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CONCRETE BRIDGE DECK CONDITION ASSESSMENT GUIDELINES

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UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

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Although the substructures and superstructures of bridges in Utah are in relatively good structural condition, the bridge decks are experiencing observable deterioration due to the routine application of deicing salts and repeated freeze-thaw cycling. This manual describes condition assessment methods and threshold values that may be used to determine whether rehabilitation or replacement of a given bridge deck is more appropriate when the severity and extent of deterioration warrant deck improvement. Threshold values given in the manual are based on a questionnaire survey conducted of state departments of transportation nationwide, as well as on standards and guidelines published by the American Society for Testing and Materials, American Association of State Highway and Transportation Officials, and Strategic Highway Research Program.</td></tr>
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INTRODUCTION

The aging and deterioration of bridges in Utah mandates increasingly cost-effective strategies for bridge maintenance, rehabilitation, and replacement (MR&R). The Utah Department of Transportation (UDOT) is responsible for 1,700 bridges throughout the state, of which 46 percent are older than 30 years. Although the substructures and superstructures of bridges in Utah are in relatively good structural condition, the bridge decks are experiencing observable deterioration due to the routine application of deicing salts, repeated freeze-thaw cycles, and other damaging effects. Therefore, the purpose of this manual is to provide guidance about when a bridge deck should be rehabilitated or replaced.

Ultimately, development of a decision-making protocol that utilizes bridge deck condition assessment information in combination with life-cycle costs is especially important, since the costs associated with replacing every bridge deck in Utah are extremely high. Identification of typical damage mechanisms and test methods for determining the extent of damage sustained by concrete bridge decks are therefore important elements of this manual. In particular, the utility of non-destructive testing to accurately and rapidly assess bridge deck condition is emphasized. This manual describes viable condition assessment methods and threshold values that UDOT may use to determine whether rehabilitation or replacement of a given bridge deck is more appropriate when the severity and extent of deterioration warrant deck improvement. Threshold values given in this manual are based on a questionnaire survey conducted of state departments of transportations (DOTs) nationwide (*1*), as well as on standards and guidelines published by the American Society of Testing and Materials (ASTM), the American Association of State Highway and Transportation Officials (AASHTO), and the Strategic Highway Research Program (SHRP).

CONDITION ASSESSMENT METHODS

Table 1 provides a summary of condition assessment methods appropriate for specific deck distress types. A preliminary plan of action can be formulated by identifying the types of bridge distresses to be investigated and then selecting the condition assessment methods that are appropriate for measuring the severity and mapping the extent of deck deterioration. Once condition assessment methods are selected from Table 1, ASTM, AASHTO, and SHRP standards corresponding to each condition assessment method can be identified from Table 2. The title of each ASTM, AASHTO, and SHRP standard is listed in Table 3.

TABLE 1 Condition Assessment Methods for Specific Deck Distresses

Distresses	Condition Assessment Methods
Air Pockets and Honeycombing	Chain Dragging, Coring, Ground Penetrating Radar, Hammer Sounding, Impact-Echo, Ultrasonics, Visual Inspection
Alkali-Silica Reaction	Coring, Petrographic Analysis, Visual Inspection
Carbonation	Coring, Penetration Dyes, Petrographic Analysis
Chloride-Induced Corrosion	Chloride Concentration Testing, Coring, Half-Cell Potential, Rapid Chloride Permeability, Resistivity
Cracking	Impact-Echo, Penetration Dyes, Ultrasonics, Visual Inspection
Delamination	Chain Dragging, Coring, Ground Penetrating Radar, Hammer Sounding, Impact-Echo, Infrared Thermography, Ultrasonics
Polishing	Skid Resistance Testing
Popouts	Visual Inspection
Potholing	Visual Inspection
Scaling	Visual Inspection
Spalling	Visual Inspection
Sulfate Attack	Coring, Petrographic Analysis

