TECHBRIEF

Incorporating Nondestructive Evaluation Methods Into Bridge Deck Preservation Strategies

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This document is a technical summary of the Federal Highway Administration report *Incorporating Nondestructive Evaluation Methods Into Bridge Deck Preservation Strategies* (FHWA-HRT-24-185).

The FHWA Advanced Sensing Technology (FAST) Nondestructive Evaluation (NDE) Laboratory leads FHWA's research and testing efforts related to the application of nondestructive testing technologies for assessing the condition of highway infrastructure.

INTRODUCTION

The primary goal of this study was to explore the feasibility and economics of using NDE to inform decisionmaking for bridge deck preservation treatment selection and planning. This study was executed by performing the following five steps:

1. Gathering background information from literature and the departments of transportation.
2. Identifying deck and wearing surface types and their associated modes of deterioration.
3. Compiling available NDE methods and associated applications for deck assessment.
4. Developing an effective decision framework for NDE-based preservation selection.
5. Evaluating example case studies to show the economic benefits of NDE for deck preservation decisionmaking.

The use of NDE and structural monitoring (SM) technologies for assessing bridge deck condition is becoming increasingly popular due to cost savings and extended service life from timely interventions. Traditional assessment relies on visual and sounding surveys, but NDE methods, such as those based on physical principles of stress-wave propagation, electromagnetic properties, and electrochemical and thermal principles, provide more information about configuration, condition, and performance than can be gleaned from visual assessment alone. The availability of digital data and advanced processing capabilities enable earlier detection of deterioration without waiting for visible damage.

FHWA sponsored this research effort to explore the feasibility and economics of incorporating NDE and SM methods into bridge deck preservation strategies for early detection and quantification of changes in bridge deck conditions. These methods can be used to trigger timely preservation treatments that will prevent, delay, or reduce deterioration of existing bridge decks, restore their function, keep them in good

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condition, extend their service lives, and help determine the quality of the preservation treatment. The report documents the state of the practice of NDE and SM and their application to deck preservation decisionmaking. Although SM was considered in this study, the research team found SM to have limited applicability for the evaluation and management of decks as a specific component of a bridge. As a result, the research team did not incorporate SM further into the proposed framework.

The study focused on suitable NDE methods for the range of common wearing surfaces and the associated inputs for selecting preservation actions. The researchers developed a framework to guide the implementation and interpretation of NDE and the selection of treatment alternatives based on the life stage of a bridge deck under consideration.

CURRENT STATE OF PRACTICE

Overview of Types of Bridge Deck Systems and Wearing Surfaces

The researchers conducted a literature review to identify the types of bridge deck systems and wearing surfaces used on highway bridges in the United States. Recent National Bridge Inventory data show that out of a total inventory of 618,456 bridges and culverts greater than 20 ft in length, 430,313 are bridges, excluding bridge-sized culverts (FHWA 2020). Those records indicate that concrete bridge decks are the most widely used type, consisting of 87.3 percent of bridge decks by number of structures. Steel and timber decks represent 3.2 percent and 6.8 percent, respectively. Common defects for each deck type are outlined in table 1.

Because concrete is the most used deck type representing the most structures, the study focused on concrete bridge decks. The wearing surface of concrete bridge decks is the surface over which vehicles ride. The wearing surface may simply be the bare bridge deck or an overlay, such as a cementitious rigid overlay, bituminous overlay, or polymer overlay that has been applied to the top of the bridge deck to address deck deterioration mechanisms. Concrete protective coatings for decks include sealers and membranes. Sealers are not typically considered a wearing surface because they are often quite thin (negligible thickness to less than 0.25 inches), or only present in local areas of the deck.

Reinforcement in concrete structures includes steel bars (deformed plain, epoxy-coated, and corrosion-resistant), wire mesh, and prestressing strands or tendons. Bridge decks often use deformed black bars, but epoxy-coated bars are used for bridges in harsh environments. Fiber reinforced polymer bars have also been employed in some constructions. Different reinforcement types may affect the viability of certain NDE methods.

The literature showed that bridge deck condition assessment primarily focuses on four key types of deterioration: delamination, reinforcement corrosion, cracks, and concrete degradation. Other defects, such as honeycombing, overlay debonding, and carbonation, also impact bridge decks to some extent.

NDE Methods Relevant to Deck Evaluation

Bridge owners and highway transportation infrastructure stakeholders are relying more on NDE technologies to obtain comprehensive information about the condition

Table 1. Common deck and wearing surface defects (AASHTO 2022).

Reinforced Concrete Deck	Prestressed Concrete Deck	Steel Deck	Timber Deck	Wearing Surface
Delamination, spalls, and patch areas	Delamination, spalls, and patch areas	Corrosion	Decay or section loss	Delamination, spalls, patched area, and potholes
Exposed reinforcement	Exposed conventional and prestressing reinforcement	Cracks	Checks and shakes	Cracks
Efflorescence and rust staining	Efflorescence and rust staining	Connection*	Cracks (timber)	Loss of effectiveness
Cracks	Cracks	—	Splits and delaminations	—
Abrasion or wear	Abrasion or wear	—	Abrasion or wear	—
—	—	—	Connection	—

—No data.
*Refers to the absence or presence of loose or missing fasteners, rust, distortion, or fractures that may impact function.

of reinforced concrete bridge elements while incurring the least impact on mobility. Reliable NDE technologies can help limit invasive sampling but still provide the information needed for decisionmaking.

