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- Faculty member of +15 years of experience teaching civil engineering (structural engineering) courses such as strength of materials, structural analysis, analysis & design of steel structures, analysis & design of concrete structures…etc.
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## PROFESSIONAL EXPERIENCE

**DHIQAR UNIVERSITY-IRAQ**
Faculty member, July 2004 – Present

- Teaching several undergraduate civil engineering courses.
- Teaching Advanced Structural Analysis, a graduate level course.
- Head of DhiQar University Engineering Affairs (TUEA) for 2 years.
- Head of the central engineering laboratory – Engineering Consulting Bureau (ECB).

**SAVE THE CHILDREN ORGINAZATION-IRAQ**
Civil Engineer, April 2006 – August 2007

- Structural engineering consultant.
- Preparing tendering documents including drawings and cost estimations of several projects.
- Supervising constructions process of several small size projects such as schools, kindergartens, playgrounds, water filtration projects, flexible & rigid pavements roads …. etc.

**PARSONS COMPANY (USA-IRAQ)**
Civil Engineer, June 2005 – August 2006

- Supervising the constructions process of two health centers and a hospital in south of Iraq area.

## EDUCATION

**University of Missouri-Columbia**

- Doctor of Philosophy, PhD, structural engineering, University of Missouri (MU), USA, 2012 – 2017.
- Master of Science, MSc, University of Technology (UOT), Baghdad-Iraq, 2000-2003.
- Bachelor degree of Science, BSc, University of Technology (UOT), Baghdad-Iraq, 1996-2000.

## ADDITIONAL SKILLS

- Nondestructive evaluation and testing of civil infrastructures.
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# A pixel-by-pixel reliability analysis of infrared thermography (IRT) for the detection of subsurface delamination

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ABSTRACT

This work presents an improved method for characterizing the reliability of Infrared Thermography (IRT) and determining the optimum thermal contrast for the detection of delamination in concrete. Receiver operating characteristics (ROC) analysis in conjunction with image processing methods were used to analyze data from a fabricated and in-service bridge decks. Results of the study demonstrated the excellent capability of IRT to discriminate delaminated from sound concrete. This conclusion was reached because the nonparametric estimate of the area under the ROC curve (AUC) was larger than 80% with its 95% confidence for each group of images. The optimum thermal contrast range was determined to be 0.6–0.8 °C. Accurately defining the actual condition of the test object is critical to implement the proposed analysis method.

## 1. Introduction

The objective of this research was to develop an improved method for characterizing the reliability of Nondestructive Evaluation (NDE) technologies applied to concrete bridge decks. NDE technologies such as Ground Penetrating Radar (GPR), Impact Echo (IE), or Infrared Thermography (IRT) are typically applied to bridge decks to identify areas of the bridge deck that are damaged. The results are frequently presented in two-dimensional plan-view images of the deck showing the areas of damage or deterioration on the bridge deck as certain colors or by using contour lines [1]. These results are used by decision-makers to prioritize maintenance and repair (M & R) activities, and therefore, the reliability of the results can have a significant impact. If the results under-estimate or over-estimate the area of damage in the bridge deck, the wrong decision may be made regarding what M & R activities are appropriate for the given bridge deck. Additionally, selection of the best NDE technology to meet the needs of the decision-maker requires the ability to compare the reliability of the different NDE technologies to each other such that the best technology can be selected.

Previous studies have attempted to characterize the reliability of NDE technologies for detecting damage in bridge decks. However, the methodologies and experimental approaches have not typically provided a quantitative measure of reliability that could be used to compare one technology to another. Generally, these studies have produced anecdotal evidence of the effectiveness of NDE technologies by comparing NDE results to some form of "ground truth," determined from extracting a limited number of concrete cores from the deck or by qualitatively comparing one NDE technology to another.

When concrete coring is used to verify NDE results, the number of cores removed from the deck is typically small. For example, Scott et al. [2] investigated the comparison of chain drag, IE, and two GPR technologies with 10 cores taken at randomly selected areas on a bridge deck in the field. Dimensions of the candidate bridge deck were 55.7 m × 7.67 m (427 $m^2$). Yehia et al. [3] also investigated the applicability of ground penetrating radar (GPR) in detecting areas of delamination by comparing GPR results with 13 core samples extracted from two concrete bridge decks of size 45.7 m × 4.3 m (196 $m^2$). Gucunski et al. [4] investigated the performance of several NDE technologies as compared with the actual conditions of eight core samples extracted from a candidate bridge deck of dimensions of 25.4 m × 3.6 m (91 $m^2$). Studies such as these provide some measure of the effectiveness of the NDE technologies by verifying results at the locations where core samples are obtained, but the core samples represent only a small fraction of the area of the deck. Results indicate only if a defect was detected or not detected at the location where the core was removed. The spatial extent (i.e., area) of the damage is not represented by the core result, and consequently these results are of limited usefulness to decision-makers that require accurate data on the extent of damage to make M & R decisions.

