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State-Of-The Art Practices in Bridge Inspection

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***Abstract*—**Government reports and published research have flagged and brought to public attention the deteriorating condition of a large percentage of bridges in Canada and the United States. With the increasing number of deteriorated bridges in the US, Canada, and around the globe, condition assessment techniques of concrete bridges are evolving. Investigation for bridges' defects such as cracks, spalls, and delamination and their level of severity are the main objectives of condition assessment. Inspection and rehabilitation programs are being implemented to monitor and maintain deteriorated bridge infrastructure. This paper highlights the state-of-the art of current practices being performed for concrete bridge inspection. The information is gathered from the literature and through a distributed questionnaire. The current practices in concrete bridge inspection rely on the use of hummer sounding and chain dragging tests. Non-Destructive Testing (NDT) techniques are not being utilized fully in the process. Nonetheless, they are being partially utilized by the recommendation of the bridge inspector after conducting visual inspection. Lanes are usually closed during the performance of visual inspection and bridge inspection in general.

***Keywords*—**Bridge Inspection, Condition Assessment, questionnaire, Non-Destructive Testing.

I. Introduction

LARGE number of bridges in North America experience extensive deterioration due to aging, environmental impacts, excessive usage and other factors. In the United States, 24.94% of the national bridges are considered to be structurally deficient and functionally obsolete [1]. In Canada, around 8% of the Canadian bridges were completely rebuilt in the past 7 years and around 15% of them are more than 50 years old [2]. Bridge Management Systems (BMSs) are being widely used by Department of Transportation to efficiently manage the condition of deteriorated bridges. One of the first steps in BMS is the inspection. It is used to identify locations of structural defects and deficiencies such as cracks, delamination, spalling, and scaling. Currently, inspection for defects is performed by visual inspection or by using non-destructive testing (NDT) techniques. For instance, visual inspection is used to determine boundaries of delaminated areas in concrete bridge decks. Hammer sounding and chain dragging are the commonly used techniques for such purpose as well [3]. These tests determine the delaminated areas by noting sound changes while striking the concrete slab of the deck with a hammer or while dragging a chain over it [4]. Visual inspection is dependent on the experience of the bridge inspector and as a result it is a highly subjective process. As an alternative, Non-Destructive Testing (NDT) techniques are used to evaluate subsurface conditions of bridge elements in a systematic way through using advanced technologies. One of the main limitations of NDT techniques, used in current practice and visual inspection, are the cause of traffic disruption and lane closure. Therefore, considering other class of technologies that capture data without direct contact with the structure such as remote sensing technologies is expected to be an alternative or to minimize the limitations stated above [5]. In addition, inspection reports of current practice describe bridge condition state in text format supported at times by images to document observed isolated defects. Thus, they lack visualization of the whole picture, i.e., the whole bridge with localized defects. Hence, considering a methodology to enhance condition assessment visualization will help in building more effective inspection in understanding bridges condition.

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II. Background Information

A. Visual Inspection

Visual inspection is the main procedure for concrete bridge inspection. According to [6], visual inspection is "an element-by-element "*close-up" visual assessment of material defects, performance deficiencies and maintenance needs of a structure... In many cases, the inspection should be conducted within arm's length of the element, possibly involving tapping with a hammer or making measurements by hand*". Visual inspection might take around 2 to 3 hours in a typical bridge [6] and might extend to a one half-day work [7].

Typically, inspection is carried out once every 24 months. To conduct inspections, bridge inspectors are equipped with specific equipment, such as camera, chalk, marker, flashlight, and measuring tape and have special supporting equipment such as bridgemaster, bucket truck, and ladders. Inspectors need to review previous records of the structure to be inspected. Visual inspection is usually completed using simple-equipment tests such as hammer sounding and chain dragging for detecting surface defects [3].

Surface concrete deck deficiencies such as cracks, wear, and spalls are visually inspected. Hammer sounding and chain dragging are used to determine the area at which the concrete is delaminated. A trained inspector will use a hammer to tap the concrete surface and notice the sound produced, where a "solid pinging" sound refers to sound concrete. Chain dragging apparatus is composed of series of attached chains; the inspector will drag a chain over the concrete surface, and watch for sound changing. In this test a clear ringing sound refers to a sound deck and a muted and hollow sound refers to a delaminated deck [8].

