Papers Related to Maintenance from the 2018 TRB Annual Meeting

Contents

This is a compendium of maintenance-related papers from the 2018 Transportation Research Board Annual Meeting as prepared by the No Boundaries pooled fund project (#TPF-5(330)). It covers the following topics:

Please note that TRB requires a login to access full papers. If you have trouble accessing the papers, check with your DOT or other transportation library.

Asset Management

This section includes papers on pavement management, bridge management, managing other assets, and program-level planning.

Pavement Management

Implementation and Calibration of a Laser Crack Measurement System for the Delaware Department of Transportation's Pavement Management Program
Paper number 18-05347, http://amonline.trb.org/2017trb-1.3983622/t024-1.3995637/807-1.3995664/18-05347-1.3990945/18-05347-1.3995669

Authors:
Aaron Gerber, The Kercher Group, Inc.
Timothy Miller, AECOM
Michael Richardson, Mandli Communications, Inc.

Abstract: The Delaware Department of Transportation (DelDOT) collects 3D pavement condition data with a laser crack measurement system (LCMS) on the State's roadway network. Pavement condition data is collected for two primary purposes: to characterize and quantify pavement distress for development of maintenance and repair (M&R) recommendations; and to develop overall pavement

condition (OPC) values for reporting to State stakeholders. Transitioning to high-speed data collection resulted in OPC values not following expected trends when compared to historic data sets. As such, DelDOT required the project team to identify and mitigate differences between field-based distress measurements, LCMS-based distress measurements, and the resulting treatment recommendations originating from the Department's pavement management system (PMS).

This paper documents the project team's approach to performing a distress calibration involving data processing and calibration iterations to narrow discrepancies between LCMS-based pavement distress data and network-level treatment selections. The project team selected calibration sites, collected baseline distress measurements, reconciled differences in manual and automated data collection processes, and executed adjustments to PMS index models. In addition, the project team adjusted data processes within the PMS to improve M&R treatment selections and index calculations. Although the calibration effort did not result in complete agreement between field and automated data, the iterations closed many of the data gaps. High-speed collection technologies in network-level pavement management is promising, and DelDOT anticipates using these results to provide consistent calibration and collection policies to vendors and consultants in the future.

Detecting and Classifying Roadway Pavement Cracks, Rutting, Raveling, Patching, and Potholes Utilizing Smartphones

Paper number 18-02674, http://amonline.trb.org/2017trb-1.3983622/t024-1.3995637/539-1.3995916/18-02674-1.3991371/18-02674-1.3995923

Authors:

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Symeon Christodoulou, University of Cyprus
Loukas Dimitriou, University of Cyprus

Abstract: Civil engineers face numerous challenges in monitoring roadway deterioration and in assuring roadway pavement maintenance to the preferred level of serviceability. The paper presents a data-driven framework and related field studies on the use of supervised machine learning and smartphone sensor technologies for the detection, classification and georeferencing of common roadway pavement surface anomalies. The study proposes a low-cost and automated method to obtain up-to-date information about roadway pavement surface anomalies, with the use of smartphones mounted on vehicles. Robust regression analysis and bagged trees classification models are used to compliment smartphone-based data collection. The technology for the suggested system is readily available and accurate, and can be utilized in crowd-sourced applications for pavement management systems (PMS) and geographical information system (GIS) implementations. Further, the proposed methodology has been field-tested (detection and classification of five types of pavement surface anomalies, exhibiting accuracy levels higher than 90%) and at this time it is expanded to include larger datasets and a bigger number of common roadway pavement surface defect types. The proposed system is of practical importance since it provides continuous information about roadway pavement surface condition which can be valuable for pavement management systems and public safety.

Quality Management Program for Pavement Condition Data Collected on the National Highway System

Paper number 18-00420, http://amonline.trb.org/2017trb-1.3983622/t024-1.3995637/209-1.3996133/18-00420-1.3991864/18-00420-1.3996138

Authors:

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Amy Simpson, Amec Foster Wheeler
Gonzalo Rada, Amec Foster Wheeler
Jonathan Groeger, Amec Foster Wheeler Environment & Infrastructure, Inc.

