify and address the damage; rather, this damage should be identified through road patrol activities (mandated by the province) and addressed immediately, either with in-house staff or under a blanket contract with a suitable contractor.
- In other words, Municipal operations departments should not be leaning on bridge inspectors to do work that properly lies with operations.

Current OSIM Methodology

Inspections within OSIM are divided into Regular and Enhanced inspections. Regular Inspections are conducted every two years. Enhanced Inspections are encouraged every six years for structures over 30 years old with critical components in poor condition, but they can occur more frequently depending on the structure's condition.

For each inspection type, every critical and non-critical element is inspected and used to calculate a bridge condition index (BCI) value [4]. The BCI, expressed as a value between 0 and 100, represents the structure's residual economic worth relative to its replacement value. Based on the current element value (CEV) and replacement (TEV) values of all components and their condition state (Excellent, Good, Fair, and Poor).

For each bridge element, an Element Condition Index (ECI) is calculated as the weighted average condition of the element:

$$ECI = \frac{(1.00 \text{ x } Q_{EXCELLENT}) + (0.75 \text{ x } Q_{GOOD}) + (0.40 \text{ x } Q_{FAIR}) + (0.00 \text{ x } Q_{POOR})}{Q_{TOTAL}}$$

where $Q_{EXCELLENT}$ is the quantity of the element assigned to the Excellent Condition State (and so on for Good, Fair and Poor), and Q_{TOTAL} is the total quantity of the element. Note that the ECI, which ranges from 0.00 to 1.00, is independent of the value of the element.

For each bridge element, the Total Element Value (TEV) is calculated as TEV = UC x Q_{TOTAL}, where UC is the unit cost of the element as prescribed in the BCI Manual [4].

This process is completed for every element of the structure; then, the weighted average of all ECIs (weighted according to element replacement values based on the MTO BCI Manual) is calculated to determine the BCI.

Proposed Refinements to OSIM Methodology

The authors propose a set of simple refinements to the manner and frequency of inspections. These refinements are intended to improve structural safety, optimize inspection efforts, and save inspection costs.

Identify Critical Elements

Some elements in *Poor* condition may perform for many years with no concerns (e.g. a delaminated or spalled abutment wall), while certain other elements in *Excellent* or *Good* condition may cause failure if they are under-designed (e.g. a slender column, deficient uplift bearing, embedded tie-down anchor, or un-reinforced cantilever slab), or if they become compromised (e.g. a tipped rocker bearing, a scoured footing). Critical elements that cannot be inspected easily (or at all in some cases) can also lead to major failure or collapse. Bridges with progressive cascading failure mechanisms can also fail suddenly if one link in the chain becomes compromised, regardless of its condition.

Accordingly, owners must identify the critical elements for each bridge. These may include:

1. Girders, especially where forces are the highest or deterioration is likely to occur.
2. Uplift bearings
3. Unrestrained rocker bearings
4. Critical connections (e.g., arch hangers)
5. Fatigue-prone elements.
6. Scour-susceptible foundations

These elements are critical because their failure could cause the whole structure to fail. The other elements identified in OSIM are less critical or non-critical to overall structural integrity.

Undertake Structural Evaluations Where Warranted

Where concerns exist regarding potential inherent latent defects or vulnerabilities, owners should engage a consultant to undertake a structural evaluation in accordance with the Canadian Highway Bridge Design Code (CHBDC). This will provide insight as to the level of concern that should exist with regard to such details.

Where acute deficiencies are identified, rehabilitation should be scheduled.

Optimize Inspection and Reporting Cycles

A global jurisdictional scan highlighted that countries such as Denmark, France, Germany, Japan, and Sweden have adopted inspection cycle times ranging from four (4) to six (6) years. This suggests that the OSIM inspection frequency may be suboptimal.

We believe that the OSIM inspection cycle should be refined to focus more on critical elements while maintaining sufficient inspection of non-critical elements.

For example, a refined five-year inspection cycle might incorporate the following timeline:

Year	Activities
1	▪ Undertake QA review of completeness and accuracy of “static” information recorded for each structure (e.g., dimensions, materials, quantities, etc.). ▪ Full OSIM inspection of all bridge elements (critical and non-critical), starting fresh, with no previous inspection notes that may bias the assessment. ▪ Identify requirements for detailed follow-up investigations. ▪ Calculate BCI.

	▪ Produce a detailed inspection report with all findings and recommendations.
2-5	▪ Inspection of critical elements only, focusing on performance and defects that could affect performance. ▪ Update BCI based on extrapolation from rational degradation curves or a reasonable annual decrement of the BCI, say a reduction of 1 point per year. ▪ Produce a brief addendum to be appended to the Year 1 report.

The length of the inspection cycle would be based on the engineering best judgement of the inspector based on their current evaluation/findings.

BCI and Asset Management

Using either the base BCI or an aggregated Structural Sufficiency Index (SSI) or Structural Priority Number (SPN) as a measure of “priority level” promotes a "worst-first" approach to asset management, contrary to the general intention of managing a network based on maintaining a minimum aggregate asset value. Consider two bridges where one is deemed to be in “Good” condition and the other is deemed to be in “Poor” condition, as defined by their BCI. The worst-first approach commits funds to the Poor bridge; however, if the Poor bridge is programmed for eventual replacement and there are no urgent structural safety or performance issues, the commitment of funds to the Poor bridge could lead to critical preventative works not being undertaken for the Good bridge.

Conclusions

Optimizing the OSIM methodology to address the issues/concerns raised in the paper will enhance bridge and culvert safety by introducing a proactive strategy to monitor and evaluate our municipal structures.

Moving to a longer inspection cycle length for a new or rehabilitated structure lifecycle does not significantly impact the maintenance treatment and rehabilitation timings. Extrapolating the cost savings over Ontario’s approximately 22,100 structures, municipalities could reinvest millions to address other asset funding needs over the lifecycle of these assets.

References

[1] Smith, J. (2021). The State of Ontario’s Municipal Infrastructure: Quantifying the Deficit. 2021 TAC Conference and Exhibition.

[2] Office of the Auditor General of Ontario. (2021). Value-for-Money Audit: Inspection and Maintenance of the Province’s Bridges. www.auditor.on.ca/en/content/annualreports/arreports/en21/AR_InspectBridges_en21.pd

[3] Ontario Ministry of Transportation. (2018). Ontario Structure Inspection Manual (OSIM). www.library.mto.gov.on.ca/SydneyPLUS/Sydney/Portal/default.aspx?component=AAAAIY&reco rd=2cc7e50c-3d41-4468-90f1-0788368ce945&lang=en-US

[4] Ontario Ministry of Transportation. (2008). Bridge Condition Index (BCI). An Overall Measure of Bridge Condition).

[5] Stephenson, J.P. (2022). The Bridge Condition Index (BCI) is NOT a measure of structural safety. Why do we keep pretending that it is? Good Roads Quarterly, Issue 03 / October 2022.