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20.1 Reinforced Concrete Bridge Deck Evaluation Introduction

The evaluation of a reinforced concrete bridge deck involves using the information available from visual inspection, non-destructive testing, and material tests to determine appropriate repair or preservation activities. Deck evaluations can be complex due to the number of variables that must be considered to determine the appropriate repair or treatment method. The following chapter describes the tools and techniques used to gather deck information, a description of the key deck decision variables, and a reinforced concrete deck evaluation methodology.

For additional evaluation and treatment methods, please see:
http://maintenance.transportation.org/documents/final_nchrp%20guidelines%2020-07%20task234_wje%20_comments%205-19-09.pdf

20.2 Deck Investigation Techniques

20.2.1 Introduction

Reinforced concrete bridge deck investigations should be carried out in a progressive manner as conditions or field findings warrant. The deck investigation progression typically begins with a visual assessment of the condition of the deck. The visual condition assessment consists of looking for cracks and spalls or other visible distress on the top and bottom surface of the deck or slab. In some cases, a deck delamination survey may be conducted during a routine NBI bridge inspection. The delamination survey typically consists of chain or hammer sounding or NDE testing to determine the delaminated concrete area and may cover portions or the entire surface of the deck. If the visual assessment and delamination survey reveal no issues then further investigation is not typically warranted. If on the other hand, the visual condition assessment and delamination survey identifies conditions that warrant further evaluation, the investigation can progress to include more detailed field tests, and/or material sampling to determine the appropriate repair or preservation treatment.

20.2.2 Preparing for a Reinforced Concrete Deck Investigation

A reinforced concrete bridge deck investigation should begin with a review of as-built plans and the history of prior inspections and testing that may have been done. The agency's records of prior NBI bridge inspection reports and any deck testing reports for the bridge should be consulted. The as-built plans and inspection history should be reviewed to determine as many of the items shown in Table 20.1 as possible. An engineer supporting the bridge maintenance activities should be consulted for information related to past inspection information and past testing results and for a recommendation of the appropriate deck investigation strategy.

Table 20.1 Deck Investigation Preparation

Deck Attributes	Key Information
Type of Reinforcing Steel	What is the reinforcing material (black steel, coated steel, galvanized steel, stainless steel, fiber reinforced polymer)? The reinforcing type will impact corrosion rates.
Material Specifications	What is the 28 day compressive strength of concrete (f'c) and the yield strength of the reinforcing (fy)?
Reinforcing layout	What is the size and spacing of the deck reinforcing? Some deck cracking will follow reinforcing lines.
Design Concrete Cover	How thick is the concrete protection over the top of the reinforcing? Concrete cover can impact corrosion rates.
Deck Structural Thickness	What is the overall deck section thickness? The overall thickness can influences deflection and cracking.
Girder/Deck Connection	Is the deck composite (i.e., rigidly attached to the girders with studs) or non-composite (i.e., not rigidly attached)? Deck performance may be impacted by the connection to the superstructure.
Girder Spacing	Identify the distance that the deck must span between girders. The deck must transfer wheel loads laterally to the girders. The girder spacing can influence deck deflections and cracking.
Prestressed or Post-Tensioned Girders	Are the girders prestressed or post-tensioned? Stressed girders may creep and shorten and could cause deck cracking.
Overlays, Membranes, Cathodic Protection Systems	Any records related to wearing surface materials, membranes or cathodic protection systems and placement dates should be noted.
Widening History	Are all the sections of the deck the same? Widenings introduce the potential for varying condition and performance limits over the deck area.
Surface Drainage Information	Where does all the water on the deck go? Is the deck crowned or on a super-elevation? Where are the longitudinal drains? Does the deck experience snow, salting, freezing temperatures?
Deck Inspection History	Review the inspection history to identify when deck distress may have been first noticed and the rate of progression of the deterioration.
Previous Material Tests	Review any previous deck material test. The previous tests can provide baseline results and possibly help explain the cause of field observed conditions.
Maintenance and Repair Records	Review the maintenance history for the bridge previous actions taken, products used and performance of past products.

20.2.3 Field Tools

The bridge inspection records and as-built plan review will usually provide clues to help determine what tools will be necessary for an in depth deck investigation. The following section describes the tools typically used for the inspection and testing of reinforced concrete bridge decks:

- Geology Pick or Hammer – The geology pick is commonly used to tap localized areas of a bridge deck to listen for potential delaminations.
- Rag Tape or Rolling Distance Measurement Device – A distance measuring device is necessary to help lay out a grid on the deck so that identified defects and test measurements can be located within the deck area.
- Crack Comparator – A crack comparator is a clear plastic credit card sized sheet with crack sizes shown along the edges. The crack comparator is placed on the concrete crack and moved up or down the crack scale until the exact crack with is determined. An example of a crack comparator is presented in Figure 20.1.

Figure 20.1 Crack Comparator

- Deck Chain – Delamination surveys done on larger areas of bridge decks are typically done with a deck chain. The deck chain may be a simple single chain or a T-bar with a number of short chain stands that hang off the bottom of the bar. The deck chain is dragged across the bridge deck in a systematic manner while the deck investigator listens for frequency changes in the resulting sound. Delaminated concrete can be readily identified by the hollow sound that emanates from the concrete when the chain passes over the delamination. An example of a T-bar deck chain is presented in Figure 20.2. (Deck chaining was previously presented in Section 5.4.3 Non-Destructive Evaluation (NDE) Techniques.) Deck chaining however is not effective if there is an asphalt riding surface.