Often, qualitative assessment of the reliability of NDE data is subjective. Consider for example the interpretation of IRT data by

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# Flexural Strengthening of Reinforced Concrete Beams Using Carbon Fiber Reinforced Polymer (CFRP) Sheets with Grooves

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**Abstract**
The most common method used to strengthening, rehabilitation or repairing of reinforced concrete (RC) members is to use external carbon fiber reinforced polymer (CFRP) sheets. CFRP can greatly improve the flexural and shear capacity of deteriorated members and therefore extends their useful life. The main problem of external CFRP is the debonding of the sheets from the concrete surface at some point of loading, which negatively affects the efficiency of strengthening and may consequently lead to an unanticipated failure of the strengthened members. The major reason for this early debonding is likely due to the low accuracy of the preparation and the high stress concentration at the flat contact area exists between CFRP sheets and the concrete. The problem has been extensively discussed in the literature and some CFRP application techniques such as "Externally Bonded Reinforcement on Grooves (EBROG)" and "Externally Bonded Reinforcement in Grooves (EBRIG)" have been proposed as alternatives to the conventional application methods. Although some research has been carried out, there have been few experimental investigations that provided quantitative discussion of the efficiency of the new developed techniques. This research was aimed to experimentally assess the efficiency of grooving techniques and to provide a quantitative data regarding the behaviour of bonding between CFRP and concrete. The effects of shape and direction of the grooves and CFRP layers on the load carrying capacity, mid-span deflection and failure mode of thirteen RC beams have been investigated and discussed. In general, CFRP has significantly improved the flexural capacity of strengthened beams especially when grooving technique has been employed.

**KEYWORDS**
CFRP; Concrete; Strengthening; Grooves; Structural behaviour

## 1. Introduction

The most common method used to strengthening, rehabilitation or repairing of reinforced concrete (RC) members is to use external carbon fiber reinforced polymer (CFRP) sheets. CFRP can greatly improve the flexural and shear capacity of deteriorated members and therefore extends their useful life. CFRP materials can used in different configurations for the strengthening of deteriorated of concrete elements as well as the main reinforcement for concrete in new constructions. Among the main advantages of using CFRP material in structural engineering applications are that CFRP can be bonded to structural elements in various configurations due to its light weight and flexibility. This material can also offer desirable structural properties such as resistance to corrosion, high stiffness to weight ratio, high tensile strength and high fatigue resistance Nguyen, Chan et al. (2001).

During the past few years, many different methods have been developed for repairing and strengthening of RC elements. Among these methods, the application of CFRP sheets has been proved as one of the most effective methods.

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# Comparison of Two Nondestructive Evaluation Technologies for the Condition Assessment of Bridge Decks

**Ali A. Sultan[1] and Glenn A. Washer[1]**

**Abstract**

Selection of the appropriate condition assessment tool to meet the decision-making needs for preservation, maintenance, and repair (PM&R) actions can be difficult, because different nondestructive evaluation (NDE) technologies have different performance characteristics. The objective of the research was to compare the reliability of ground-penetrating radar (GPR) and infrared thermography (IRT) for the detection of delamination in concrete bridge decks. Field tests were conducted on two in-service concrete decks constructed in the same era and having significant deterioration due to corrosion damage. Reliability of the technologies was evaluated using receiver operator characteristics (ROC) analysis, a methodology that allows for a quantitative point-by-point comparison of results from NDE technologies with ground truth. The analysis results quantified the reliability of IRT and GPR for the two candidate concrete decks. It was found that IRT exhibited a higher reliability measure as compared with GPR for these two bridge decks. The implication of the test results for implementation of these technologies is discussed. The results of the analysis provide useful data for bridge owners making decisions regarding suitable NDE technologies for the condition assessment of bridge decks.