To effectively evaluate the condition of reinforced concrete bridge decks, NDE techniques should be combined with informed, limited destructive probing to obtain ground truth information and perform supplemental laboratory tests. NDE techniques include ground penetrating radar (GPR), impact echo (IE), ultrasonic surface waves (USW), ultrasonic (shear wave and P-wave) tomography (UST), electrochemical half-cell potential (HCP), electrical resistivity (ER), infrared thermography (IRT), hammer sounding and chain drag (HSCD) and automated concrete sounding (ACS). Each method operates on different principles, has unique strengths and limitations, and is suitable for assessing specific structural features or defects (table 2). The selection of techniques depends on the investigation's objectives.

SM identifies and measures structural performance and changes through load paths, component actions, stresses, temperature, humidity, and corrosion. The American Concrete Institute (ACI) Committee 444 outlines SM techniques for concrete structures (ACI 444.2 2021). Bridge assessment typically involves load rating using *The AASHTO Manual for Bridge Evaluation* (AASHTO 2018). Physical testing or monitoring may follow if the capacity does not meet demand. SM ranges from basic (crack widths, deflections) to advanced (corrosion rate, vibration) methods. The selection of appropriate SM technology depends on the bridge deck type. SM is not widely used to assess the condition of bridge decks.

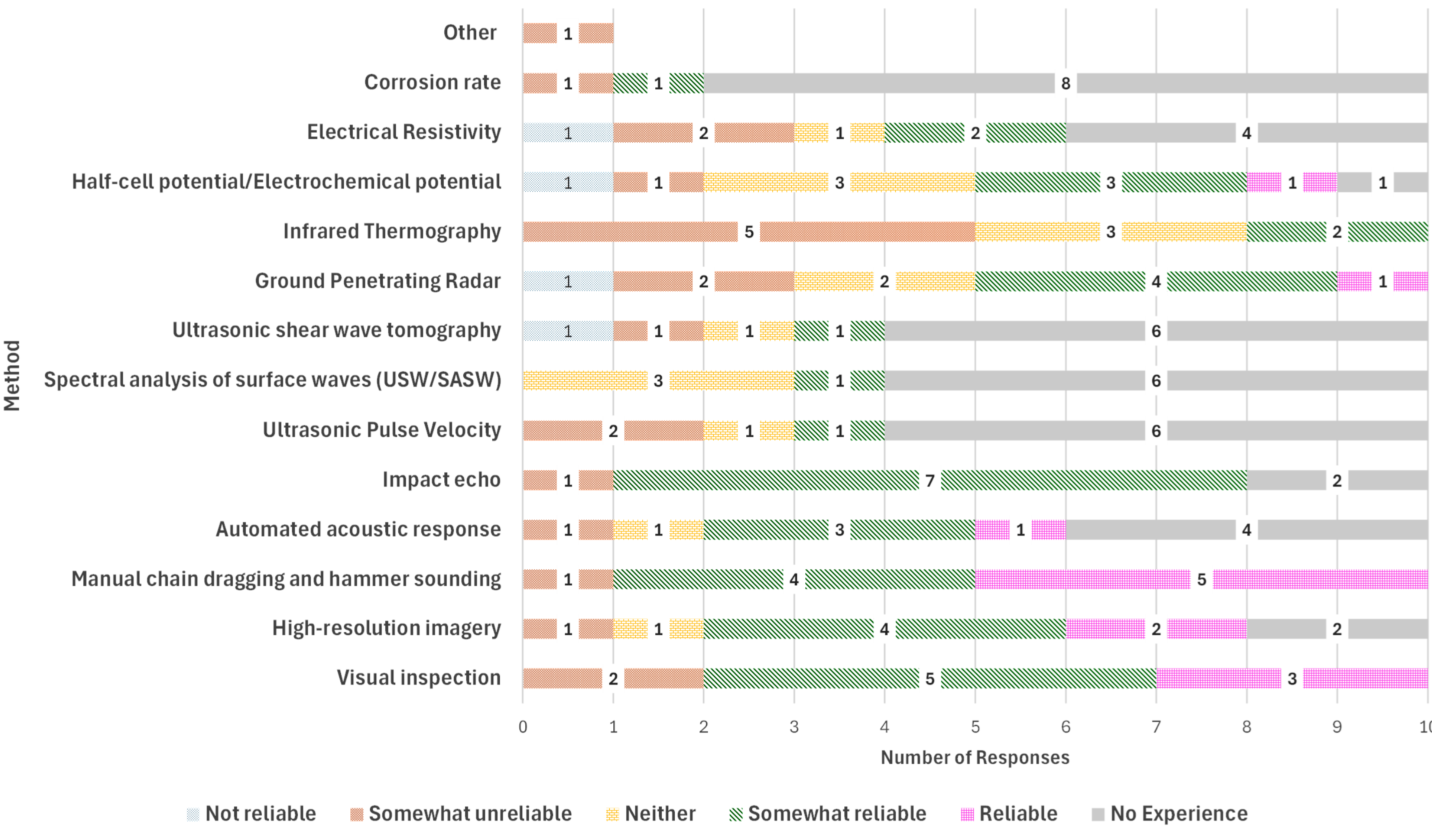
To further evaluate the use of NDE and SM for bridge deck condition assessment, the research team prepared a questionnaire to seek input from State highway agencies (SHAs) with experience using these technologies. Figure 1 presents the reported agency confidence level in NDE methods for concrete deck evaluation.