Figure 20.2 T-bar Deck Chain

- Ground Penetrating Radar (GPR) – GPR equipment can be used as an alternative to deck chaining or impact echo methods to determine the areas of delaminated concrete. The GPR method involves sending electromagnetic waves into the deck surface from the GPR antenna and measuring the return strength. The internal makeup of the deck being investigated can then be mapped including rebar locations, depths, concrete cracking and voids. An example of a ground penetrating radar schematic is shown in Figure 20.3, and a van-mounted ground penetrating radar system is shown in Figure 20.4. GPR was also discussed in Sections 5.4.3.7 Advanced NDT Techniques and 16.2.1 Inspection of Masonry Bridges.

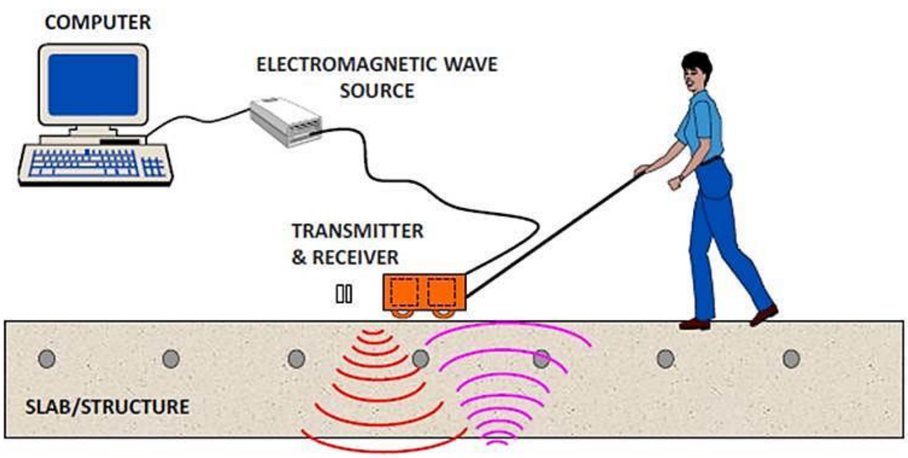

Figure 20.3 Ground Penetrating Radar Schematic

Figure 20.4 Van Mounted GPR

- Impact Echo Testing – An impact echo device is used to identify and locate the limits of delaminations below the concrete surface. The impact echo device mechanically impacts the deck at grid points and records response sound waves (echoes) that bounce back from internal flaws before reaching the bottom edge of the deck. Delaminations internal to the deck will cause the sound to bounce back faster than expected allowing the computer to determine the depth of the flaw. Impact echo testing has been proven to be very effective at locating delaminations in concrete. An example of impact echo testing equipment is shown in Figure 20.5. Impact echo testing was also discussed in Sections 5.4.3.7 Advanced NDT Techniques and 16.2.1 Inspection of Masonry Bridges.

Figure 20.5 Impact Echo Testing Equipment

- Coring Equipment – Drilling and coring equipment may be necessary to collect concrete samples for laboratory testing or to expose reinforcing steel for field corrosion testing. An example of concrete deck coring equipment is shown in Figure 20.6. Coring was also introduced in Section 5.4.4 Destructive Testing.

Figure 20.6 Concrete Deck Coring Equipment

- Pachometer – A handheld pachometer (i.e., cover meter) is typically used to locate reinforcing steel beneath the concrete deck surface. The pachometer can also determine the depth of concrete cover over the steel without disturbing the concrete. An example of a pachometer device is shown in Figure 20.7. The pachometer was previously introduced in Section 5.4.3.4 Corrosion Survey in Chapter 5 – Concrete Basics.

Figure 20.7 Pachometer Device

- Potentiometer – A potentiometer will be necessary if the investigation includes half-cell corrosion potential testing. The potentiometer may be a handheld digital device or tube device with a wire and probe on one end and a rebar attachment device on the other end. The current between the concrete and steel is measured. An example of a potentiometer is shown in Figure 20.8.

Figure 20.8 Potentiometer

20.2.4 Traffic Management

Detailed deck investigations typically require lane closures to properly assess the condition of the deck. Most agencies have standard lane closure plans that can be used to safely shut down one or more lanes on the bridge for the deck investigation. The Federal Highway Administration also produces the Manual for Uniform Traffic Control Devices (MUTCD) that provides traffic control plans for commonly occurring closure situations.

20.2.5 Inspection Grid Layout

A deck investigation requires detailed note taking of field measurements and conditions. The best way to get accurate field investigation notes is to lay out a grid pattern on the deck to demark smaller sections of the deck that can be individually assessed and reported. The size of the grid can vary depending on the nature of the distress being investigated and the overall size of the deck. Common grid layouts range from 2 by 2 feet to 5 by 5 foot grids. The accuracy of some field measurements, such as half-cell testing, can have significant loss of accuracy as the grid size increases from 2 feet to 5 feet.

The grid can be established in the field by marking fixed intervals on the deck with spray paint or chalk using a rag tape measure or rolling distance measuring device (see Figure 20.9). Once the grid has been laid out within the closure limits, the investigation can begin. Notes are taken grid by grid to quantify field measurements and distress within the defined localized area of each grid. The investigation progresses until all grids of the deck have been investigated. Each grid assessment is like a single piece in a puzzle, when all the grid results are documented a picture of the extent and nature of distress emerges.

Figure 20.9 Field Grid Layout

20.2.6 Visual Deck Inspection

Visual inspection of reinforced concrete bridge decks provides the inspector with information that can be used to determine if more in-depth investigation or testing is warranted. Visual indicators of bridge deck deterioration or potential for deterioration include: cracking, spalling, abrasion, scaling, efflorescence, rust staining, and freeze thaw damage.

What To Look For

Indicators of bridge deck deterioration, such as cracking, spalling, abrasion, scaling, efflorescence, rust staining, and freeze thaw damage.