Abstract: This paper proposes a framework for a pavement condition data Quality Management Program (QMP). The framework complies with the final rule for national performance management measure regulations published by the Federal Highway Administration (FHWA) to implement requirements from the Moving Ahead for Progress in the 21st Century Act and the Fixing America's Surface Transportation Act. The quality check procedures and criteria recommended for the different elements of the framework are based on the experience and recommendations that resulted from developing a QMP for collecting approximately 10,000 miles of pavement condition data on Interstate Highways using an automated measurement system. The findings from implementation of the study QMP and the intervention needed for automated data collection condition metrics were documented for future improvements. The improved data quality achieved through implementing these recommendations will allow for more reliable estimates of the condition of the State's network of pavements as well as other benefits beyond compliance with the rule.

A Method to Assess and Improve the Reliability on Highway Visual Inspections

Paper number 18-02531, http://amonline.trb.org/2017trb-1.3983622/t001-1.4002183/355-1.4002304/18-02531-1.3991646/18-02531-1.4002309

Authors:

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Abstract: Human visual inspection is the most common evaluation technique to estimate roadway conditions. Highway agencies use statistical tools to conjecture overall conditions of highway networks based on a limited number of surveys. This approach requires a high level of coherence and accuracy during the sampling process. Unfortunately, human visual inspections are error-prone activities that may bias the results. This paper presents a two-phase sampling strategy to account for the uncertainty inherent to visual inspections. The proposed design allows to evaluate inspectors' performance using parameters such as Probability of Detection (POD) or False Alarm Rate (FAR). Receiver Operating Characteristic (ROC) and Precision Recall (PR) graphs are used to illustrate the results. An effective and straightforward method is developed to correct the estimates based on performance results. The methodology is applied to Wisconsin highways data demonstrating its ease of use and efficiency.

Validation Protocol for a Pavement Management System

Paper number 18-01863, http://amonline.trb.org/2017trb-1.3983622/t001-1.4002183/510-1.4002255/18-01863-1.3991422/18-01863-1.4002276

Authors:

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Abstract: Being able to undertake more efficient maintenance and renewal planning of road networks has seen a number of Pavement Management Systems (PMS) being developed between the 80's to mid-90's. During the initial years, there was a significant focus on substantiating the need and demonstrating the benefits of using these tools to assist in the investment planning for roads. Today, with substantial experience with, and legislative support such as MAP-21 and PASS-55, the use of PMS in the asset management cycle of roads is a given. The challenge these days is to effectively use these tools and ensure robust outcomes are achieved from the overall PMS process. The success of any Pavement Management System (PMS) is determined by a number of factors including having skilled resources, institutional support, legislative and funding drivers demanding evidence based forecasted investment needs. Asset managers also realise the importance of having technical robustness in the process to ensure likely outcomes. This paper documents the evolutionary development pathway of the New Zealand PMS that has now been in use across the entire country for more than 18 years. It shows how by always challenging the status quo has resulted in consistently increasing the overall robustness of the system. In particular, it shows how different validation techniques have been used to improve the practicality and appropriateness of long-term forecasting capabilities.

Determining the Age and Smoothness of Asphalt and Concrete Pavements at the Time of First Rehabilitation Using LTPP Program Data

Paper number 18-03354, http://amonline.trb.org/2017trb-1.3983622/t024-1.3995637/209-1.3996133/18-03354-1.3991862/18-03354-1.3996134

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Abstract: Initial performance period is an important input in life cycle cost analysis (LCCA); thus, an objective of this study was to determine actual initial performance periods, as the pavement age at first rehabilitation, for asphalt and concrete pavements using Long-Term Pavement Performance (LTPP) program data. In addition, most agencies use IRI, a measure of pavement roughness applicable to both asphalt and concrete pavements, in their decision making and performance evaluation process; therefore, a secondary objective was to determine pavement roughness condition at the time of first rehabilitation using the same dataset. Based on surveys of highway agencies, initial performance periods frequently used in LCCA for asphalt pavements are between 10 and 15 years, while the average asphalt pavement age at time of first rehabilitation in the LTPP program was found to be approximately 18 years. For concrete pavements, most initial performance periods used in LCCA are between 20 and 25 years, whereas the average concrete pavement age at the time of first rehabilitation in the LTPP program is about 24 years. This suggests initial performance period values used for LCCA do not

adequately represent the actual age of asphalt pavements at time of first rehabilitation, while they are generally representative of actual concrete pavement age at time of first rehabilitation. Also, it was found that asphalt pavements are typically rehabilitated when they are in good or fair condition according to FHWA IRI criteria whereas concrete pavements are typically not rehabilitated until the pavement is in fair or poor condition.