Table 2. Summary of applicable NDE methods for reinforced concrete decks.

Category	NDE Method	Defect or Deterioration
General	Visual inspection	Identify cracks, spalls, and areas with visual degradation (such as corrosion staining, efflorescence).
	Scanners (photogrammetry, high-resolution image, video, 3D scanning)	Identify cracks, spalls, and areas with visual degradation (such as corrosion staining, efflorescence); identify structural features for location reference and filtering.
Acoustic and stress waves	HSCD	Detect deck delamination.
	IE	Detect and characterize deck delamination or deeper voids.
	USW	Measure elastic moduli and associated degradation.
	UST	Identify embedded reinforcement, detect and characterize cavities, flaws, cracks, honeycombing, and posttensioning grout defects.
	ACS	Detect deck delamination.
Electromagnetic	GPR	Locate and detect internal reinforcement elements. Indirectly detect deterioration caused by corrosion, delamination, voids and honeycombing.
	IRT and IRT-UTD	Identify cracks and areas of suspected water flow, debonded and delaminated concrete.
Electrochemical	HCP	Measure the probability of active steel corrosion.
	ER	Estimate the likelihood of corrosive environment in concrete.
	LPR	Measure corrosion rate.
	GPM	Measure corrosion rate.

3D = three dimensional; IRT-UTD = ultra-time domain infrared thermography; LPR = linear polarization resistance; GPM = galvanostatic pulse method.

Figure 1. Chart. Reported level of confidence in NDE methods for concrete deck evaluation.



Source: FHWA.

The agency feedback on the reliability of the NDE methodologies varies. A perceived average reliability level is discussed based on the responses and feedback from the follow-up interviews.

On average, agencies find visual inspection somewhat reliable and note that it is the method that they have used for the longest time and most frequently, and with which they are most familiar. HRI is reported as somewhat reliable. Some agencies note that HRI tends to be good quality but unsuitable for broad application because using it for the full inventory would be expensive, and HRI will not give input on anything underneath the surface. Manual HSCD were considered overall the most reliable method compared. Chain dragging is perceived as somewhat subjective and more suitable for low-noise environments (not ideal for interstate). A few agencies have seen better results with automated concrete sounding (ACS) (rapid chain data) than other NDE methods and find it desirable for condition assessment to avoid having to do manual chain drag on high-volume roadways.

IE is reported as somewhat reliable, but experience from most agencies was limited to a few trials. The experiences with ultrasonic pulse velocity (UPV), USW/spectral analysis of surface waves (SASW), and ultrasonic Shear Wave Tomography were also limited. The assessment for UPV was somewhat unreliable, for USW/SASW neutral, and for ultrasonic shear wave tomography somewhat unreliable.

GPR is reported to be somewhat reliable, with some agencies noting poor correlation from GPR on repair quantities or “hit or miss” due to inconsistency in application and interpretation. Miscommunication between contractors and regional bridge maintenance personnel has been an issue. GPR does lend itself to rapid data collection with minimal traffic impact. GPR is not assessed as a great tool for finding concrete defects. Overall, agencies note GPR has not been useful in finding delamination but is great for finding steel or areas of high moisture.

Agencies have some experience with IR and assess it as somewhat unreliable and subject to constraints (clean deck, shallow depth limitation, hard to distinguish). IR is subject to weather conditions and shading and is unreliable when deployments do not have enough thermal contrast. Vehicle-based applications were noted to be more reliable than fixed-wing aerial applications.

Agency experience with HCP is broadly variable. In Iowa DOT’s experience, HCP is perceived as somewhat reliable for the probability of corrosion but does not correlate well with delaminations and damage detection. Overall experience with ER is also limited, though some considered it a great test on new concrete for quality assurance. The local environment plays a big role in situ, as moisture content of concrete may vary and influences the results too much. Only two agencies reported experience with corrosion rate measurements, mostly for research purposes. One agency noted that multiple technologies may be needed to obtain a good picture of what is happening in a structure. The full report provides details about the questionnaire's results.

NDE INFORMED PRESERVATION ACTIONS

NDE methods may be used to identify conditions for bridge deck assessment. Several agencies routinely incorporate these techniques. Common NDE methods for bridge deck evaluation and their suitability for detecting specific defects were evaluated, and potential thresholds for action were sought. SM is not generally used for bridge deck condition assessment, which makes preservation thresholds irrelevant for these methods.