20.2.6.1 Deck Cracks

The severity of deck cracking is classified based on the frequency, width and length of the cracks. Deck cracks can be classified into several basic types generally based on the orientation of the cracking or the crack patterns produced. Typical crack types and causes are shown in Table 20.2.

Table 20.2 Typical Crack Types and Causes

Crack Type	Cause	Orientation
Shrinkage cracks (Plastic and Drying Shrinkage)	Concrete drying too quickly	Well-defined widely spaced pattern with shallow and wide cracks
Stress Cracks	Stresses in the concrete exceeding tensile capacity	Pronounced on stress lines, typically transverse or diagonal
Settlement Cracks	Settlement of hardened concrete	They can be of any orientation and width
Map Cracks	Reactions between the cement and aggregate (alkali-silica and alkali-carbonate reactions)	Map cracks are a closely spaced uniform pattern over large areas
Corrosion Induced Cracks	Expansion of corroding reinforcement	Oriented along reinforcement lines
Restricted Movement Induced Cracks	Temperature expansion and contraction of concrete that is restricted	At acute corners of skewed bridges

Regardless of cause, reinforced concrete bridge deck cracking creates potential pathways for water and salts to penetrate the concrete matrix and cause deterioration of the concrete or reinforcing steel. Minimizing reinforced concrete deck cracking through proper mix design, placement and curing methods will improve the service life of the deck. When cracks occur, sealing the cracks or applying other preservation treatments that minimize the ingress of water and salts will extend the life of the bridge deck.

20.2.6.2 Deck Spalls

Decks spalls can be caused by pressure exerted by the corrosion of reinforcement and the resulting expansion that causes cracking beneath the surface of a bridge deck in a plane parallel to the roadway surface. The cracked concrete is pounded by traffic ultimately causing it to break off completely as a spall. The spalled area left behind is characterized by sharp edges on the sides and bottom of the area. Spalls can also be caused by vehicular forces on exposed concrete edges such as deck joints or construction joints. Additionally, spalling may be caused by overloading of the concrete in compression (commonly from restricted thermal expansion). This results in the breaking off of the concrete cover to the depth of the outer layer of reinforcement.

Spalls are visible during a deck inspection and are typically reported using the area spalled out and the depth of the spall. Spalls often occur in areas where delaminations are occurring. The area around a spall should be hammer tapped or chained to determine if there is any delaminated area outside the limits of the spall. Delaminated areas surrounding a spall should be chipped out and patched when the spall is repaired. For more information regarding concrete repair, please refer to Section 11.1.3 Spall and Crack Repair and 11.5.3 Concrete Superstructure Patching.

20.2.6.3 Abrasion and Rutting

Abrasion of the top surface of concrete bridge decks can occur from the wearing action of studded tires, snow chains and snow plows. Abrasion is most often found in the wheel lines of the lanes only. The abrasive action slowly chips away the top layer of cement in the concrete exposing the aggregate below the surface. If abrasion is allowed to progress over time, ruts can develop in the wheel lines of the deck. Rutting is characterized by shallow depressions in the wheel lines caused by the concrete being worn away from abrasion. If left untreated, abrasion and rutting tend to attract water and salts into the depression, and expose the concrete matrix which may accelerate the ingress of chlorides.

20.2.6.4 Scaling

Scaling is the deterioration of the upper quarter to half inch of the concrete deck surface and is characterized by the peeling or flaking away of the surface concrete. Scaling results from repeated freezing and thawing of concrete at high moisture levels. Freezing water held in the concrete expands and causes deterioration of the concrete. The effects of scaling are accentuated by the presence of deicers and salts. Scaling decks will often have the course aggregate exposed and some of the aggregate may have been dislodged by the lack of sound concrete paste holding it in place.

20.2.6.5 Efflorescence

Efflorescence is a white crystal residue that results when salt laden water reaches the surface of the concrete, evaporates, and salt deposit is left behind. There are different types of salts, and efflorescence on bridges is most often caused by salts that were in the original concrete ingredients. Efflorescence is common on the underside of reinforced concrete bridge decks at cracks or other areas of high permeability. Although efflorescence is harmless, it is an indicator that water is moving through the deck at that location, and the water is likely to contribute to reinforcing steel corrosion and possibly freeze/thaw damage. Advanced efflorescence may result in crystallized deposit building up over time to form stalactites that protrude down from the underside of the bridge deck. A photographic example of efflorescence is shown in Figure 20.10.

Figure 20.10 Typical Soffit Crack with Efflorescence

20.2.6.6 Rust Staining

Rust staining visible on the top surface, or soffit, of the deck is a clear indication that corrosion is actively occurring within the reinforced concrete deck. Rust staining on the soffit is also an indication of areas where water is passing through the deck from above. The location of all rust staining should be noted during the deck investigation to support other evidence of reinforcing steel corrosion at that location.

20.2.6.7 Follow the Water

Water is a conveyance method for chlorides and can cause deterioration in the concrete on its own. When conducting a deck investigation, it is important to understand the flow of surface water. By following the water path, the investigator can quickly locate high deterioration risk areas on the deck. When in the field, take note of the cross slope of the deck. Does the water flow to one side or both? Note how the water flows along the length of the bridge. Are there deck drains at low points along the deck or does the water flow off the bridge? If there are construction joints that may be more permeable than the surrounding deck concrete, focus attention there particularly if the construction joint is at a low point in the deck. The investigator should also look at the profile of the deck and rails to identify any potential low points that resulted from poor grade setting during construction. The low points will tend to have more moisture and chlorides than other areas of the deck, increasing chances of deterioration.