The objective of the research was to compare the reliability of ground-penetrating radar (GPR) and infrared thermography (IRT) for the detection of areas of delamination in concrete bridge decks. This comparison was made by developing a high-resolution reliability analysis using receiver-operator characteristic (ROC) analysis, a statistical method for quantitatively assessing the reliability of diagnostic systems. The field testing consisted of implementing IRT and GPR scanning on two bridge decks constructed in 1968. Ground truth was established by a combination of multiple soundings of the deck, some selected applications of the impact echo (IE) method, and physical sampling for confirmation of the sounding results. These data were used to complete a quantitative reliability analysis. The contributions of this research are (1) the development of an ROC methodology for assessing the reliability of nondestructive evaluation (NDE) technologies for in-service bridge decks; and (2) the quantitative comparison of the performance of IRT and GPR detecting areas of subsurface delamination in two case studies assessing reinforced concrete (RC) bridge decks. The results of the analysis can provide information for decision-makers for the selection and application of GPR and IRT as part of a condition assessment strategy for highway bridge decks.

## Background

The condition assessment of concrete bridge decks is important for determining preservation, maintenance, and repair (PM&R) actions required to maintain the serviceability and safety of bridges. The RC from which the deck is formed can be affected by the corrosion of embedded reinforcing steel that manifests in concrete spalling, forming potholes in the deck that require repair to maintain the serviceability of the deck. Spalling may also occur as the result of mechanically induced stresses, construction defects, or debonding of an overlay layer from the concrete deck substrate.

The typical condition assessment method used for bridges is visual inspection, which detects the onset of damage once spalling and cracking initiates and is visually observable. Nondestructive evaluation (NDE) tools are sometimes used to detect damage before the formation of spalling when the damage is not visually observable. Sounding of the deck with a hammer or chain is sometimes part of a visual inspection; more

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# EFFECTS OF POLYPROPYLENE FIBERS ON COMPRESSIVE AND FLEXURAL STRENGTH OF CONCRETE MATERIAL

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Civil Department / College of Engineering / DhiQar University

**ABSTRACT**

*This research aims to explore the effects of using polypropylene fibers to produce concrete with certain strength characteristics. The study concerns the compressive and flexural strength of concrete with polypropylene fiber (PF). The experimental phase of the research has included testing fifteen groups of concrete with different characteristics. The main variables considered in the experimental program are the percentage of polypropylene fiber, type of concrete mix and presence of steel reinforcement in a prism. The effect of these variables on the compressive and flexure strength of concrete was investigated. The results of this study indicated that the variation in the compressive and flexure strength of concrete depends mainly on the polypropylene fiber percentage. It was found that the compressive strength of concrete increases by increasing the percentage of polypropylene fiber from 0 to 0.2%, while the increasing in the strength started to vanish when approached to 0.3% of PF. Similarly, the flexural strength of concrete has also increased by increasing the percentage of PF from 0 to 0.3%. By further increasing PF up to 0.5%, it was determined that the compressive and flexural strength of concrete started to decrease significantly as compared to the control mix.*

**Key words:** Concrete, Polypropylene Fiber, Compressive Strength, Flexural Strength

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## 1. INTRODUCTION

Concrete material is strong in compression while it is very weak in tension so, it tends to be brittle material. Using steel reinforcement and/or a sufficient amount of fibers, the weakness in tension can be resolved. Using of fibers also leads to change the behavior of concrete members after it has been cracked, thereby improving its toughness.

Nowadays, many types of fiber, such as carbon, glass, steel and polypropylene fibers are frequently used in many projects such as high buildings, prestressed and precast concrete