Current SHA practices do not rely on NDE to trigger preservation or maintenance actions for bridge decks due to the lack of research to establish thresholds. However, two approaches are proposed for using NDE data to initiate bridge deck preservation and maintenance:

- Approach 1: Focus on using NDE methods to define different element-level condition states for bridge decks. These condition states can then be used to guide the selection of bridge deck preservation strategies based on the input of NDE and other factors.
- Approach 2: Focus on using NDE methods to directly guide the selection of bridge deck preservation strategies. Due to the complexity of this approach, the lack of available literature and supporting data to fully develop NDE thresholds for all the available NDE techniques, and project scope limitations, the research team focused on developing a framework that can be used to establish NDE thresholds for the different methods. Examples of the potential use of NDE methods to guide the selection of bridge deck preservation strategies are provided.

The study outlines these approaches and their resulting NDE thresholds and the strategic deployment of NDE methods to support bridge management objectives throughout a bridge's lifecycle based on age, exposure, and condition.

Condition Rating-Based Preservation Thresholds

Approach 1 aims to establish NDE thresholds for bridge deck preservation and maintenance using condition ratings. SHAs currently employ condition rating-based or element-level data to determine appropriate actions. To align with Approach 1, NDE data need to be converted to inform existing general condition rating and element-level condition state thresholds. For element-level data, overlap between visual inspections, sounding surveys, and NDE techniques allows for a direct translation. However, linking NDE data to general condition ratings is less straightforward due to the aggregated nature of condition ratings. SHAs often use both methods for decisionmaking. Table 3 shows a summary of current preservation and maintenance guidelines from 10 SHAs, and the research team created a table that connects general condition ratings and element-level condition criteria to potential actions.

Table 3. Condition-based bridge deck preservation triggers based on element-level data regarding spalls and delamination.

Rating	Primary Criteria (Defect 1080 Delamination, and Spall, and Patch Area)	Preservation and Maintenance Action
9*	0 percent spalls and delamination.	Surface sealer, do nothing.
8	0 percent < spalls and delamination <2 percent.	Repair and surface sealer, fill cracks, thin-polymer overlay.**
7	2 percent < spalls and delamination <5 percent.	Repair and surface sealer, fill cracks, thin-polymer overlay, HMA + membrane, premixed polymer overlay.
6	5 percent < spalls and delamination <10 percent.	Repair and mill and hydrodemolition and HMA + membrane, premixed polymer overlay, and rigid overlay.
5	10 percent < spalls and delamination <20 percent.	Repair and mill and hydrodemolition and HMA + membrane, premixed polymer overlay, and rigid overlay.
4***	20 percent < spalls and delamination <30 percent.	Repair and mill and hydrodemolition and late-life asphalt overlay, rigid overlay, and replace.
3***	30 percent < spalls and delamination.	Replace, mill, and hydrodemolition and late-life asphalt overlay, repair, and rigid overlay.

*Some agencies place a sacrificial and protective layer at construction, such as HMA with membrane or dense concrete overlay.
**Some agencies do not apply polymer overlays until they reach a certain maturity.
***Not considered as preservation actions.
HMA = hot-mix asphalt.

Most Suitable NDE Methods for Deck Condition State Assessment

While all of the methods identified by the study have applications for evaluating the condition or configuration of reinforced concrete elements, the following methods can be currently deployed on a broad production basis to assess relatively large surface area elements like a bridge deck. Other methods are typically applied pointwise and require too much time, maintenance of traffic, and analysis to be broadly used for preservation decisionmaking on a bridge inventory.

High-Resolution Imagery: Digital photography significantly enhances field inspections by making it simpler to collect, document, and archive high-resolution images of structural components' visible conditions. Geotagging features in modern digital devices provide precise location references, which enable large-area surveys using vehicles or drones equipped with georeferencing and distance measurement tools. Advanced image processing algorithms allow the creation of large-scale composites or 3D renderings by stitching together multiple images. Advances in machine learning and improved image resolution enable fine details like crack widths to be identified, which provides more accurate analysis than previously available. Digital image correlation can monitor short-term changes by comparing a sequential series of images to measure strain fields for monitoring structural responses.

GPR: GPR is a widely used NDE method for locating embedded elements such as steel reinforcement and posttensioning ducts in concrete structures like bridge decks. The technique provides quick data acquisition through various platforms and offers information about cover depth, embedded element locations, and wave attenuation. Cover depth assessment helps to evaluate concrete protection against corrosion and to determine safe milling depths for deck rehabilitation. Attenuation can indicate regions of high moisture content, voids, fractures, or corrosion but cannot distinguish among them precisely. GPR is not the best method for directly detecting delamination but can identify areas with higher deterioration risk resulting from shallow cover, high moisture content, and potential active corrosion.

Acoustic Wave Methods: Acoustic methods have been effective for detecting concrete defects, like shallow voids or delamination, using techniques such as HSCD. However, these methods are subjective based on human hearing limitations and external factors such as ambient noise. Automation through portable microphones, analog-to-digital conversion, and digital filtering has improved precision and objectivity. Impact or vibration induces an audible concrete response, which is then filtered to isolate relevant frequencies that correlate to defects and create precise maps of findings. The IE method uses geophones and employs the fast Fourier transform, which transcribes waveforms from the time domain (amplitude versus time) to the frequency domain (amplitude versus frequency), to assess the absence or presence of flaws and their depths. IE requires point measurements rather than large-area mapping in realtime.