Creating a Predictive Model for Pavement Deterioration Using Geographic Weighted Regression

Paper number 18-03144, http://amonline.trb.org/2017trb-1.3983622/t024-1.3995637/677-1.3995762/18-03144-1.3995768/18-03144-1.3995769

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Abstract: New York City Department of Transportation (NYC DOT, "the agency") is tasked with maintaining a safe, resilient and sustainable transportation network that serves the mobility needs of New Yorkers while minimizing life cycle costs. This paper represents an effort by NYC DOT to predict the end of life of transportation assets so that the agency can decide on the best investment and long-term funding strategies for management, maintenance, and preservation. This paper presents a methodology for a predictive model for pavement deterioration for the five boroughs of New York City. Existing literature surrounding the nature of pavement deterioration, as well as statistical modeling techniques and applications, are examined to determine the best-fitting model. A logarithmic model using Ordinary Least Squares (OLS) and Geographic Weighted Regression (GWR) were both tested to determine the best methodology. Model validation demonstrated clustering in the OLS residuals (Moran's I z-score > 313), indicating GWR was the more appropriate technique. There was a 100 percent decrease in error using GWR compared to OLS (R2 of .35 and .17, respectively). This indicates that the logarithmic model and GWR methodology is a promising tool for forecasting pavement deterioration. More research is currently underway to obtain better data to improve the reliability of this model.

Bridge Management

Developing a Systematic Approach to Prioritize Bridge Rehabilitation

Paper number 18-06336, http://amonline.trb.org/2017trb-1.3983622/t003-1.4001637/424-1.4001793/18-06336-1.3991551/18-06336-1.4001794

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Abstract: Due to budget constraints of Departments of Transportation (DOTs) and a significant number of deficient bridges around the U.S., there is a need for a systematic approach to allocate limited resources for the bridge rehabilitation effort. This paper presents a decision-making framework to prioritize bridge rehabilitation using a combination of aggregated bridge ratings and average daily traffic

(ADT). The aggregated bridge rating is a weighted rating system; the weights for deck, substructure, superstructure, and scour ratings were determined by analyzing a group of bridge experts' opinions on the relative importance of National Bridge Inventory's bridge ratings with respect to resiliency, riding comfort, safety, and serviceability using the Analytic Hierarchy Process (AHP). Through a case study validation with Oklahoma DOT (ODOT) Division 4, the developed framework was proven to be robust and reliable. This study contributes to the industry practice by providing a systematic and quick approach to facilitate state DOTs' decision-making on bridge rehabilitation and replacement efforts.

Bridge Reconstruction Prioritization by Cost–Benefit Ratio in New York City

Paper number 18-03322, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/474-1.3997844/18-03322-1.3994066/18-03322-1.3997849

Author:

Edward Hernandez

Abstract: The New York City Department of Transportation (DOT) maintains a portfolio of 789 bridges within the five boroughs of the City of New York. Because funding from all levels of government is limited, DOT anticipates the need to make difficult decisions regarding the allocation of its resources. In an effort to inform this decision making process, DOT has begun a study to rank its bridges by benefit cost ratio (BCR). DOT's emphasis is not on whether the projects show a benefit cost ratio of above or below 1.0 in an absolute sense, but on developing a consistent benefit cost methodology based on readily available data that can produce dependable and replicable rankings across hundreds of projects. This effort has required that DOT think creatively with regards to travel time savings, safety, and social benefits. It is DOT's hope that by developing a proper BCR metric for our bridges, DOT can better inform decision makers regarding the relative importance and cost effectiveness of each of our infrastructure investments. DOT feels that the lessons learned in producing this analysis would be of great interest to other municipalities facing similarly difficult decisions regarding their aging infrastructure.

