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Aging Concrete Slab on Steel Girder Bridges in Changing Climate

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***Abstract* –** Concrete Slab on Steel Girder (CSSG) bridges are a common type of bridge in Canada, constituting 25% of the inventory of certain bridge owners. These bridges have typically exceeded half of their design life. However, bridge owners currently lack practical tools for predicting the residual capacity of their aging assets. In light of the changing climate, it is imperative to have the ability to estimate the residual capacity of these bridges for various loading conditions and failure modes. This paper provides a brief overview of the future research that the National Research Council Canada's Construction Research Centre plans to undertake over the coming years on the prediction of residual capacity and structural behaviour of aging CSSG bridges. The research will focus on the residual shear and bearing capacity of deteriorated steel girders, the impact of axial load on moment resistance, and the effects of deterioration on dynamic behaviour. The outcomes of this research are expected to provide Canadian bridge owners with practical tools for evaluating the residual capacity of their aging CSSG bridges, facilitating informed, data-driven decision-making.

***Keywords*:** ageing bridges, residual capacity, shear, bearing, dynamic behaviour, steel, girder, concrete, slab

1. Introduction

1.1. Background

According to the Government of Canada [1], there are over 53,000 publicly-owned roadway bridges in Canada that include highway/expressway bridges, arterial bridges, collector bridges, local bridges, and footbridges. Over 37% of these bridges are rated fair (i.e., the asset requires attention; the assets show signs of deterioration and some elements exhibit deficiencies.), poor (i.e., increasing potential of affecting service; the asset is approaching the end of service life; condition below standard and a large portion of the system exhibits significant deterioration), or very poor (i.e., the asset is unfit for sustained service; near or beyond expected service life; widespread signs of advanced deterioration; some assets may be unusable) [2]. With the global warming that imposes climatic loads on infrastructure such as increasing temperatures, changing wind speeds, changing snowfall and rain intensities, changing river flow characteristics, etc., which may also impact deterioration rates [3] the risk of failure for aging bridges may increase. In order to ensure safe and efficient bridge management, bridge owners may need practical methods for predicting the residual resistance of their aging bridges.

1.2. Focus Bridge Type

This literature review study focuses on a concrete slab on steel girder (CSSG) bridges. According to data from the 2017 edition of Ontario Bridge Condition (OTC), approximately 25% of the bridges managed by the Ministry of Transportation of Ontario (MTO) are CSSG type [4]. If generalized, it could mean that there are over 13,000 CSSG roadway bridges across the country. The average age of these CSSG bridges, as reported by the OTC (2017), is over 39 years, which means that they have typically exceeded half of their design life of 75 years as required by the Canadian Highway Bridge Design Code (CHBDC) [5] and in relatively worse condition compared to their concrete girder counterparts.

1.2. Objective

In this paper, the research areas that the National Research Council Canada's Construction Research Centre (NRC-CRC) plans to undertake in the coming years for the prediction of the residual capacity and structural behaviour of aging CSSG bridges in changing climate are briefly discussed. The focus is on the residual shear and overall bearing capacity of aging steel girders, the effects of axial load on moment resistance, and the effects of the deterioration on dynamic behaviour. The main objective of this paper is to identify the research needs and gaps in the quantitative evaluation of the residual capacity of aging concrete slabs on steel girder bridges subjected to accelerated deterioration in changing climate and receive feedback from bridge experts and owners.

2. Residual Shear and Bearing Capacity of Ageing Steel Girders

Various studies reported that the corrosion deterioration of the ends of a simply supported steel girder may be significant due to leakage from expansion joints [6, 7, 8, 9, 10]. Kayser [9] and Czarnecki [11] proposed models for corrosion patterns and long-term corrosion penetration for simply supported steel bridge girders based on field surveys and experience. Utilizing these models, they predicted the change in capacity and reliability of such girders throughout their proposed service life. Their studies outlined that the decline in shear and bearing capacities in the vicinity of the supports was significant for the cases considered whereas the decline for span moment capacities was low (less than 10%) compared to shear and bearing capacities at the supports.

Relatively more recent studies [12, 13, 14, 15, 16] further quantified that web thinning due to corrosion can lead to a decline in shear and web buckling strength such that a 10% reduction in effective thickness potentially results in a decline of 25% or more. Additionally, they demonstrated that initial lateral web imperfections can further reduce the shear and bearing capacity of the beam ends. They also report that current procedures outlined in the standards and codes for shear and bearing capacity estimation do not accurately predict the actual capacity of corroded steel girders.