20.2.6.8 Freeze Thaw Damage

Freezing causes a nine percent expansion in the volume of water held in concrete cracks and pores. The freezing expansion of the water can cause pressure to build up in the cracks and pores causing localized fractures. Freeze thaw damage is usually isolated near the top surface or edge of the deck.

20.2.6.9 Evaluating Decks with Wearing Surfaces

When the bridge deck top surface is covered with an overlay, visual inspection cannot quantify cracking or spalls unless they reflect through the wearing surface material. In these situations, other indicators of deck deterioration must be used to assess the condition under the wearing surface. Cracking in the underlying deck is not of significant concern if the wearing surface is protecting the deck and does not have cracks or spalls, and if the wearing surface is low permeability or impervious. If the wearing surface is cracked, spalled, or delaminated, these conditions can be addressed using many of the same sealing and patching methods used for decks without wearing surfaces. Soffit conditions such as spalling, cracking and efflorescence or rust staining can provide clues to the condition of the deck under the wearing surface. If the underlying deck is suspected to have significant deterioration under the wearing surface, sections of the wearing surface can be removed for visual inspection. Alternately, core testing can be conducted to ascertain the deck condition.

20.2.6.10 Evaluating Decks with Stay-in-Place Forms

Stay-in-place forms are used in many areas to speed up forming and construction of bridge decks. Stay-in-place forms eliminate the possibility of visually inspecting the underside of the deck for cracking, efflorescence, rusting and spalling. If the top surface is visible for inspection, the deck investigation should use only to the top surface visual findings. Sometimes, the top surface is covered with a wearing surface and the soffit is covered with stay-in-place forms. In this case, the deck investigation must rely on non-destructive testing methods and coring to determine the condition of the deck sandwiched between wearing surface and stay-in-place forms.

20.2.7Material Testing

20.2.7.1 Determining Chloride Content

Reinforced concrete bridge decks exposed to deicing salts and seawater are vulnerable to the ingress of chloride ions. High chloride content in concrete encourages corrosion of steel reinforcement by destroying the passive protective layer on the reinforcement. Loss of the passive protective layer leads to corrosion in the reinforcing bar. The most damaging chlorides can be found in the concrete pore water and travel through cracks and voids in the concrete matrix. The application of deicing salts causes ice and snow to melt creating a highly concentrated chloride solution. The chlorides in the pore water are the principal cause of breakdown in the passive oxide film protecting the reinforcement from corrosion.

20.2.7.2 Determining pH Levels

The pH levels in concrete can be lowered to levels that cause the reinforcing steel to corrode through carbonation of the concrete. In the presence of moisture, carbon dioxide from the air reacts with materials in the concrete to form calcium carbonate and carbonic acid. Both of these products can lower the alkalinity of normal concrete, so that the pH is below the level at which the protective oxide film on the reinforcing steel is stable. Without the protective oxide film, the reinforcing steel begins to corrode. The degree of carbonation can be determined by measuring the amount of calcium carbonate through a petrographic analysis (petrographic analysis will be discussed in Section 20.2.7.4). The depth of carbonation is measured with a phenolphthalein color test, which determines the pH of concrete. In poor-quality, carbonated concrete (pH of 9.0 to 9.5), the phenolphthalein solution remains colorless. In high quality, noncarbonated concrete (pH of 12.5 or greater), the solution turns pink. An example of a petrographic cross section used to measure carbonation depth is shown in Figure 20.11.

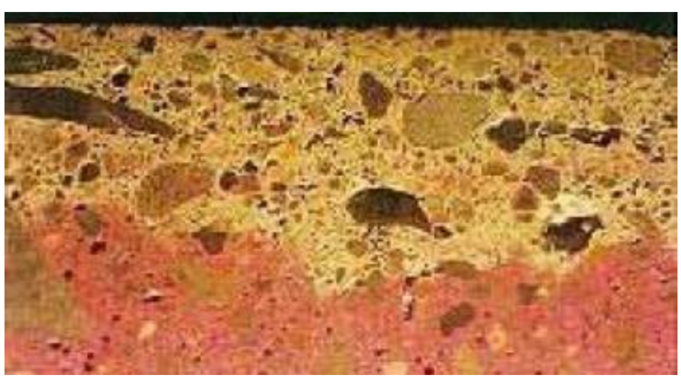

Figure 20.11 Phenolphthalein Reveals Noncarbonated Areas

20.2.7.3 Determining Concrete Compression Strength

Bridge deck concrete has specified minimum compression strength requirements that typically range from 2,500 psi to 5,000 psi after a 28 day cure. The compression strength of any in-situ concrete deck can be evaluated by extracting cores and testing the material to failure in the lab.

The lab will report the compressive stress that caused the core sample to fail. The results from the lab can be compared to the design compressive strength to determine if the capacity of the deck has been reduced. Compressive strengths of concrete can diminish over time due to alkali silica reactivity (which will be discussed in Section 20.3.4), freeze thaw damage, and excessive cracking.

20.2.7.4 Petrographic Analysis

A petrographic analysis looks at the microscopic structure of the concrete using a petrographic microscope. Very thin slices of concrete from a concrete core sample are examined to determine characteristics of cracking, air entrainment, reactive aggregates, effect of fire exposure, carbonation, and many other properties of the hardened concrete. Petrographic analysis is very thorough but is significantly more expensive than other test methods used for concrete deck investigations. The high cost of the petrographic testing typically limits the use of this test to decks first evaluated using other investigation methods and found to have problems. An example of a petrographic analysis of a shrinkage crack in concrete is shown below in Figure 20.12.