Systematic Procedures for the Analysis of Agency and User Costs of Bridge Repair Actions

Paper number 18-05384, http://amonline.trb.org/2017trb-1.3983622/t003-1.4001637/424-1.4001793/18-05384-1.3997877/18-05384-1.4001798

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Abstract: A primary goal of bridge management systems is to identify Maintenance, Repair, and Replacement (MR&R) strategies that maximize benefits and minimize losses often expressed in terms of cost. A major factor that greatly impacts outcomes of these frameworks, i.e. the most appropriate MR&R strategies, is the cost of implementation and associated consequences of performing such actions. Given that the inventory of bridges maintained by a state DOT is significantly large, this study is

aimed at developing a systematic procedure to reliably estimate the costs through effective utilization of DOTs' databases. The considered costs include agency cost of Administration, Engineering and Mobilization; agency direct cost of performing MR&R actions; agency cost of Maintenance of Traffic; and user cost incurred from traffic Delays; Vehicle operation, and Excess emission. For the estimation of each of these cost terms, analytical formulations and algorithms based on realistic considerations are proposed. Furthermore, a set of models are developed to estimate the required time for conducting various MR&R work plans. The recommended procedures are employed to estimate the agency and user costs associated with a series of light to extensive repair actions on three bridges in Ohio. Some of these costs are verified by independent estimates provided by ODOT engineers. The proposed procedure for cost estimation enables state DOTs and other entities to reliably estimate implementation costs of actions for their large inventory of bridges and identify the most cost-effective MR&R strategies and work plans.

A Bridge Performance Index with Objective Incorporation of Safety Risks

Paper number 18-05255, http://amonline.trb.org/2017trb-1.3983622/t003-1.4001637/253-1.4001896/18-05255-1.3997947/18-05255-1.4001897

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Abstract: Employing efficient bridge performance measures can significantly enhance management of large inventory of bridges by state DOTs and other entities. In a collaborative effort with Ohio DOT, an efficient performance measure called Ohio Bridge Condition Index (OBCI) was developed. Two variations of the index included: OBCI_min and OBCI_current. Primary features of these indices are that they are cost- and condition-based, and objectively represent the performance of bridge members based on the most recent element-level AASHTO recommended condition-rating system. As such, these indices successfully reflect severity and extent of deficiencies within constituent elements of the system. However, for elements that are in the load path of bridges, location or pattern of defects may also raise safety concerns. In such cases, safety risks are key factors that need to be captured in the performance index of bridge members. To address this need, an enhanced version of OBCI, OBCI_current(risk-based), is proposed here to directly account for such safety concerns in bridge members within the cost- and condition-based framework of OBCI. In OBCI_current(risk-based), summary ratings of bridge components and general appraisal ratings that are recorded in inspection reports of bridges are analytically related to the probability of improper functionality of elements/components/bridges. The proposed index is employed for performance assessment of two sample Ohio bridges with safety concerns for some of their elements. Results indicate that OBCI_current(risk-based) successfully reflects safety concerns in the performance index of elements/components/bridges. On this basis, OBCI_current(risk-based) can assist in efficient risk-informed decision making regarding repair and replacement plans of bridges.

Assessing the Relative Performance of Highway Bridge Decks Across States: A Preliminary Aggregate Analysis

Paper number 18-05025, http://amonline.trb.org/2017trb-1.3983622/t001-1.4002183/509-1.4002280/18-05025-1.3995926/18-05025-1.4002281

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Abstract: In the United States, oversight agencies such as the U.S. Department of Transportation, the Federal Highway Administration, and the Government Accountability Office are responsible for the measuring and monitoring the overall accountability of state highway agencies. To help these oversight bodies to carry out this task, it is often useful to show the extent to which the infrastructure repair expenditure and other state specific factors, at an aggregate level, influence the average condition of infrastructure. Doing this will facilitate the establishment of a methodology that these oversight agencies can use to assess the performance of the individual compared to other states. To address this issue, this paper uses interstate highway bridge decks as a case study to compare the states' interstate bridge deck average expenditures, condition and the deterioration factor values. The unit of observation in this paper is the state, thus, the analysis is aggregate in nature and does not consider design-specific or site-specific variables. The paper recognizes that there exist jurisdiction-specific variables that affect interstate bridge deck condition, and therefore attempts to remove some of this bias by normalizing the expenditure as a ratio of the inventory size and by considering state-specific values of the key deterioration variables. The paper also offers plausible explanations of the observed differences in the resulting overall performance across the states.