TABLE 2 ASTM, AASHTO, and SHRP Standards for Deck Condition Assessment

Condition Assessment Methods	Standards
Chain Dragging	ASTM D 4580-86
Chloride Concentration Testing	ASTM C 1218-99, AASHTO T 260-97 SHRP Product 2030
Coring	ASTM C 42-99, AASHTO T 24-02
Ground Penetrating Radar	ASTM D 6087-97, ASTM D 6432-99
Half-Cell Potential	ASTM C 876-91
Sounding	ASTM D 4580-86
Impact-Echo	ASTM C 1383-98a
Infrared Thermography	ASTM D 4788-88
Penetration Dyes	None Identified
Petrographic Analysis	ASTM C 856-95
Rapid Chloride Permeability	ASTM C 1202-97, AASHTO T 277-96
Resistivity Testing	ASTM D 3633-98, ASTM D 6431-99
Skid Resistance	ASTM E 274-97, AASHTO T 242-96 ASTM E 303-93, AASHTO T 278-90
Ultrasonic Testing	ASTM E 494-95
Visual Inspection	None Identified

TABLE 3 Titles of ASTM, AASHTO, and SHRP Standards

Standards	Titles
ASTM C 42-99	Standard Test Method for Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
ASTM C 856-95	Standard Practice for Petrographic Examination of Hardened Concrete
ASTM C 876-91	Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete
ASTM C 1202-97	Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
ASTM C 1218-99	Standard Test Method for Water-Soluble Chloride in Mortar and Concrete
ASTM C 1383-98a	Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method
ASTM D 3633-98	Standard Test Method for Electrical Resistivity of Membrane-Pavement Systems
ASTM D 4580-86	Standard Practice for Measuring Delaminations in Concrete Bridge Decks by Sounding
ASTM D 4788-88	Standard Test Method for Detecting Delaminations in Bridge Decks Using Infrared Thermography
ASTM D 6087-97	Standard Test Method for Evaluating Asphalt-Covered Concrete Bridge Decks Using Ground Penetrating Radar
ASTM D 6431-99	Standard Guide for Using the Direct Current Resistivity Method for Subsurface Investigation
ASTM D 6432-99	Standard Guide for Using the Surface Ground Penetrating Radar Method for Subsurface Investigation
ASTM E 274-97	Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire
ASTM E 303-93	Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester
ASTM E 494-95	Standard Practice for Measuring Ultrasonic Velocity in Materials
AASHTO T 24-02	Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
AASHTO T 242-96	Frictional Properties of Paved Surfaces Using a Full-Scale Tire
AASHTO T 260-97	Sampling and Testing for Chloride Ion in Concrete and Concrete Raw Materials
AASHTO T 277-96	Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration
AASHTO T 278-90	Surface Frictional Properties Using the British Pendulum Tester
SHRP Product 2030	Standard Test Method for Chloride Content in Concrete

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DATA EVALUATION

Both technical and economic factors influence the decision to rehabilitate or replace a bridge deck. Project-level information is obtained from condition assessment surveys to determine the overall condition of a bridge deck. Typically, this information includes measurements associated with specific distresses and deterioration mechanisms. The information is then analyzed to determine the types of rehabilitation methods that should be employed to extend the service life of the bridge deck or to determine if a full-deck replacement is required.

The decision to rehabilitate or replace a bridge deck typically requires an economics analysis for identifying the approach that will minimize the life-cycle cost of a bridge deck. An economics analysis determines whether the costs for rehabilitation are more economical over a given period of time than a full-deck replacement. However, bridge decks that exhibit significant deterioration may not require an economics analysis; condition assessment alone may be sufficient to eliminate rehabilitation as a viable option. In these cases, deterioration would be so severe that the cost of a full-deck replacement would be unmistakably less expensive than rehabilitative measures. Nonetheless, the use of economic analyses is usually vital for bridge deck management and must be used in combination with technical factors to provide optimal solutions in managing individual bridge decks.