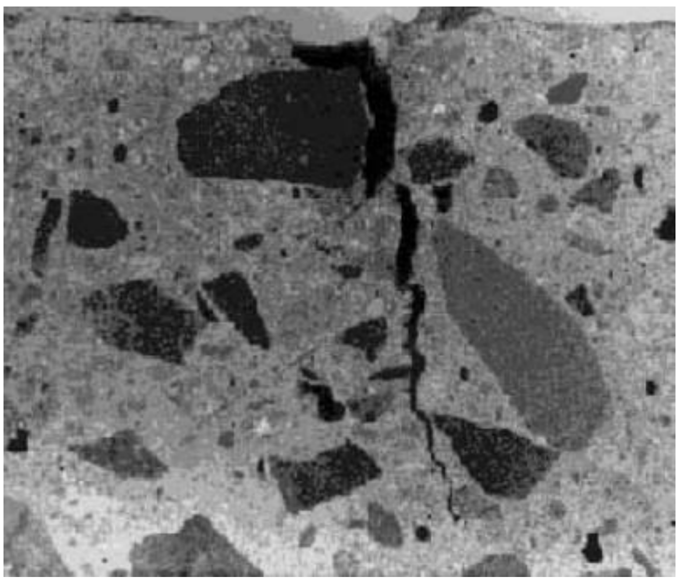

Figure 20.12 Petrographic Analysis of a Shrinkage Crack in Concrete

20.2.7.5 ASR Testing Methods

There are two common methods used to determine if ASR is present in concrete: uranyl-acetate testing and petrographic analysis. Both tests require concrete core samples to be taken for analysis in the lab. The uranyl-acetate test involves treating a core sample section surface with uranyl-acetate. ASR present in or around the aggregate will fluoresce under ultraviolet lights. Petrographic analysis is the most reliable test method for determining ASR.

20.3 Evaluating Test Results

20.3.1 Compressive Strength

Compressive strength results collected during a deck investigation should be compared to the design concrete strength. If the tested concrete strength is below the design strength specified on the plans, an analysis of the member capacity should be undertaken using the tested concrete strength. If the structure is found to have reduced capacity at the tested concrete strength, then petrographic analysis would be warranted to determine the cause of the loss of strength. If the concrete compressive strength is found to be acceptable through analysis, but is below the specific design strength, the deck should be protected from further deterioration of the concrete.

20.3.2 Chloride Content

Chloride content is an indicator of the potential for corrosion. The presence of chlorides and water provide the necessary ingredients for corrosion in a reinforced concrete bridge deck. The generally accepted chloride levels that can cause corrosion in reinforcing bars are shown in Table 20.3.

Table 20.3 Impact of Chloride on Potential for Corrosion

Potential for Corrosion	Chlorides at Reinforcing (Black Bars) Pounds per Cubic Yard	Chlorides at Reinforcing (Coated Bars) Pounds per Cubic Yard
Low (< 10%)	< 2.0	< 10
Moderate (~ 50%)	2.0 - 2.5	10 - 15
High (> 90%)	> 2.5	> 15

Note: 1 pound/cubic yard = 255 parts per million

20.3.3 Half-Cell Potential

Half-cell testing, when performed on bridges, measures the electrical potential between the reinforcing and the concrete. The half-cell device consists of a reference electrode, a sensitive volt meter, and a data logger. The negative end of the volt meter is connected directly to the reinforcement by drilling a hole in the deck. The electrode is placed on top of the concrete deck at grid points and the corresponding voltage is measured. It is important when doing half-cell testing to use a grid that does not exceed 2 feet by 2 feet. The more negative the voltage reader the greater the potential for corrosion. The half-cell results typically consist of a corrosion potential map similar to the one shown in Figure 20.13. It should be noted that the second y-axis in the figure is presented in millivolts (not volts).

The corrosion potential map can be used to identify areas that are more prone or less prone to corrosion and should have correspondence to any identified delaminations. For epoxy coated bars, the potential should be significantly less than uncoated bars because the epoxy coating will not conduct electricity. Half-cell testing results of epoxy coated steel decks should be closely evaluated for validity and repeatability given the relatively low corrosion potential. If the epoxy coating has been damaged during placement or through deterioration, the half-cell potential will become more negative (increase). If the half-cell potential levels reach levels defined in Table 20.4, corrosion can occur even though the bars are coated.

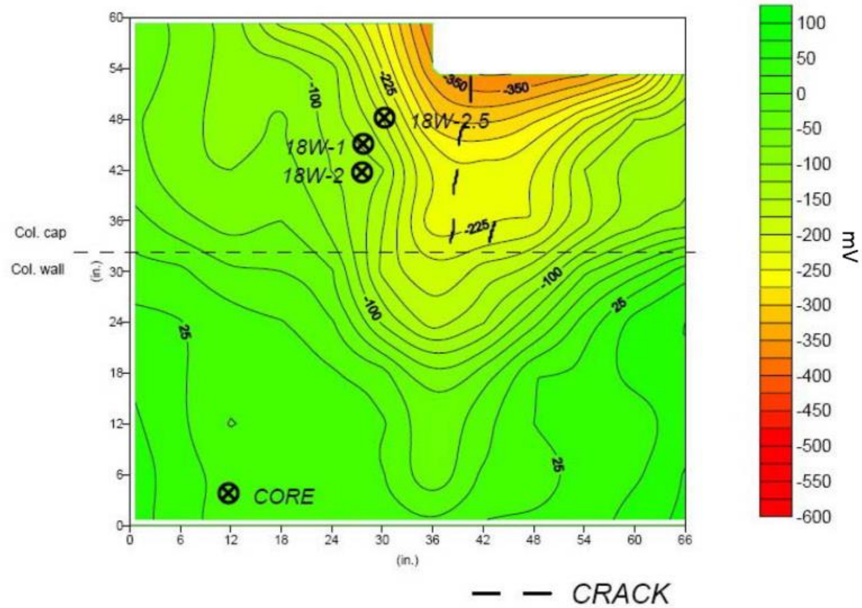

Figure 20.13 Half-Cell Potential Map

Table 20.4 Potential for Corrosion

Potential For Corrosion (Coated and Uncoated Bars)	Concrete Half-Cell Potential (Volts)
Low	More positive than -0.20
Moderate	Between -0.2 and -0.35
High	More negative than -0.35