Managing Other Assets and Program-Level Planning

Integrating Remote Sensing Data in Decision Support Systems for Transportation Asset Management

Paper number 18-00489, http://amonline.trb.org/2017trb-1.3983622/t005-1.4000488/859-1.4000500/18-00489-1.3990863/18-00489-1.4000561

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Abstract: This study presents and makes available a novel set of analysis tools that are fully integrated in ArcGIS and developed to leverage the rich information provided by remote sensing data. Specifically, interferometric synthetic aperture radar (InSAR) and its derivatives are employed in this system. Each tool is designed to target a specific asset of interest to the transportation community: sinkhole detection, bridge differential settlement detection, slope stability assessment, and pavement distress evaluation. Furthermore, to allow interested parties to test the introduction of remote sensing data into

their decision-making process without requiring the full integration with existing workflows, a web-based decision support system (DSS) is introduced where these novel analysis products can be seamlessly integrated with existing dataset. Thanks to the large coverage and the high update frequencies offered by satellite-based remote sensing data, datasets augmented with these new products can offer a near real-time overview of the network status and lead to a better support in decisions regarding resources allocation, existing infrastructure monitoring, new infrastructure planning, and post-construction assessment.

Estimating Event Likelihood for Rock Slope Assets on Transportation Networks

Paper number 18-04621, http://amonline.trb.org/2017trb-1.3983622/t013-1.3998674/351-1.3998770/18-04621-1.3993414/18-04621-1.3998773

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Abstract: Recent federal regulations in 23 CFR 515 require that states develop risk-based Transportation Asset Management (TAM) plans for bridge and pavement assets. As these regulations make TAM principles increasingly familiar, there is a need to use these tools to better manage additional state assets. The Montana Department of Transportation (MDT) is nearing completion of a multi-year project to update its existing Rock slope Asset Management Program (RAMP), incorporating some of these new tools. Incorporating risk into decision making is an important component, but it is difficult for departments to quantify risk posed to mobility and safety by deteriorating geotechnical assets. Adverse event data is often collected in an ad-hoc fashion at the maintenance station level, with only the worst events attracting higher-level attention. As part of the RAMP research project, an MDT-administered adverse event survey was combined with a statewide dataset of detailed rock slope assessments. This data was used to develop initial correlations between rock slope condition and adverse event likelihood per unit area of rock slope face. Annual likelihood of both service disrupting events and accidents was calculated for each rock slope in MDT's database and used to identify high-risk corridors statewide. Using established AASHTO methods, event likelihood was combined with traffic and detour data, generating site-specific estimates of annual safety and mobility risks, expressed as dollar amounts, which can be incorporated into benefit/cost tools at various planning levels. This approach permits dollar-to-dollar comparisons of the risks posed by rock slope assets to other actively managed MDT assets.

Highway Asset Deterioration Rates

Paper number 18-00004, http://amonline.trb.org/2017trb-1.3983622/t001-1.4002183/355-1.4002304/18-00004-1.3991647/18-00004-1.4002311

Authors:

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Abstract: This paper is about highway asset deterioration rates. Typically, these are difficult to determine. However, using a data collection method adopted in NC (and the resulting data obtained over a 5 year timespan), an approach was developed to determine accurate deterioration rates for a number of highway assets. This was not previously done, and thus, deterioration was not included as a factor in estimating future maintenance needs for these assets despite the ready availability of the necessary data. This paper focuses on unpaved shoulders and outlines how their deterioration rates were obtained and how such rates can also be obtained for other assets. The resulting deterioration rates are presented and compared over various road systems and geographical regions. With this new knowledge, deterioration rates can now be included in life cycle asset analysis, resulting in more accurate condition predictions and maintenance budgeting. The paper focuses on highway assets and does not address bridge or pavement maintenance.