Chain dragging is generally used to inspect the top surface

of concrete decks rather than hammer sounding since hammer test is sometimes a slower process. Hammer sounding is used to inspect the bottom surface of concrete decks to define boundaries of delaminated areas where chains cannot be used [4]. During inspection, the inspector assesses the overall adequacy of the bridge and identifies locations where more detailed inspection is required. The inspector also observes the bridge under truckload and notes any deflection or abnormality. The inspector usually fills out a report and records observations, writes down comments about the condition of the bridge, and takes photos while assessing the bridge condition. The report summarizes the findings of the inspector about deteriorated areas, defects locations, and a condition rating of elements inspected. Inspection findings are typically based on the inspector's judgment and experience.

Upon completing inspection, the inspector recommends a period for the next inspection that is normally two years or any time sooner if deemed to be necessary. Additional investigations may be suggested if the inspector felt a need. Severe material defects and deficiencies in performance are considered criteria for recommending additional investigations. Bridge inspector also specifies when the investigation should take place. Results obtained from previously mentioned techniques are subjective and rely on the inspector's experience due to lack of generic frameworks to generate quantitative results for bridge conditions. One of the attempts to overcome these drawbacks is the use of Non-Destructive Testing or Techniques (NDT), which also called Non-Destructive Evaluation (NDE) techniques in bridge condition assessment [5].

B. Non-Destructive Testing (NDT)

NDT in general is the evaluation or examination of an object or an element to investigate the conditions, which may affect the serviceability of the tested object without the need to change or alter its shape [9]. NDT techniques are currently used in several countries as a supplemental procedure for visual inspection if needed or when performing in-depth inspection. Some examples of popular NDT techniques are half-cell potential, impact-echo testing, and Ultrasonic Pulse Echo [4], [8].

Half-Cell Potential test is used to locate active corrosion in the steel reinforcements embedded in concrete. The main procedure in this technique is measuring the electrical potential difference between the steel reinforcements and a standard portable reference electrode placed on the surface of the concrete. A pre-defined grid is designed to assign locations where potential differences are measured. The electrode is connected to the negative end of the voltmeter and the other end on concrete is connected to the positive side. The measured values will be plotted on a diagram of the inspected structure as a contour map. [10] Summarizes the procedure to interpret half-cell potential results. Basically, if the potential is greater than -200 mV then the probability of corrosion is less than 10%, while if the potential is lower than -350 mV then the probability of corrosion is greater than 90%. All the values between these two limits are drawn in the contour map [11].

Impact-Echo Testing is one of the reliable NDT techniques conducted to detect concrete delamination and identifying dimensions in concrete decks [12]. The main procedure performed in this method is detecting and characterizing wave resonators in a concrete bridge deck. This can be done by striking the inspected object, by a wire-mounted steel ball for example, and measuring the response at a close location using a sensor. The reflected frequency, called the return frequency, will be used to measure the depth of the reflector. The depth of the reflector determines the state of the concrete. Shallow reflectors represent delamination and deep reflectors represent sound concrete. That is because the sharper the contrast in acoustic impedances of materials the stronger the reflector will be. For instance, in sound concrete the dominant reflector is the bottom of the concrete in which the air-concrete interface has a contrast in acoustic impedance [8].

Ultrasonic Pulse Echo is a method mainly used to detect objects, interfaces, and anomalies such as cracks, voids, and delamination. This can be achieved by transmitting high amplitude pulses through the inspected object. The basic principle applied is measuring the time or velocity of the ultrasonic waves being transmitted through the object and reflected back to the surface. Defects are identified where difference in impedance occurs. Therefore, deteriorated regions in the concrete will appear as areas with lower velocity waves compared to sound concrete [8]. More information regarding other NDT techniques is presented in [8].

III. Questionnaire

A questionnaire was sent to professionals in the field of bridge inspection and condition assessment. The main objectives of the questionnaire can be summarized as:

- Understand the current practice in concrete bridge inspection.
- Obtain statistical information regarding bridge inventory.
- Study the usefulness of NDT in bridge condition assessment.

A. Part I

The questionnaire was distributed among bridge professionals. Personal information was solicited in Part I. The questionnaire was surveyed to 53 participants. The main information about the respondents is as follows:

- 40% response rate
- 43% lies in North America
- 60% possess over 10 years of experience
- 24% senior engineers
- 19% managers

Below figures illustrate pie charts that represent locations of respondents (Fig. 1) and professional positions (Fig. 2).