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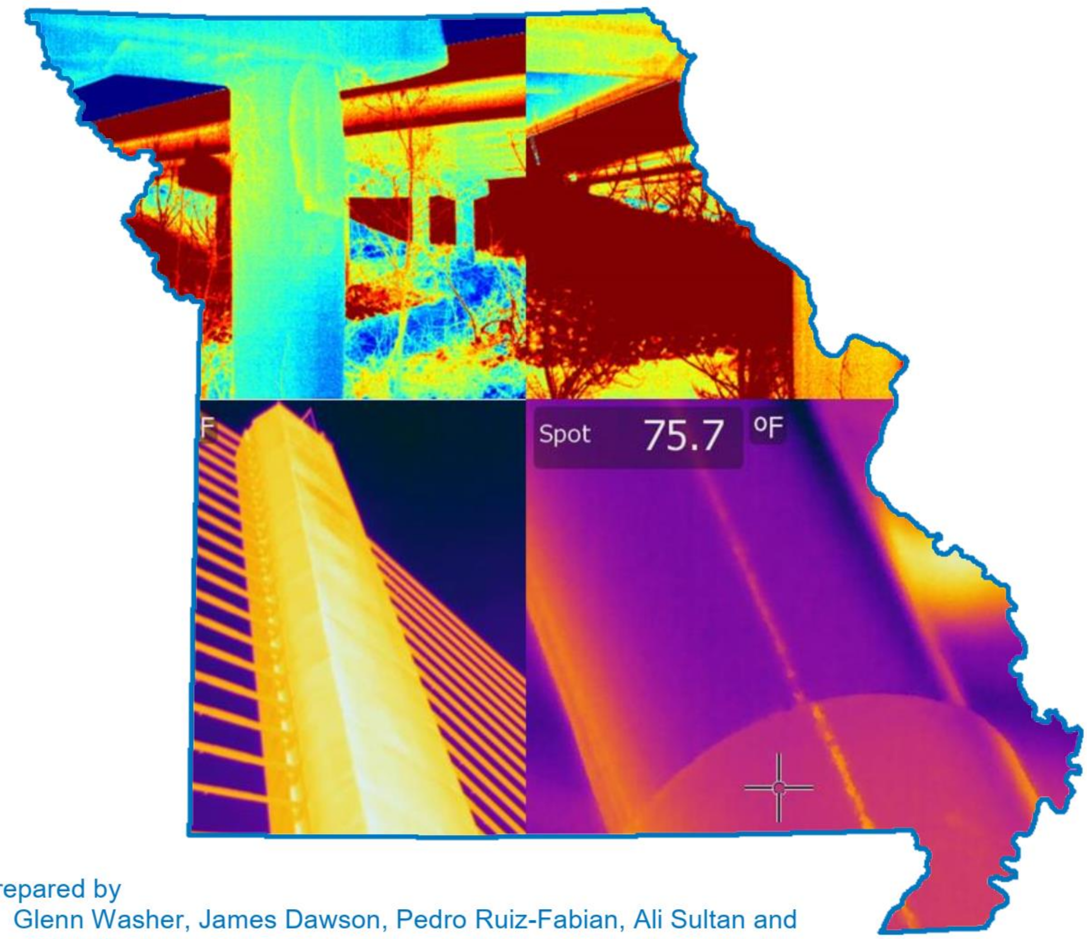
# Field Testing of Hand-Held Infrared Thermography, Phase II TPF-5(247) Final Report

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# Reliability Analysis of Ground-Penetrating Radar for the Detection of Subsurface Delamination

Ali A. Sultan, Ph.D.[1]; and Glenn A. Washer, Ph.D., P.E., M.ASCE[2]

**Abstract:** This article reports on research to experimentally analyze the reliability of ground-coupled ground-penetrating radar (GPR) for the detection and imaging of subsurface delamination in concrete. Experimental studies were conducted that included a RC deck mock-up with synthetic delamination targets and two highway bridge decks. Both of the bridge decks had areas of delamination as determined through sounding, infrared thermography, and some limited physical sampling. Receiver operating characteristics (ROC) analysis was used to evaluate the reliability of GPR when implemented using the procedure described in the current ASTM standard that employs signal reflections from uppermost steel bars. The overall results indicate that GPR had limited ability to detect and image areas of delamination in concrete using the aforementioned ASTM procedure. After almost four decades of implementation of GPR for the condition assessment of concrete bridge decks, confusion remains regarding the ability of GPR to directly detect areas of delamination. The findings from this research should make an important contribution to clarifying this issue to improve decision making for maintenance and repair when considering GPR as a condition assessment tool. **DOI: 10.1061/(ASCE)BE.1943-5592.0001182.** *© 2017 American Society of Civil Engineers.*

**Author keywords:** Nondestructive evaluation; Decks; Ground-penetrating radar (GPR); Delamination; Receiver operating characteristics (ROC); Reliability; Bridge.