Prioritizing Assets for Inclusion in Transportation Asset Management 1 Programs

Paper number 18-05775, http://amonline.trb.org/2017trb-1.3983622/t001-1.4002183/510-1.4002255/18-05775-1.3991416/18-05775-1.4002262

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Abstract: This paper provides a summary of a methodology that will aid highway asset owners and maintenance personnel with determining what assets, beyond pavements and bridges are most important to support their agencies' mission and goals. The methodology prioritizes classes of assets and identifies data related to those assets that best support a performance-based approach to managing the condition and utilization of those assets. A reliability-centered maintenance (RCM)-based approach for determining the most effective maintenance strategy is introduced. The use of civil integrated management (CIM) for integrating data management across the agency is also discussed. The methodology presented in this paper is comprehensive, yet flexible, so it may be tailored to each agency's specific needs.

Assessment of Resource Allocation and Trade-Off Analysis Approaches in Transportation Asset Management

Paper number 18-01200, http://amonline.trb.org/2017trb-1.3983622/t001-1.4002183/510-1.4002255/18-01200-1.3991423/18-01200-1.4002278

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Abstract: Transportation asset management (TAM) practices continue to grow and to develop as transportation agencies seek to make more objective and defensible decisions, as well as to respond to recent legislation. One primary goal of TAM is to provide a structure in which decisions regarding how to distribute resources across many disparate assets can be made using a systematic process. Resource allocation is analogous to multi-objective optimization, and thus presents the complication that many potential optimal solutions (i.e., a Pareto set) can be found. In order to solve the multi-objective resource allocation problem, many approaches have been recommended, such as the use of utility theory and weighting functions to express preferences that result in a single solution being selected. This paper discusses those recommendations, as well as describes the current state of the resource allocation process in an effort to identify gaps in practice and, in turn, to provide recommendations for addressing those gaps. First, the process of cross-asset resource allocation is deconstructed to highlight the key steps. Then, current practices identified from the literature as well as from interviews with five State agencies are discussed. Finally, a set of recommendations for improving resource allocation and the supporting processes within resource allocation are presented.

Asset Value Index for Infrastructure Asset Management

Paper number 18-06250, http://amonline.trb.org/2017trb-1.3983622/t001-1.4002183/510-1.4002255/18-06250-1.3991414/18-06250-1.4002258

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Abstract: Asset valuation is an essential component of effective asset management. It is an important method to demonstrate proper management of public assets and effective utilization of tax payers' money. Asset valuation is used in standard reporting, depreciation schedules, auditor requirements and condition assessments. In addition, several government regulatory bodies mandate agencies to report their Capital Tangible Assets' (TCA) values within their annual statement. For example, the Canadian Public Sector Accounting Board (PSAB), the Governmental Accounting Standard Board (GASB) and the New Zealand International Financial Reporting Standards (NZ IFRS) to name a few. Therefore, it is essential to integrate asset value in asset management systems to effectively manage assets while maintaining or enhancing the value of these assets. The paper introduces an asset management methodology to integrate asset value and valuation concepts and techniques in asset management decision support system. This is important to manage assets in the most optimized and cost-effective ways while maintaining or enhancing the value of these assets. To achieve this objective, an Asset Value Index (AVI) is proposed. The AVI development and implementation is illustrated through a case study using data from Ministry of Transportation Ontario's (MTO) Pavement Management System (PMS2).

Bridge Repair and Rehabilitation

This section includes papers on repair methods and bridge inspection and management.

Repair Methods

Durable Concrete Overlays in Two Virginia Bridges

Paper number 18-04566, http://amonline.trb.org/2017trb-1.3983622/t003-1.4001637/681-1.4001709/18-04566-1.3991162/18-04566-1.4001710

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Abstract: Penetration of deicing salts, particularly chlorides, is the main cause of the deterioration of concrete bridge decks. Chloride-induced corrosion of steel reinforcement causes cracking, delaminations, and spalls in the concrete, affecting the integrity and ride quality of the deck. The expansion of the rust products is the cause of corrosion-related distresses. Protective deck overlays can be used to prevent the penetration of chloride ions commonly resulting from the intensified application of deicers and the marine environment.