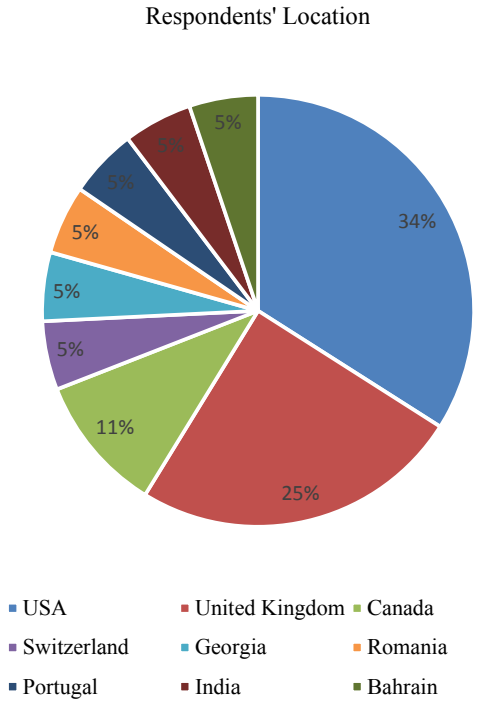

Fig. 1 Respondent's locations

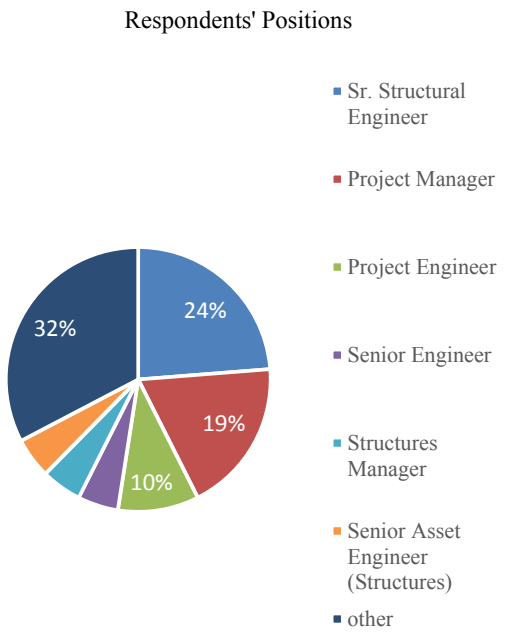

Fig. 2 Respondent's positions

B. Part II

Part II of the questionnaire was designed to solicit statistical information on the statues of bridges in inventory. Information regarding number of bridges in inventory, average age, and average rating of bridges are being surveyed. Fig. 3 is a sample of the questions addressed with the percentage of responses received for each answer in every question. Table I shows answers received from every respondent regarding number of bridges, average age, and average rating. Number of bridges ranges from hundreds to thousands in each record. The average age of bridges is 59 years with around 42% being over 50 years old. The overall condition rating of bridges is satisfactory.

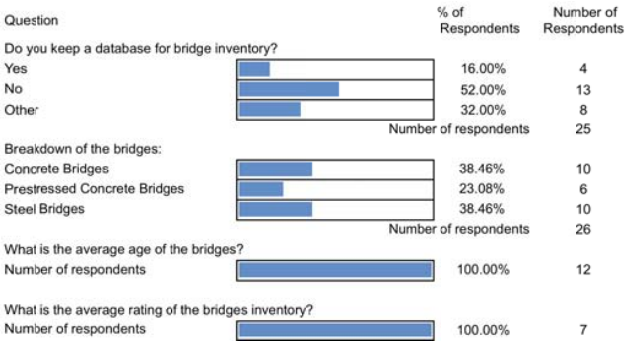

Fig. 3 Sample of inventory questions

TABLE I
PART II QUESTIONS DETAILS

Bridges breakdown			Average Age	Average Rating
Concrete	Pre-stressed	Steel		
34%	3%	57%	40	5
6581	3274	2700	50	78
600	57	15	30	fair
30	100s	180	30	6
Data base	30	100s	45	
100s	15	0	40	we are not rating them
82		N/A	70	
1780		200	20	B
20		5	90	Good
2000		4000	45	
			100	
			150	
Average age			**59**	**Satisfactory**