20.3.4 Alkali Silica Reactivity (ASR)

Alkali Silica Reactivity (ASR) affects concrete structures in almost every area of the U.S. It occurs when silica in the aggregate and alkali in the cement react in the presence of water. This reaction creates a gel in the hardened concrete. Over time, this gel expands causing closely spaced map cracking and disintegration of the bond between the concrete ingredients. Most agencies have implemented material specifications that limit the potential on new bridges, however many older bridges may not have had similar specifications in place to control ASR.

There are two common methods used to determine if ASR is present in concrete: uranyl-acetate testing and petrographic analysis. Refer to Sections 20.2.7.4 and 20.2.7.5 for more information on these lab tests.

ASR test results will confirm the presence of ASR. If reactive aggregates are present, the test will typically classify the concrete as having the potential for ASR or having active ASR. The potential for ASR usually means that the aggregate has the potential to react, but the gels produced from reaction are not evident. Active ASR results indicate that reactive aggregates are present in the concrete and that these aggregates have already produced expansive reactive gel by-products. Positive test results for ASR would typically require protective treatment or replacement of the concrete in severe situations.

20.4 Deck Evaluation Decision Matrices

20.4.1 Deck Evaluation Methodology

There are two broad categories of reinforced concrete bridge deck deterioration: corrosion and material breakdown. A systematic process to evaluate the most common and relevant bridge deck variables for each deterioration category is presented in this section.

20.4.2 Determining Potential for Corrosion

Corrosion potential can be influenced by cracking, half-cell results, chloride content, pH levels in the concrete, and rebar cover depths. Although not an ideal situation, the potential for corrosion can be determined without knowing all the attribute information. Table 20.5 and Table 20.6 can be used to assess the risk of deterioration of reinforced concrete decks with uncoated and coated reinforcing. For decks with stainless steel or galvanized reinforcing steel, use Table 20.6.

It is possible that deck investigation results will have attributes that fall into multiple corrosion potential classifications. If this is the case, use the most aggressive corrosion classification.

Table 20.5 Uncoated Deck Reinforcing Corrosion Potential Classification

Test Result	Low Potential	Moderate Potential	High Potential
Chloride Levels (Pounds per Cubic Yard)	< 2	2.0 to 2.5	> 2.5
Half-cell Potential (Volts)	More positive than -0.2	-0.2 to -0.35	More negative than -0.35
Cover Concrete Depth (Inches)	> 1.9	1.0 to 1.9	< 1.0
Concrete pH	> 9.0	7.0 to 9.0	< 7.0

Table 20.6 Coated Deck Reinforcing Corrosion Potential Classification

Test Result	Low Potential	Moderate Potential	High Potential
Chloride Levels (Pounds per Cubic Yard)	< 10	10 to 15	> 15
Half-cell Potential (Volts)	More positive than -0.2	-0.2 to -0.35	More negative than -0.35
Cover Concrete Depth (Inches)	> 9.0	7.0 to 9.0	< 7.0

The corrosion potential classification results above can be used to select the appropriate action table (Table 20.7 through Table 20.9). The action tables should be used with the results of the visual deck assessment of cracking and spalls and the delamination survey. The visual assessment information will intersect on a recommended action class.

20.4.3 Reinforced Concrete Deck Action Classes

Having assessed the corrosion potential of the deck being investigated, select the appropriate action class table for low, moderate, or high corrosion potentials determined in Section 20.4.2. Use investigation results for cracking, spalls and delaminations to identify the appropriate action class provided in Table 20.7 through Table 20.9.

The cracking attribute should reflect the predominate size and spacing over the entire deck or over the localized area of concern if the deck investigation or repair is limited to certain areas of the deck. In general, the potential for water and salts to enter the deck matrix is being evaluated with the crack information. Spalls and delaminations, on the other hand, are damage that has already occurred.

Table 20.7 Low Corrosion Potential Actions

	Percent Spalls and Delaminated Deck Area 0% < Distress <2%	**Percent Spalls and Delaminated Deck Area 2% < Distress < 5%**	**Percent Spalls and Delaminated Deck Area 5% < Distress < 10%**	**Percent Spalls and Delaminated Deck Area Distress > 10%**
Deck Cracking Width < 0.02 inch AND Spacing > 3 feet	Do Nothing OR Repair	Repair	Repair	Rehab OR Replace Deck
Deck Cracking Width < 0.02 inch AND 1 foot < Spacing < 3 feet	Do Nothing OR Repair	Repair	Repair	Rehab OR Replace Deck
Deck Cracking Width ≥ 0.02 inch AND 1 foot < Spacing < 3 feet	Do Nothing OR Repair	Repair AND Seal Deck	Repair AND Overlay	Rehab OR Replace Deck
Deck Cracking Width ≥ 0.02 inch AND Spacing < 1 foot	Repair AND Seal Deck	Repair AND Overlay	Repair AND Overlay	Rehab OR Replace Deck