Although the value of correct economics analyses cannot be over-emphasized, this manual focuses strictly on providing technical information concerning threshold values for several condition assessment methods and parameters; the mechanics of economics analyses are not addressed. Condition assessment methods and parameters available for evaluating existing damage and predicting the occurrence of future damage are presented. These specifically include chloride concentration, cracking, delamination, half-cell potential, popouts, potholes, rapid chloride permeability, resistivity, spalling, skid number, and ultrasonic velocity. To the extent possible, threshold values associated with both the severity of the distress and the percentage of the deck that is affected are discussed in the following sections.

Chloride Concentration

In condition assessments of chloride-damaged bridge decks, chloride concentrations in the vicinity of the top mat of reinforcement generally govern the decision to rehabilitate or replace the deck. In general, state DOTs require action when chloride concentrations exceed a threshold of 2.0 lbs/yd^3 of concrete (*1*). The North Carolina DOT suggested in the DOT survey that a full-deck replacement may be required if this threshold level is exceeded on more than 30 percent of the deck area (*1*). While chloride concentration testing provides a valuable assessment of the condition of concrete, the test cannot stand alone as a means for determining an appropriate deck improvement strategy. Chloride concentration testing should be used in conjunction with other condition assessment methods to determine whether a bridge deck should be rehabilitated or replaced. For example, if not accompanied by cracking, delaminations, or other deteriorative elements, corrosion may not be occurring even though chloride concentrations may be high.

Cracking

A crack is defined as a break without a complete separation of parts. In bridge decks, cracks are the precursors to more significant problems since they allow for the infiltration of harmful chemicals and substances. The severity of deterioration caused by cracking is based on crack width, crack density, and precipitation of solids in the cracks (*1*). In general, the survey respondents indicated that action should be taken to correct crack deterioration when crack thickness exceeds 0.0625 in. (1/16 in.) with moderate crack density, the extent of cracking is greater than 30 percent of the total deck area, or efflorescence is evident in the vicinity of the crack (*1*). The New Jersey DOT specified that any crack that is thought to be more than a shrinkage crack should be sealed (*1*).

Delamination

Corrosion-related delaminations form when the upper layer of reinforcing steel rusts, thereby breaking the bond between the steel and the surrounding concrete. Debonding of the concrete from the reinforcing steel reduces the structural capacity of the deck and allows for harmful substances to migrate at accelerated rates towards the reinforcement. In general, DOTs indicated that the extent of concrete delamination that requires action is between 5 and 20 percent of the total deck area. The New Jersey DOT requires action when 40 percent or more of the deck area exhibits spalling or delaminations (*1*). The Wyoming DOT indicated that patching is utilized when up to 5 percent of the deck area is delaminated; however, delaminations exceeding 5 percent of the deck area require patching with silica fume concrete followed by a bridge deck overlay (*1*).

The Washington DOT suggested that delaminations should be repaired and a 1.5-in. modified concrete overlay should be applied when delaminations exceed more than 2 percent of the total deck area (*1*). This criterion for repair is deliberately conservative since a year or more is often required to secure funding for the repair project; the Washington DOT indicated that during the waiting period the extent of delaminations typically increases to 5 percent or more.

The *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* gives guidelines for delaminations exhibited on bare concrete decks with uncoated reinforcement, with coated reinforcement, or with a cathodic system (*2*). Delaminations affecting less than 10 percent of the deck area may be repaired, or a protective system may be installed to mask the damage. Delaminations affecting 10 to 50 percent of the deck area should be repaired, and an optional protective system may be applied to the entire deck surface. If delaminations are present on more than 50 percent of the deck area, the deteriorated areas should be repaired, and a protective system should be installed across the entire deck; otherwise, a full-deck replacement is required.

The *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* gives additional guidelines for delaminations exhibited on concrete decks with thin or rigid overlays (*2*). Delaminations affecting less than 25 percent of the deck area should be repaired; however, if delaminations affect more than 25 percent of the deck area, the existing overlay should be removed, and the repairs should be followed with installation of a new protective overlay.