IRT: IRT uses specialized cameras to detect heat emissions from structural elements in the infrared spectrum, which reveals defects such as delamination or voids filled with water or air that affect heat transfer rates. Modern IRT cameras have improved resolution, precision, and data collection speed for use in hand-held, unmanned aircraft systems, or vehicle-mounted surveys. Significant temperature fluctuations are necessary for optimal thermal contrast between defects and the base element, and inclement weather can hinder adequate heat transfer, leading to false negatives. False positives may result from ignoring influences like variations in shade, surface reflectivity, and material changes. IRT can document large areas quickly but requires careful analysis. Time-lapse infrared imaging (ultra-time domain infrared thermography) for subsurface defect detection limits the influence of weather conditions but requires prolonged data collection from fixed points of reference and advanced analysis.

Electrochemical HCP: The HCP method evaluates corrosion risk in embedded steel reinforcement by measuring the voltage difference between the steel inside the concrete and a reference electrode, such as copper-copper sulfate or silver-silver chloride. An electrochemical cell is established via electrical contact with the reinforcement through a voltmeter and to a reference cell on the concrete surface. The ionic path of the concrete paste pore structure completes the circuit. The method's effectiveness depends on the reinforcement grid being electrically continuous, and nonconductive layers like paint or coatings can impact results. Lane closures are necessary for pointwise HCP tests of bridge decks, making it less efficient for large scale production but valuable for assessing project-level repair needs.

Framework for NDE-Specific Thresholds

Approach 2 focused on developing a framework for establishing direct NDE thresholds to initiate preservation measures for common concrete bridge decks in the United States. The objective is to create triggers primarily based on NDE data, building on the use of NDE data for condition ratings and maintenance decisions outlined in the previous section. However, Approach 2 is intricate because it requires using NDE in specific situations that may not easily be generalized and for which the literature available for developing comprehensive NDE thresholds is limited across the range of potential techniques. The research team developed the framework considering specific NDE methods to target certain types of deterioration in concrete bridge decks at different life stages.

PRESERVATION DECISION MATRIX TO INCORPORATE NDE METHODS INTO BRIDGE PRESERVATION STRATEGIES

NDE can aid bridge preservation decisions from new construction through rehabilitation. Figure 2 outlines potential uses of NDE, including current applications and anticipated results.

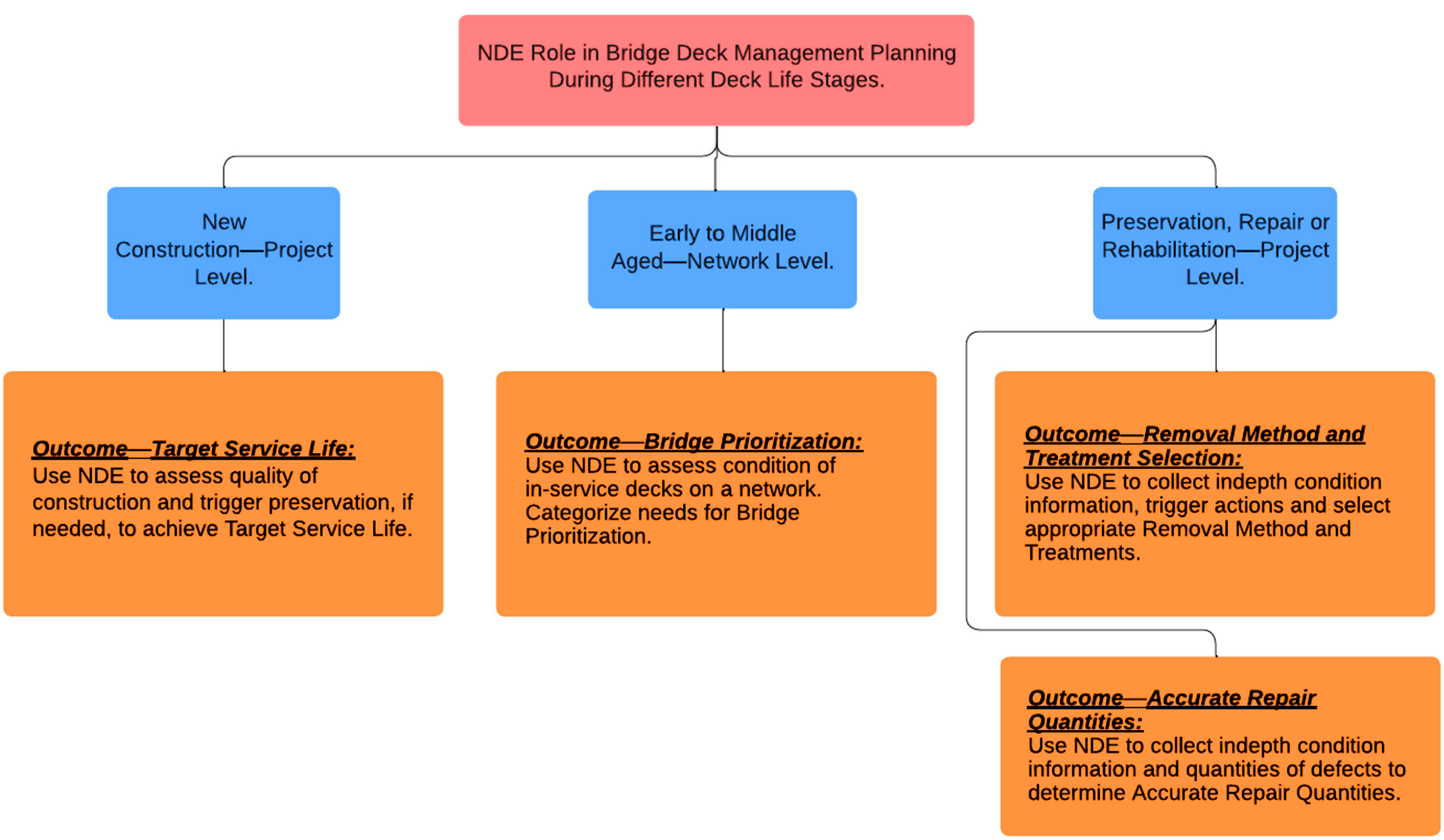
In this study, a methodology is proposed for integrating NDE techniques into bridge preservation strategies using decision matrices. The types of information that are useful and the effectiveness of various NDE methods depend on the age of the bridge decks. The framework outlines decision matrices that will suggest preferred NDE application timing and establish triggers for preservation actions based on NDE outputs.