Table 20.8 Moderate Corrosion Potential Actions

	Percent Spalls and Delaminated Deck Area 0% < Distress <2%	Percent Spalls and Delaminated Deck Area 2% < Distress < 5%	Percent Spalls and Delaminated Deck Area 5% < Distress < 10%	Percent Spalls and Delaminated Deck Area Distress > 10%
Deck Cracking Width < 0.02 inch AND Spacing > 3 feet	Repair	Repair	Repair AND Seal Deck	Rehab OR Replace Deck
Deck Cracking Width < 0.02 inch AND 1 foot < Spacing < 3 feet	Repair AND Seal Deck	Repair AND Seal Deck	Repair AND Seal Deck	Rehab OR Replace Deck
Deck Cracking Width ≥ 0.02 inch AND 1 foot < Spacing < 3 feet	Repair AND Seal Deck	Repair AND Protect Deck	Repair AND Overlay	Rehab OR Replace Deck
Deck Cracking Width ≥ 0.02 inch AND Spacing < 1 foot	Repair AND Seal Deck	Repair AND Overlay	Repair AND Overlay	Rehab OR Replace Deck

Table 20.9 High Corrosion Potential Actions

	Percent Spalls and Delaminated Deck Area 0% < Distress <2%	Percent Spalls and Delaminated Deck Area 2% < Distress < 5%	Percent Spalls and Delaminated Deck Area 5% < Distress < 10%	Percent Spalls and Delaminated Deck Area Distress > 10%
Deck Cracking Width < 0.02 inch AND Spacing > 3 feet	Repair AND Seal Deck	Repair AND Seal Deck	Repair AND Seal Deck	Rehab OR Replace Deck
Deck Cracking Width < 0.02 inch AND 1 foot < Spacing < 3 feet	Repair AND Seal Deck	Repair AND Seal Deck	Repair AND Overlay	Rehab OR Replace Deck
Deck Cracking Width ≥ 0.02 inch AND 1 foot < Spacing < 3 feet	Repair AND Seal Deck	Repair AND Overlay	Repair AND Overlay	Rehab OR Replace Deck
Deck Cracking Width ≥ 0.02 inch AND Spacing < 1 foot	Repair AND Overlay	Repair AND Overlay	Repair AND Overlay	Rehab OR Replace Deck

20.4.4 Selecting the Appropriate Deck Actions

Having determined the appropriate action class from Table 20.7 thru Table 20.9, use the following discussion to further refine the action class for determining the specific deck repair or treatment.

Do Nothing

- **Low Corrosion Potential** – The likelihood of reinforcement corrosion is minimal in these decks. For decks with minimal deck spall and delamination damage, it may be advisable to do nothing if the area of repairs is on the low end of the given range or if there is any uncertainty in the delamination determination. The cracking does not need to be treated until it increases in size or spacing is reduced. However, in areas where deicing chemicals are used, sealing the deck with a low permeability overlay is often a cost effective long term preventive maintenance strategy.
- **Moderate Corrosion Potential** – Doing nothing is not advised for moderate corrosion potential decks with identified delaminations. The delamination may provide a pathway for accelerated deterioration.
- **High Corrosion Potential** – Doing nothing is not advised for high corrosion potential decks with identified delaminations. The delamination may provide a pathway for accelerated deterioration.

Repair

This action class includes spall and delamination repair methods for full and partial depth repairs that are described in Chapter 7. Repairs may be done with a vast number of concrete patch products. Usually these are rapid setting concrete products with high bond strengths. For moderate and high corrosion potential decks, sacrificial anodes should be placed within the patch area to increase the life of the repair.

- **Low Corrosion Potential** decks may warrant spall and delamination repair without further action if delaminations are less than 10% of the total deck area. The low probability of corrosion in these decks wouldn't typically warrant the expense of sealing or overlays. However, in areas where deicing chemicals are used, sealing the deck with a low permeability overlay is often a cost effective long term preventative maintenance strategy.
- **Moderate Corrosion Potential** decks may warrant repair of spalls and delaminations without further action if combined area is less than 5% of the total deck area.
- **High Corrosion Potential** decks should always include an additional protection action (sealing overlay, sacrificial anode or cathodic protection) when delaminations are repaired.

Repair and Seal

This action class involves repairing all spalls and delaminations using techniques described in Chapter 7 and as described under the repair action above. In addition, the combination of cracking severity and spalls/delaminated area warrants sealing the deck from the ingress of water and salts. Sealing the deck is typically accomplished using a penetrating sealer or water proofing treatments, however low permeability overlays will also seal the deck. See Section 20.4.5 for more information on deck sealers.

Overlay

This action class includes a vast number of overlay products. The recommendation for an overlay is to span over and seal larger or densely spaced deck cracks and to provide a low permeability barrier that will limit the amount of water and salts that penetrate into the concrete matrix. Overlays are also effective treatments for rutting, abrasion, and scaling that may have been observed during the visual inspection. Common overlays that will seal include asphalt with a membrane seal, thin bonded polymer overlays, modified concrete overlays and polyester concretes. The selection between overlays that will provide the corrosion protection is typically governed by a variety of factors that may include load capacity, profile grade, joint type, rail height, agency experience and how quickly the overlay can handle traffic. See Section 20.4.5 for more information on deck overlay products.

Rehabilitate

This action class is recommended when the spalled and delaminated deck area exceeds 10% of the total bridge deck area. The rehabilitate action class includes several methods to remove varying depths of concrete, removing rebar corrosion and patching the areas disturbed. Chapter 7 describes the saw cutting, chipping and sand blasting method commonly used for smaller scattered areas and hydrodemolition methods typically used for larger areas. If a deck has experienced this level of spalls and delaminations, a complete deck overlay with a low permeability overlay should be considered to prevent future corrosion damage in the deck. An overlay after rehabilitation will also provide a smooth riding surface on the deck instead of a patchwork of repaired areas (as discussed in Section 20.4.5). Alternatively, an active cathodic protection system could be installed to prevent the future corrosion, although this will not address the ride quality.