## Introduction

After almost four decades of implementation of ground-penetrating radar (GPR) for the condition assessment of RC bridge decks, confusion remains regarding the ability of GPR to directly detect and image areas of subsurface delamination. Some researchers clearly indicate that GPR does not detect delamination but instead provides a qualitative measure of the potential for corrosion damage (Maser and Roddis 1990; Barnes and Trottier 2000, 2004; Scott et al. 2001; Kim et al. 2003). Other researchers and the current ASTM standard [D6087-08(2015)] (ASTM 2015) infer that the technology can detect delamination (Clemeña 1993; Yehia et al. 2008; Robison and Tanner 2012; Gucunski 2013). Bridge owners seeking condition assessments to guide repair and maintenance activities may be left with the expectation that repairable damage such as delamination will be revealed in a GPR survey. When results do not correlate with these expectations, the owners are disappointed. In some cases, bridge owners are using the percentage of deficient deck area as a decision threshold. For example, Michigan utilizes a bridge preservation matrix that recommends different deck repairs for bridges with less than 5%, less than 10%, 10–25%, and more than 25% deficiency (Winn and Burgueño 2013). Practically, the deficiency is based on the percentage of deck area assigned a Condition State of 3, Poor Condition, meaning the deck has delamination, spalling, or unsound patches larger than 15.24 cm (6 in.) in diameter or greater than 2.54 cm (1 in.) deep (AASHTO 2013). Therefore, it is important that bridge owners understand if nondestructive evaluation (NDE) technologies can provide the necessary data to support decisions. In this research, an effort was made to experimentally analyze the reliability of ground-coupled GPR for the detection of subsurface delamination in concrete, so as to clarify this issue and provide important information for decision makers.

The objective of the research was to evaluate the capability of ground-coupled GPR scanning for detecting and imaging areas of delamination in RC bridge decks. To meet this objective, a quantitative reliability analysis was completed that compared the performance of ground-coupled GPR implemented on a laboratory mock-up and two highway bridge decks. The most widely used procedure for data analysis provided in the current ASTM standard was used to analyze the GPR data.

The main contribution of this research is to provide a quantitative reliability analysis of the data of GPR technology for the detection and imaging of subsurface delamination in concrete. The experimental data and associated quantitative reliability analysis reported herein will help to clarify the confusion regarding the capabilities of GPR, providing important information for decision makers who may rely on GPR results for making maintenance and repair decisions.

Other methods of analyzing GPR data, such as using expert judgment and visual analysis of GPR data to subjectively identify areas of the deterioration, were not included in this study, nor were other methods that may exist beyond the ASTM procedures. For example, Rhazi (2011) reported some deficiencies in the ASTM D6087-08(2015) standard and proposed another method to analyze GPR data instead. Dinh et al. (2015) showed that the ASTM data analysis procedure could result in apparent improvements in deck condition when the same deck was scanned at two different times. An alternative data-processing methodology was suggested that requires periodic survey of the deck from the time of construction (Dinh et al. 2015). Others have suggested that a visual interpretation of the data would provide improved results (Tarussov et al. 2013).

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# Reliability Analysis of Infrared Thermography (IRT) for the Detection of Subsurface Delamination

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## ABSTRACT

The detection of subsurface damage using Infrared Thermography (IRT) typically relies on a subjective assessment of a color-coded image representing the surface temperature of the concrete. The accuracy of the technique may be analyzed by comparison with cores extracted from the test object in areas where subsurface damage is detected in the IR image. Assessing the accuracy in this way may be of limited utility if it is not accompanied with an assessment of the false positive rate (FPR) and the false negative rate (FNR). This paper presents an analysis method to quantitatively interpret IRT data and objectively assess its reliability for the detection of subsurface delamination, considering all correct and incorrect output. Receiver operating characteristics (ROC) in conjunction with a simplified image processing method were used to accomplish the objective of the research. Results of the study have demonstrated the capability of IRT technology to discern delaminated and sound concrete based on testing of simulated delamination. This conclusion was reached since the nonparametric estimate of the area under the ROC curve (AUC) and its 95% confidence limits were 0.867 and 0.842~0.884, respectively.

## INTRODUCTION

Analyzing the capability of NDE technologies often depends on comparison with visual inspection, comparison with a different NDE technology, or by estimating the true positive rate (TPR) or the accuracy index based on limited physical sampling such as cores. Data are analyzed by comparing the results from the NDE technology at "test points," e.g., at the location where a core was removed. TPR is defined as the proportion of damaged test points that have a positive test result, i.e., the NDE technology correctly identified damage at a location where damage was present. An accuracy index is the proportion of test points that have been correctly identified as positive or negative. TPR and accuracy indices typically do not estimate the false positive rate (FPR) that results from testing sound test points and identifying those test points as damaged, and the false negative rate (FNR) that results from testing damaged test points and identifying those points as sound. As a result, the reliability analysis does not fully represent the performance of the technology.