The research team categorized the recommendations for applying NDE techniques using different life stages of bridge decks: new construction, early- to middle-aged bridges, and bridge deck preservation, repair, or rehabilitation. For each stage, the team created decision trees that target specific characteristics (concrete cover, cracking, and damage) of a bridge deck or network of decks, along with recommended NDE techniques. The researchers developed use cases to illustrate how to create state specific decision matrices using this framework to initiate preservation or maintenance actions based on NDE data. Details of the use cases are in the full report.

New Construction Decision Tree—Project Level

For new bridge construction, NDE techniques primarily serve quality assurance purposes to ensure that the deck is constructed as intended. Concrete cover and early-age cracking are key factors that can influence bridge deck service life. The concrete cover protects reinforcement from corrosive elements, while cracks allow a direct path for contaminants. Magnetometers and GPR both measure concrete cover reliably, but GPR offers faster data collection.

Figure 2. Diagram. Applications and outcomes of NDE during the life of a bridge deck.



Source: FHWA.

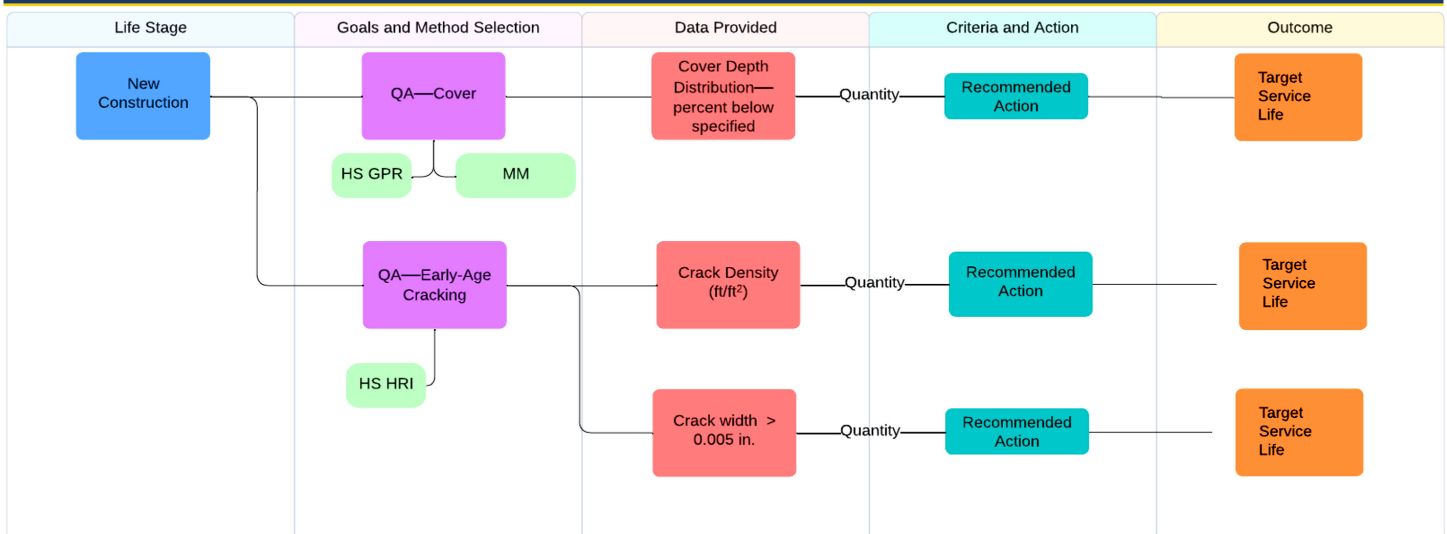
Crack mapping via high-resolution imagery automates traditional manual inspection and enables the triggering of preservation actions based on crack density and width. The conceptual decision tree in figure 3 includes the life stage, recommended methods for cover depth or crack density and width, data provided, and corresponding outcomes. Detailed decision trees with example criteria for the two specific cases of concrete cover and cracking can be found in the full report.

