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Integrated condition rating and forecasting method for bridge decks using Visual Inspection and Ground Penetrating Radar

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ABSTRACT

The growing problem of bridge deterioration globally has imposed prominent challenges on transportation agencies, mainly in terms of ensuring safety and serviceability of the bridge infrastructure. The large number of bridges built during the 20th century has aged and produced a complex decision-making problem that departments of transportation need to deal with. Bridge management, as a particular domain of infrastructure asset management, has focused on developing methods for condition rating and deterioration modeling. The current research reviews bridge inspection practices and identifies the main defects and deterioration signs of concrete bridge decks that are typically captured by Visual Inspection (VI) and Non-Destructive Evaluation (NDE) techniques. The research introduces the Quality Function Deployment (QFD) theory and Weibull Distribution Function (WDF) as an integrated novel method to the area of bridge condition assessment and deterioration modeling. The proposed QFD condition assessment model is developed based on integrating VI and Ground Penetrating Radar (GPR) evaluation results to provide consistent condition ratings and performance predictions. The QFD model is demonstrated with a real case study and compared to other condition assessment models. Moreover, the QFD method is validated with data extracted from twenty bridge inspection reports completed by bridge inspectors and assessed by bridge experts. The developed deterioration curves using the reliability function for the Weibull distribution show absolute matching in these results through predicting the structure future performance and defining its useful service life. Accordingly, these models can enhance bridge Maintenance, Repair and Replacement (MRR) decisions since they produce reliable condition ratings and predictions that can link to proper rehabilitation action, and eventually assist in the decision making and planning for the selected MRR action. All these processes are integrated within one framework.

1. Introduction

The 2016 Canada infrastructure report card alarmed that > 26% of bridges in Canada have deteriorated and the bridges are mostly rated as fair, poor or very poor [1]. In the United States, the report card on America's infrastructure assigned grade "C+" to bridge infrastructure, which refers to a mediocre condition that requires immediate attention [2]. According to the Federal Highway Administration (FHWA), around 24% of the total bridges in the US is either structurally deficient (SD) or functionally obsolete (FO) [3]. With the increasing number of deteriorating bridges in Canada, the US and around the globe, condition assessment and deterioration modeling techniques of bridges are in demand. To address the deterioration problem of the bridge infrastructure, Bridge Management Systems (BMSs) and decision support methods have become paramount.

Bridge management decisions are mainly based on information and reports streaming to the bridge managers on the performance and needs of the different bridges in a network. Bridge condition assessment and rating and future performance under different Maintenance, Repair and Replacement (MRR) scenarios are the most important input needed for the decision making process. The commonly used techniques to assess bridge conditions are through Visual Inspection (VI) and close observation to bridge elements because it is inexpensive and requires a minimal level of experience. The visual examination provides valuable information on bridges condition, but it is not always reliable because it depends mainly on the inspector judgment while completing the VI which can be imprecise. Advances in technology have enabled the development of Non-Destructive Evaluation (NDE) techniques as an alternative or supplement to VI methods [4]. The Ground Penetrating Radar (GPR) has been considered for many years as a highly promising technique for deterioration mapping. Further, the combined application of the GPR with the VI can improve the identification and