Replace

This action class is for complete removal and replacement of the concrete deck. Replacement of the deck may be warranted as the percentage of spalls and delamination increases. Agencies typically use a spalling and delamination percentage of 30 - 50% of the total deck area as the triggering threshold for replacement in lieu of rehabilitation. The presence of exposed and corroded bottom mat reinforcing over significant areas also tips the decision toward deck replacement. Material defects such as ASR or other deterioration that causes a loss of strength in the concrete may also trigger replacement. If the delaminations and spalls are extensive and very deep, the concrete removal process for rehabilitation may require shoring of the bridge during the repair. In these cases, replacement may be the preferred alternative because the cost of rehabilitation can approach replacement costs.

20.4.5 Common Deck Seals and Overlay Products

Many products are commercially available for sealing and overlaying bridge decks. The selection among the available deck sealing products may be governed by attributes such as viscosity, modulus of elasticity, gel times, time until traffic can ride on the treated deck, and temperature at the time of application. Low viscosity sealers can penetrate deeply into fine cracks and higher viscosity sealers are better suited for larger crack widths. High modulus sealers are typically very stiff, while low modulus sealers are flexible.

When to Call the Engineer

Call the Engineer prior to installing or increasing the thickness of overlays.

For overlays, the selection may be governed by cost, thickness of overlay, time required before traffic can use the overlay, and the permeability of the overlay. The additional dead load on the bridge, and the required minimum height of bridge rails, are considerations when determining the allowable thickness of overlays. An engineering review should be conducted prior to installing or increasing the thickness of overlays. Table 20.10 and Table 20.11 present the attributes of common deck seals and overlays, respectively.

Table 20.10 Common Deck Sealing Products

Seal Type	Viscosity (Centipoise)	Modulus of Elasticity	Expected Life (Years)	Time-to Traffic-Use (Hours)	Cost Range (Dollars per Square Foot)
Low Modulus Low Viscosity	≤ 50	Low	5 - 10	2 - 6	0.20 - 3
Low Modulus Super Low Viscosity	> 50	Low	5 - 10	2 - 6	0.20 - 3
High Modulus Low Viscosity	≤ 50	High	5 - 10	4 - 8	0.20 - 3
High Modulus Super Low Viscosity	> 50	High	5 - 10	2 - 6	0.20 - 3

Table 20.11 Common Deck Overlay Products

Overlay Type	Thickness (Inches)	Permeability	Expected Life (Years)	Time-to Traffic-Use (Hours)[6]	Relative Cost[7]
Asphalt w/o Membrane	2 – 12[1,2]	Variable, but generally high	10 - 15	2 - 6	$ - $$
Asphalt with Membrane	3 – 12[1,2,3]	Zero[4]	10 - 20[5]	2 - 6	$$
Thin Bonded Polymers	0.125 - 0.5	Zero[4]	5 - 15	2 - 6	$ - $$$
Modified Concretes	1 - 12	Very Low	20 - 30	4	$$$ - $$$$
Polyester Concretes	0.75 - 12	Very Low	20 - 30	2	$$$ - $$$$

[1] *Asphalt thicknesses over 4 inches are not recommended on bridges due to the weight of the asphalt. The live load capacity of a bridge is decreased by the weight of an overlay.*

[2] *Asphalt overlays provide a protective wearing surface, but tend to trap moisture and chlorides. Asphalt overlays without waterproofing membranes are not recommended for bridge decks where deicing chemicals are used.*

[3] *Three inch minimum is recommended to prevent disturbing membrane during asphalt resurfacing that includes rotomilling and replacing the asphalt to the original thickness.*

[4] *The sealing material is impermeable where there are no imperfections due to installation, aging, or wear.*

[5] *Waterproofing membranes are known to last over 30 years when not disturbed. However, the asphalt typically needs resurfacing every 10 to 20 years to maintain the wearing surface and protect the membrane. It is important to not disturb the membrane during resurfacing operations.*

[6] *Time-to Traffic Use is the time after the last operation has been completed before traffic can be restored.*

[7] *All costs are for deck preparation, furnishing of material and placement.*

20.4.6 Strength Evaluation

Concrete deck strength should be tested during construction to verify that the bridge deck being built meets the design specifications. In rare cases, the deck concrete may lose strength over time due to material deterioration. The most common cause of strength loss of existing bridge decks is ASR. Table 20.12 provides a decision matrix for evaluating strength and ASR results for reinforced concrete bridge decks.

Table 20.12 Concrete Compressive Strength Evaluation

ASR Present?	Concrete Compressive Strength ≥ Design Strength	Concrete Compressive Strength < Design Strength but Acceptable for Applied Loads	Concrete Compressive Strength < Applied Loads (Unacceptable)
ASR Not Present	Do Nothing	Do Nothing	Replace Deck
ASR Potential in Aggregate	Treat ASR	Treat Deck	Replace Deck
ASR Active	Treat ASR	Treat ASR OR Replace Deck	Replace Deck

Do Nothing - If ASR cannot be confirmed by lab testing and the strength of the concrete is adequate for the loads it carries, it is appropriate to do nothing.

Treat ASR - The appropriate treatment could involve penetrating deck sealers, such as high molecular weight methacrylate or protection methods, that would typically involve the application of a low permeability or impervious overlay to limit the moisture flow into the concrete matrix. If the deck can be kept dry, the ASR will be denied the moisture necessary to further react.

Replace Deck - If the concrete strength is found to be inadequate, there are two possible corrective strategies: deck replacement or the construction of a reinforced deck on top of the existing deck.

20.5 Chapter 20 Reference List

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