C. Part III

Part III collects information regarding current practices in bridge inspection. One main objective was to investigate the use of NDT and GPR. Also, questions regarding collected data storage and analysis were included in the questionnaire. Sample of the questions is shown in Fig. 4. In general, 71% of the respondents stated that NDT techniques are being used when required by bridge inspectors. Around 21% of the respondents indicated that hammer sound and chain drag are the commonly used techniques. Around 74% of the respondents do not use GPR for inspection. Lane closure is performed during biennial inspection and in some other ad-hoc inspections. Microsoft Excel is the most commonly used software for data storage and analysis. About 47% of the respondents use Excel for data storage and 40% of the respondents use it for data analysis.

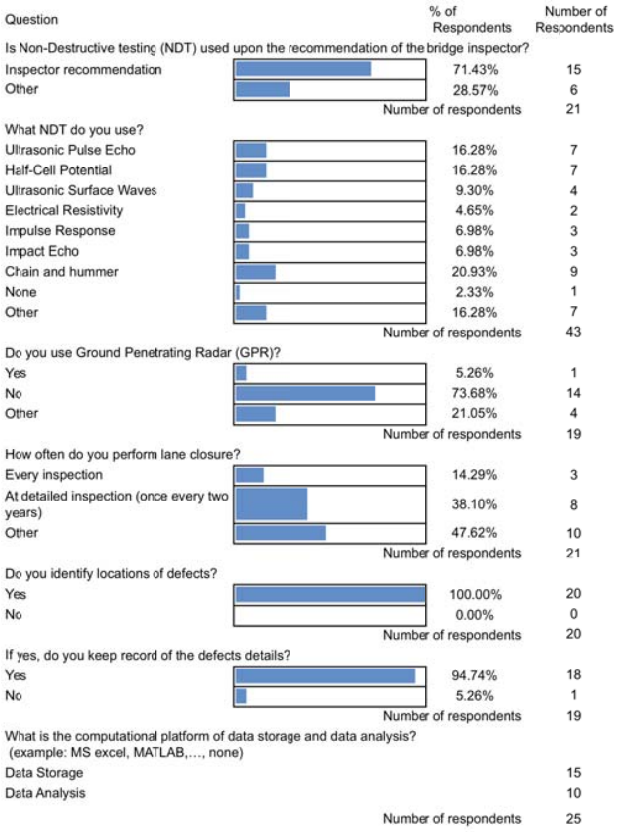

Fig. 4 Sample of current practice questions

IV. Conclusion

Conclusions were made after collecting and analyzing the questionnaire responses. The conclusions serve in understanding the current practice from a professional perspective, and they reinforce the information summarized in the literature form a theoretical perspective. In addition, the questionnaire helped in defining objectives for the methodology to overcome some of the problems addressed in the questionnaire. Below is a summary of the conclusions drawn from the questionnaire:

- Transportation infrastructure includes a large bridge inventory ranging from hundreds to thousands of bridges in each inventory.
- The average bridges age based on the collected sample is 59 years.
- The average overall condition rating of bridges in the inventory of the questionnaire is satisfactory.

Those conclusions motivated current research to create a methodology that assesses bridges in the best manner. Consequently, maintenance and rehabilitations actions can be applied efficiently on the large number of bridges. Otherwise, the bridges are getting older with time and their condition will reach below satisfactory, which might lead to catastrophic events, more conclusions as follows:

- Non-destructive techniques are being used by the recommendation of the bridge inspector.
- Several NDT techniques are not being utilized often and the reliance is on hammer sounding and chain dragging.
- Ground Penetrating Radar is not being implemented, and if so, it is for strands or rebars detection generally.
- Lane closure is being performed every detailed inspection (every two years) and also on other occasions.
- The main software used for data analysis and storage is Microsoft Excel.

Based on the second part of conclusions, several actions should take place. Improving inspection processes is required as NDT techniques, which are considered advanced techniques, are still not in operation due to several technical reasons. Microsoft Excel is the main software used with limited abilities and other advanced software can be considered such as ArcGIS with advancements in building maps and wireless databases access. Hence, considering an improved methodology for bridge inspection is required, such methodology should have several features: 1) Being similar to the current practice 2) Can overcome the main limitation of causing traffic disruption 3) Utilizes advanced techniques for bridge inspection.

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