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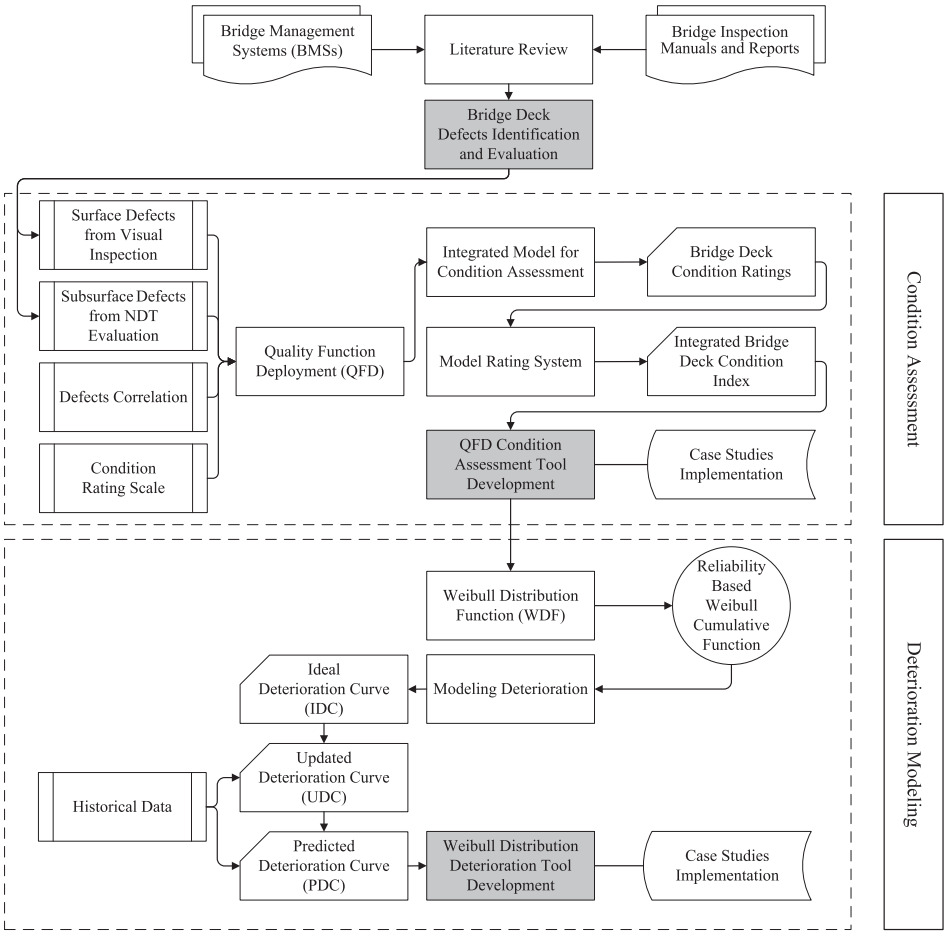

Fig. 1. Schematic flow diagram of the proposed methodology.

quantification of the deck defects [5].

Periodic bridge inspection results and the produced condition ratings are essential to predict the future condition of the bridge elements, which in turns enables scheduling of the MRR decisions. The accurate modeling of the deterioration process is important to allocate the available resources efficiently. Markovian-based models are the most widely used approach for calculating deterioration rates. However, they assume that the history of the deteriorated element is irrelevant and suffer from other limitations discussed in the literature [6,7]. Weibull-based approach performs better for developing deterioration curves for different bridge elements [7]. Generally, Weibull distribution provides the best overall fit for infrastructure deterioration data [8] and can be efficient in accounting for the deterioration process uncertainties [9].

2. Research objectives

The main objective of this paper is to propose an integrated condition assessment and deterioration prediction method for concrete bridge decks. To achieve this objective, the following sub-objectives are sought:

1. Identify and study bridge deck common defects.
2. Integrate results collected from Visual Inspection and GPR techniques to enhance the reliability of bridge condition assessment.
3. Develop a condition-based reliability model to forecast bridge deck deterioration rates.

3. Background

3.1. Current practices and methods for condition assessment

VI involves using specific techniques to provide valuable information on the physical condition of the inspected bridge. This inspection process can evaluate surface defects such as cracking and spalling. Hammer sounding and chain dragging are the most commonly used techniques to determine subsurface defects such as delamination. If severe damages are identified during the VI, a more in-depth condition survey is conducted with the aid of NDE techniques. Several NDE technologies have been utilized and assessed for reinforced concrete bridge inspection. Washer et al. [10] used Infrared thermography (IR). Gucunski et al. [11] used Ultrasonic Surface Waves (USW) and Half-Cell Potential (HCP). Chase [12] and Gucunski et al. [11] used Impact Echo (IE). Dinh et al. [13] and Gucunski et al. [11] used GPR. In general, the main challenges in deploying the NDE techniques are the complex data interpretation and the detection of a certain type of defect. Recently, the GPR has been widely used for bridge deterioration evaluation. An extensive number of studies investigated GPR technology for reinforced concrete bridge inspection, particularly bridge decks. Thus, in this research, the GPR is integrated with the VI technique to assess the condition of concrete bridge decks using the Quality Function Deployment (QFD) theory. The QFD was utilized earlier [14] and extended in this paper to provide an integrated condition rating for the bridge deck.

3.2. Common deterioration models

Bridge deterioration models can be categorized into deterministic, stochastic, and artificial intelligence [6,15]. A number of bridge