Half-Cell Potential

The severity of steel corrosion in concrete can be determined by measuring the electrical half-cell potential of uncoated reinforcing steel (*3*). ASTM C 876 (Standard Test Method for Half-Cell Potentials of Uncoated Reinforcing Steel in Concrete) specifies that potential measurements more negative than −0.35 V using a copper-copper sulfate electrode (CSE) indicate a probability greater than 90 percent that corrosion is occurring. Potential measurements more positive than −0.20 V CSE indicate a probability greater than 90 percent that corrosion is not occurring in that area. Potential measurements between −0.20 and −0.35 V CSE indicate that corrosion in that area is uncertain. However, studies have been conducted that conflict with these threshold values designated in ASTM C 876 (*4, 5*). Therefore, published threshold values in ASTM C 876 should only be used as guidelines since a precise delineation of steel from a passive to an active state cannot be made to encompass all bridges.

Nonetheless, the threshold values reported in the DOT surveys are consistent with ASTM C 876. The Connecticut DOT specified that action should be taken when more than 40 percent of the potential measurements are more negative than −0.35 V CSE (*1*). The Rhode Island DOT confirmed that action should be taken when values are below −0.35 V CSE, provided that other forms of deterioration are present (*1*).

The Oklahoma DOT provided several threshold values for rehabilitation and replacement (*1*). A full-depth replacement of the bridge deck is required when potential measurements are more negative than −0.40 V CSE. Potential measurements between −0.35 and −0.40 V CSE require reparations to delaminations, spalls, and cracks below the top mat of reinforcement. Repair of the top mat of reinforcement is required when potential measurements are between −0.25 and −0.35 V CSE.

Popouts

Popouts are conically shaped depressions that are associated with the removal or rupturing of aggregate particles near the concrete surface. DOTs indicated in the questionnaire survey that popouts should be repaired when deterioration impacts the traveling public; such impacts may appear in the form of roughness of the roadway surface or vehicle damage caused by popouts being projected into the air (*1*).

Potholes

Potholes are bowl-shaped holes of various sizes with a minimum width of 6 in. They constitute a dangerous safety hazard that can produce substantial damage to vehicles, force drivers to veer suddenly in traffic, or even cause drivers to lose control of their vehicles after contact. State DOTs reported taking remedial action when the deck area exhibits any sign of potholes.

The *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* gives guidelines for repairing potholes exhibited on concrete decks with or without asphalt concrete overlays (*2*). Potholes occurring on less than 10 percent of the total deck area should be repaired. If potholes affect 10 to 50 percent of the deck area, the deteriorated areas should be repaired, and a new protective overlay should be applied to the entire deck surface upon removal of an existing overlay, if present. Potholes exhibited on more than 50 percent of the deck area may also be repaired in this manner but may also warrant a full-deck replacement instead.

Rapid Chloride Permeability

Low-permeability concrete generally possesses high strength and is resistant to the infiltration of water and chlorides. Conversely, extremely porous concrete allows water, salts, and oxygen to more easily reach the reinforcing steel, which accelerates corrosion of the reinforcement. By measuring the chloride permeability of concrete, durability problems can be detected early so that timely and cost-effective protective measures can be implemented before the occurrence of significant steel corrosion or concrete deterioration. Table 4 provides values that relate the charge passed in the Rapid Chloride Permeability Test (RCPT) to chloride-ion penetrability (*6*). A high charge indicates a low resistance to chloride ions that is typical of poor quality concrete.