Bridges in the early- to middle-aged life stage have been in service long enough to potentially experience significant environmental deterioration. The optimal timeframe depends on factors such as exposure conditions, concrete properties, and reinforcement type. NDE techniques can detect damage at this stage for effective resource allocation in bridge preservation and maintenance. High-speed methods are suitable for inspecting a network of bridges without lane closures or extended downtime as follows:

- Approximate damage area, percent delamination: high-speed automated acoustic sounding (HS ACS) or high-speed infrared thermography (HS IRT).
- Approximate damage area, percent spalls and patches: high-speed high-resolution imagery (HS HRI).
- Approximate susceptible area, percent areas of high attenuation: high-speed GPR (HS GPR).

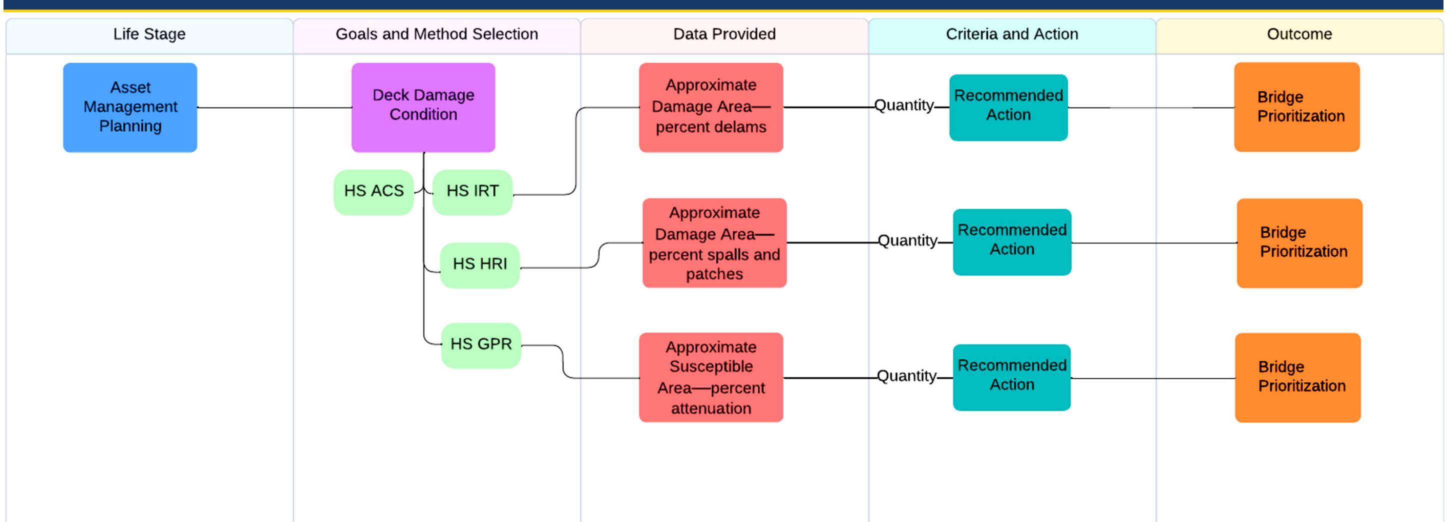
The conceptual decision matrix (figure 4) guides the use of NDE techniques for managing early to middle-aged bridge decks. The full report includes detailed decision trees with criteria for the three specific cases.

Figure 3. Diagram. Decision tree framework for using NDE data to trigger preservation actions for new construction.



Source: FHWA.
MM = magnetometer; QA = quality assurance.

Figure 4. Diagram. Decision tree for using NDE data for asset management planning of early- to middle-aged bridge decks.



Source: FHWA.

Preservation, Repair, or Rehabilitation Decision Tree—Project Level

For in-service bridge decks, several factors can guide the selection of preservation and maintenance actions, including a detailed assessment of damaged areas, susceptible areas, and cover depth distribution. NDE can provide accurate repair quantity estimates that aid in distinguishing between available options like surface treatments versus overlays. For these applications, low-speed NDE methods are generally preferred for their increased reliability as follows:

- Detailed damage area, percent delamination: low-speed hammer sounding and chain dragging (LS HSCD), low-speed automated acoustic sounding (LS ACS), low-speed infrared thermography (LS IRT), or low-speed impact echo (LS IE).
- Detailed damage area, percent spalls and patches: low-speed high-resolution imagery (LS HRI).
- Detailed susceptible area: low-speed half-cell potential (LS HCP).
- Detailed cover depth distribution, cover depth inches: low-speed GPR (LS GPR).

The research team developed a conceptual decision matrix (figure 5) with information on the bridge deck life stage and recommended NDE techniques for damage assessment, susceptible areas, and cover depth distribution, and their corresponding actions and outcomes. Detailed decision trees with example criteria for the four specific cases are in the full report.