Some of the recent studies mentioned above [12, 14, 15, 16] proposed new models for the prediction of the shear and bearing capacity of deteriorated steel girder ends which were able to predict the bearing and shear capacity of corroded girders for certain cases; however, the applicability of these models to Canadian bridge girders designed according to CHBDC and the deterioration conditions they experience in Canadian climate is not clear. The evaluation of these recent models and others that are readily available in the literature is proposed to be conducted for Canadian applications.

3. Effects of Axial Load on Moment Resistance

According to a study by Palu and Mahmoud [17], the malfunctioning of expansion joints is a common issue that impacts bridges. They further report that the most vulnerable bridges are those in regions of the U.S. bordering Canada (i.e., Northern Rockies & Plains, Northwest and Upper Midwest). Therefore, similar issues may be expected for Canadian bridges. Climate change-induced temperature increases may further accelerate the deterioration of expansion joints, leading to potential structural issues [18]. The bridge girders are designed for bending and shear, but with malfunctioning joints, they may be subjected to simultaneous bending, shear, and thermal axial loads due to expansion restrictions [17].

Ozkan and Almansour [19] showed that clogged expansion joints may lead to high axial compressive forces on bridges, which they are not originally designed for. Various studies in the literature [20, 21, 22, 23] demonstrated that the reduction in the moment resistance of bridges in the presence of axial compressive forces is significant. Thus, they proposed axial force-moment-shear interaction diagrams based on reduced-scale laboratory tests on CSSG segments and parametric numerical experimentation with relatively large slab-to-beam aspect ratios and compact steel sections. The authors also recognized that more tests and numerical analyses should be conducted to expand the interaction diagrams to CSSG Bridges having smaller slab-to-beam aspect ratios and slenderness [23], which are commonly used in Canadian bridges. The proposed study aims to assess these interaction relationships and develop guidelines for their utilization in Canada.

4. Effect of Deteriorations in Dynamic Behaviour

As referred to in previous sections, various element and segment-level studies have been conducted on the impacts of deterioration in the concrete slab on steel girder bridges. Most of these studies aim to determine the residual capacity of members/segments (moment, shear, and bearing) when the bridge is subject to steel girder deterioration (i.e., corrosion). On the other hand, a few of these studies have focused on evaluating the actual response of the bridge systems as a whole when subject to deterioration and enter into the plastic range of deformation [24]. In practice, most of the in-service bridge superstructures behave elastically under routine daily traffic; however, existing damage and deteriorating conditions would significantly influence different aspects of the structural performance [24]. In addition to ultimate resistances such as positive and negative moment capacities at span (sagging) and support (hogging) regions, respectively, and shear and bearing capacities discussed above, the deterioration of bridge superstructure may change its mass and overall stiffness leading to altered natural frequencies and vibration modes which is a Serviceability Limit State (SLS) for CHBDC. objective of the proposed study is to evaluate how the dynamic structural behaviours of CSSG bridges may change with various deterioration mechanisms and patterns of their concrete decks and steel girders both in elastic and plastic range of deformations when subject to climate parameters that may be altered by climate change.

7. Summary and Conclusion

Concrete slab on steel girder (CSSG) bridges are one of the most common bridge types in Canada. They constitute about 25% of the inventory of certain bridge owners and they are generally older than their concrete girder counterparts on average. With the global warming that imposes climatic loads on infrastructure such as increasing temperatures, changing wind speeds, changing snowfall and rain intensities, changing river flow characteristics, and changing deterioration characteristics, the risk of failure for aging CSSG bridges may increase.

Previous studies have shown that corrosion of steel girder ends may have a significant impact on the structural performance of bridges. It was also shown that malfunctioning expansion joints can result in the bridge girders to be subjected to thermal axial loads due to expansion limitations simultaneously with bending and shear loads. It is imperative to comprehend the impact and extent of the deterioration and how changing conditions due to climate change impact structural integrity and performance. Based on these findings, NRC-CRC identified the following areas to focus for CSSG Bridges: prediction of residual shear and bearing capacity of aging steel girders, the effects of axial load on moment resistance, and the effects of deterioration on dynamic behaviour. The research outcomes are expected to provide Canadian bridge owners with practical tools for evaluating their aging CSSG bridges, leading to informed and data-driven decision-making.

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