NDE technologies that have exactly the same accuracy index or TPR do not perform the same if their FPR and FNR indices are different. For example, in SHRP 2 report, it was shown that some NDE technologies have similar accuracy indexes, based on a limited number of cores samples [1]. However, examination of the data provided by these technologies (i.e., color-coded plan view images or contour diagrams) indicates that these technologies perform differently because their FPRs are different. The spatial extent of the area identified as damaged may be different between different technologies, even if these technologies have the same results at the location where the core was removed from the deck. This, in fact, explains why the accuracy index may be of limited usefulness for reliability assessments unless the FPR is also considered. Without considering the FPR (and the FNR), the NDE technology presenting the least risk to decision-makers cannot be identified.

Assume that the purpose of implementing NDE technologies on a bridge deck is to characterize the condition of the deck to guide decision-making regarding future actions, such as maintenance and repair. The reliability of the technology can only be characterized by fully analyzing the accuracy of the technology (considering both correct and incorrect outputs). A high FPR result may lead to incorrect decisions, because the condition of the deck appears much worse than its actual condition. Many efforts have attempted to correlate the results provided by NDE technologies with the actual condition of the test objects in order to assess the reliability. However, shortcomings of





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# Assessing the Reliability of Impact-Echo for the Detection of Delamination Using Wilcoxon-Mann-Whitney Statistics

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## ABSTRACT

Impact echo (IE) is a widely used nondestructive evaluation (NDE) technique for the detection of subsurface delamination in concrete bridge decks. Reviewing the existing literature reveals that there have been limited in-depth quantitative assessments of the reliability of IE. In most of the previous studies, the reliability of IE has either been anecdotally discussed through a visual comparison of the test results with the actual condition, by sounding, or by estimation of the probability of detection (POD) considering limited number of core samples extracted from the test object. Although POD is an important component, it is only a portion of a comprehensive reliability assessment. For optimum decision-making, reliability assessments of NDE technologies should consider both the true detection rate and also the false detection (or false alarm) rate. This manuscript aims to quantitatively assess the reliability of IE through a statistical analysis method called Wilcoxon-Mann-Whitney (WMW), which inherently considers all expected true and false detection rates. As compared to the well-known POD analysis, WMW analysis has not been widely used in the field of NDE. This analysis method was explored due to its ability to provide a quantitative reliability index and therefore, can provide the complementary information necessary for transportation agencies regarding to the performance of NDE technologies. Results of the analysis showed the effectiveness of WMW analysis for evaluating the overall reliability of NDE technologies and for assessing the capability of IE for detecting subsurface delamination in concrete bridge decks. Results demonstrated the excellent capability of IE technology for detecting subsurface voids in concrete plate-like members.

**Keywords**: reliability, impact echo, WMW statistics, bridge deck, delamination

## INTRODUCTION

Several Nondestructive evaluation (NDE) technologies are available to assess the condition of in-service infrastructures such as bridges and buildings. Results of evaluations are intended to be used for decision making regarding repair or replacement needs. Therefore, the reliability of NDE technologies needs to be carefully assessed in terms of the detection and false alarm rates to prevent erroneous decisions that could have significant financial costs. The detection rate is necessary to ensure that deteriorated regions of the inspected element are accurately identified. On the other hand, the false alarm rate is crucial to ensure that the technology has adequate ability to delineate deteriorated regions from sound regions and doesn't overestimate the deterioration. Overestimation of the deterioration of the structure can result in inappropriate repair or replacement decisions.

In addition, careful assessment of the reliability of NDE technologies is crucial to compare the performance of different NDE technologies that may be used to detect certain types of damage, for example, to compare the use of IE with the use of Ground Penetrating Radar (GPR) to detect areas of delamination in concrete. Subjective assessment of the reliability of NDE technologies cannot provide any quantitative index that can be used for such purposes, and therefore, a quantitative analysis of NDE data is becoming a necessity due to the large number of available NDE technologies.

Reviewing the existing literature reveals that little work has been done to quantitatively assess the reliability of the available NDE technologies such as impact echo, which has been extensively used for the detection of delamination since 1980's. Some of the previous studies have indicated the capability of IE for detection of delamination in concrete [1-4]. However, the reliability of the technology has either been anecdotally described or estimated using





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