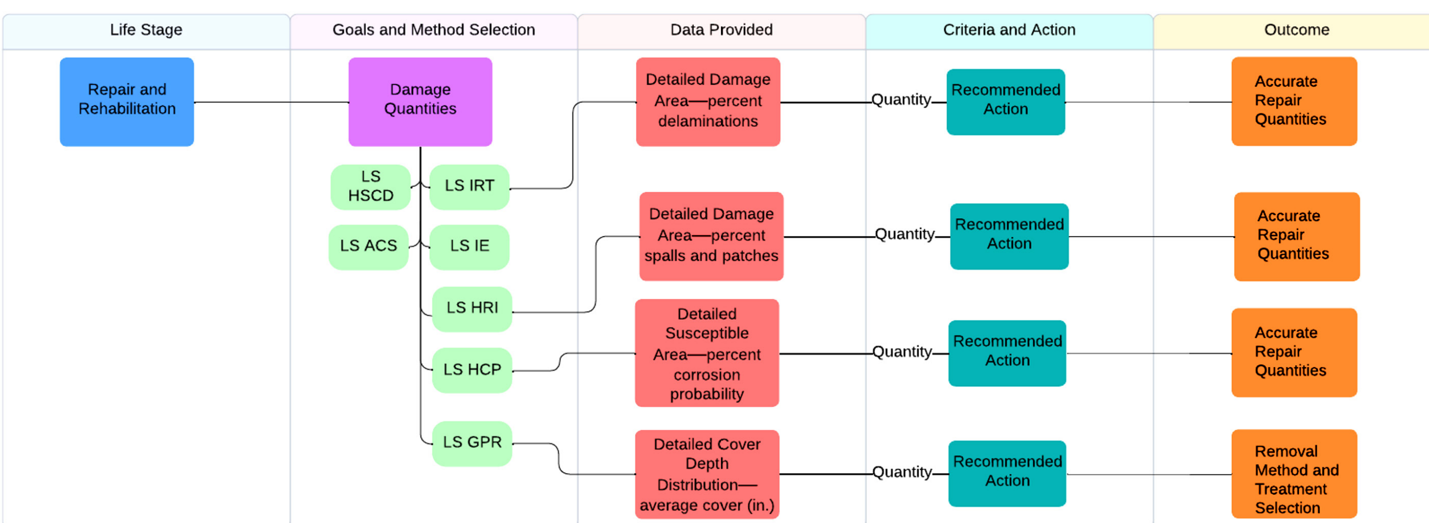
Decisionmaking

Synthesis of NDE methods: Multiple NDE methods can enhance bridge assessment by providing information on various parameters or damage types. Using multiple parameters and NDE methods increases the reliability of assessments and improves data quality for informed decisionmaking, such as preservation, repair, or rehabilitation plans. For instance, percent delamination data are essential, but HCP data can reveal additional imminent damage areas. Engineers must synthesize this information through evaluation and judgment. The benefits of using multiple techniques often outweigh the costs, according to case examples presented in the full report. Researchers at FHWA continue to further investigate the return on investment for NDE data.

Other considerations: Material testing can inform about other factors, such as concrete diffusion coefficients and chloride content, which influence decisions on bridge deck preservation. These indicators help assess corrosion risks and inform service life modeling. A calibrated model estimates potential damage and treatment benefits, aiding in cost effective decisionmaking for bridge repairs. Finally, decision trees are presented as guidance, but engineering judgment remains crucial for a suitable option selection.

Selection of appropriate actions: The developed decision trees demonstrate how NDE data can inform preservation and maintenance actions for bridge decks. Overlapping threshold limits exist in some instances, while multiple repair alternatives may apply based on deck condition.

Figure 5. Diagram. Decision tree for using NDE data for preservation, repair, or rehabilitation of bridge decks.



Source: FHWA.

Technical evaluation is necessary to determine the best choice, which often involves nontechnical factors. Engineers must assess the advantages and disadvantages of each option, considering purpose, desired service life extension, lifecycle cost, and traffic disruption associated with each option.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, various NDE techniques exist for evaluating bridge deck conditions with differences in principles and data output. Confidence in these methods varies among SHAs, which highlights the need for consistent application and proper use. SM is rarely used for the assessment of bridge decks in current practice. Commonly used NDE methods include high resolution imaging, GPR, acoustic wave methods, IRT, and HCP. NDE complements traditional visually based condition states for decisionmaking, but few agencies use it as the primary input. A framework for the use of NDE during different life stages of bridge decks was developed in this project. The framework considers the use of different NDE methods that are most applicable to certain parameters that can be measured and tied to the expected service life of bridge decks. Examples of the framework are presented in three life stages of a bridge deck: new construction, early to middle age, and bridge deck preservation, repair, or rehabilitation. The study demonstrated that NDE costs are often negligible in comparison to the potential benefits or savings that could be realized during the deck lifecycle by making informed decisions.

The framework can help individual SHAs create State-specific decision matrices for using NDE to guide preservation or maintenance actions for bridge decks. To do this effectively, States should develop NDE inspection manuals that outline the various techniques applicable to each bridge life stage, standard procedures for data collection, and NDE threshold values for follow up actions and decision matrices. The study identified the following research gaps:

- Creating methods to combine data from multiple NDE techniques and link specific actions to criteria on a resulting standardized scale.
- Providing consistent guidelines for applying various NDE methods in bridge deck assessments (e.g., NDE pocket guides).
- Developing a standardized method to incorporate NDE data into bridge management systems.
- Establishing correlations between predictive NDE methods and the deterioration rates they represent.
- Connecting NDE outputs directly to physical deterioration models rather than relying on statistical analysis based primarily on age.

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