TABLE 4 Chloride-Ion Penetrability Based on RCPT Measurements (*6*)

Charge Passed (Coulombs)	Chloride Ion Penetrability
> 4,000	High
2,000 - 4,000	Moderate
1,000 - 2,000	Low
100 - 1,000	Very Low
< 100	Negligible

Resistivity

Resistivity testing is a method that uses electrical resistance to evaluate the quality of reinforced concrete. The technique measures the likelihood of the reinforcing steel to corrode, rather than the amount of distress that has already occurred due to corrosion (*7*). Tests have been performed to investigate the resistivity of concrete in various conditions. Moist concrete typically displays a resistivity of 10 Kohm-cm, while oven-dried concrete exhibits a resistivity of 10 Mohm-cm (*7*). Data from a study in Great Britain indicate that corrosion is almost certain to occur when resistivity measurements are less than 5 Kohm-cm (*7*). When resistivity measurements are between 5 and 12 Kohm-cm, corrosion is probable (*7*). The research results suggest that corrosion is unlikely to occur when resistivity measurements are in excess of 12 Kohm-cm (*7*). The instruction manual for the James RM-8000 resistivity meter provides a table that correlates resistivity measurements to possible rates of reinforcement corrosion, as shown in Table 5.

Table 5 Corrosion Rates Based on Resistivity Measurements (*8*)

Resistivity (Kohm-cm)	Reinforcement Corrosion Rate
< 5	Very High
5 to 10	High
10 to 20	Moderate to Low
> 20	Insignificant

Spalling

Spalling is characterized by the breaking apart or flaking away of surface concrete. Typically, spalling is a result of rusting or freeze-thaw cycling, which can cause bursting stresses that exceed the tensile strength of the concrete. State DOTs suggested taking action against spalling when reinforcing bars are exposed or corroded.

The *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* gives guidelines for spalling exhibited on bare concrete decks with uncoated reinforcement, with coated reinforcement, or with a cathodic system (*2*). Spalling exhibited on less than 10 percent of the deck area may be repaired, or a protective system may be installed to mask the damage. Spalls that exist on 10 to 50 percent of the deck area should be repaired, and an optional protective system may be applied to the entire deck surface. Spalling exhibited on more than 50 percent of the deck area requires repair and installation of a protective system; otherwise, a full-deck replacement is required.

The *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* gives additional guidelines for spalling exhibited on concrete decks with a thin or rigid overlay (*2*). Spalling exhibited on less than 25 percent of the deck area should be repaired. However, when spalling exists on more than 25 percent of the deck area, simple repairs may be inappropriate; instead, the existing overlay may need to be removed and replaced with a new protective overlay.

Skid Number

The skid number reflects the surface texture of a bridge deck. State DOTs reported taking corrective measures for skid resistance numbers below 30 to 35 when measured according to ASTM E 274 (Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire).

Ultrasonic Velocity

Pulse-velocity measurements are reliable for assessing concrete quality and uniformity. As the pulse passes through concrete, its velocity decreases due to the presence of voids associated with porosity and internal cracking (*7*). Several researchers have developed scales correlating pulse-velocity measurements to concrete quality to be used as guides in interpreting pulse-velocity readings in concrete (*7*). Examples of two such scales are presented in Table 6 (*7*).

TABLE 6 Pulse-Velocity Ratings for Concrete (*7*)

Pulse Velocity (ft/sec)		
Concrete Quality	**Malhotra Scale**	**Leslie and Cheesman Scale**
Excellent	> 15,000	--
Good	12,000 to 15,000	> 16,000
Fair	10,000 to 12,000	13,000 to 16,000
Poor	7,000 to 10,000	10,000 to 12,000
Very Poor	< 7,000	--

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CONCLUSION

This manual describes viable condition assessment methods and threshold values that UDOT may use to determine whether rehabilitation or replacement of a given bridge deck is more appropriate when the severity and extent of deterioration warrant deck improvement. Condition assessment methods and parameters for evaluating existing damage and predicting the occurrence of future damage are presented. Corresponding threshold values are based on data collected through a questionnaire survey conducted of state DOTs nationwide, as well as on standards and guidelines published by ASTM, AASHTO, and SHRP. This information should be useful to bridge engineers responsible for rating concrete bridge deck condition and programming MR&R strategies at primarily the project level of bridge management. While in some cases deck condition information may directly dictate whether or not the deck should be replaced, the value of economics analyses to compute life-cycle costs cannot be over-emphasized. The results of economic analyses must be considered in combination with technical data to provide optimal management solutions for individual bridge decks.

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