In this study, hydraulic cement concrete overlays with a low cracking potential and low permeability were placed on two parallel bridges on Route 64 over Dunlap Creek in Alleghany County, Virginia; each had five simple spans. For low cracking potential, relatively low water contents, shrinkage reducing admixtures, and lightweight aggregates were used. For low permeability, concretes had supplementary cementitious material and relatively low water–cementitious material ratios. In the overlays, five different materials were used: latex-modified concrete with rapid set cement; silica fume concrete alone; and silica fume concrete with shrinkage reducing admixture, lightweight coarse aggregate, and lightweight fine aggregate. A compressive strength of 3,000 psi at 3 days was sought. The performance of the overlay concretes was observed after two to three winters.

The overlays achieved the specified strength and low permeability. There were minimal tight cracks except for one section with the latex-modified concrete with rapid set cement in the left lane of the westbound bridge. The extensive cracks in that section were attributed to plastic shrinkage from adverse weather conditions at placement and the fact that a truck had caught fire in that lane. Silica fume concrete overlays with shrinkage reducing admixture, lightweight coarse aggregate, or lightweight fine aggregate are ready for implementation in the field for low cracking overlays.

Optimum Timing for Application of Sealers or Polymer Overlays on New Bridge Decks

Paper number 18-06129, http://amonline.trb.org/2017trb-1.3983622/t003-1.4001637/424-1.4001793/18-06129-1.3991552/18-06129-1.4001796

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Abstract: Many states have used polymer overlays and penetrating deck sealers to extend the service life of concrete bridge decks. These preventive maintenance techniques provide protection to the concrete from deterioration by inhibiting the ingress of chlorides, chemicals, and moisture which slows active corrosion. This paper provides summary of a research report for the Iowa Department of Transportation that focuses on the use of polymer overlays and penetrating deck sealers to achieve extended service life objectives. The main objective of the study was to determine the optimum timing for application of preventive maintenance options on new bridge decks to maximize the benefit to cost ratio. A limited service life modeling and life-cycle cost analysis was conducted on a typical bridge deck in Iowa. For bridges with a typical life of 50 years, the results indicate that the greatest extensions in service life are obtained through a hybrid approach with sealers applied shortly after construction and polymer overlays installed within the first 5 years of service. For bridges with desired service life of 100 years, polymer overlays should be reinstalled through the life of the deck, at 25 years interval or less. Bridges with desired service life exceeding 50 years should be analyzed on a case-by-case basis.

Effects of Realistic Heat Straightening Repair on Damaged Steel Beam Bridges

Paper number 18-01985, http://amonline.trb.org/2017trb-1.3983622/t003-1.4001637/212-1.4001944/18-01985-1.3991856/18-01985-1.4001947

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Abstract: It is common to observe applied temperatures being both much higher or lower than recommended, over straining, mechanical hot or cold bending, or multiple heat straightening in the same spot more than three times in the real heat straightening repair process. Experimental investigations were performed to evaluate the effects of such variations on the material properties and serviceability performance of steel beam bridges. Serviceability performance was compared by measuring midspan deflections by subjecting static loads simulating the AASHTO 2007 HL-93 live load during all the stages of testing. Impact damage was simulated statically damaged using a hydraulic actuator and subsequently repaired using heat straightening by applying Vee heats and restraining forces in the damaged region. The damage and repair parameters considered in the test were restraining force, maximum heating temperature, and number of multiple damage-repair cycles. Specimens subjected to overheating (up to 1400 °F) during repair and those subjected to heating up to the accepted limit of 1200 ºF had similar structural properties and fracture toughness values after repair. Specimens subjected to three damage-repair cycles, and those subjected to only one damage-repair cycle had similar structural properties and fracture toughness. However, specimens subjected to mechanical hot bending, i.e. heat straightening repair with underheating (temperature less than 1000 ºF and excessive restraining force over 50% of the plastic moment capacity of the section), showed the lowest fracture toughness values. In serviceability performance, heat straightening repaired girders and undamaged girders showed similar midspan deflections under the AASHTO 2007 HL-93 live loading.

Bridge Substructure Repairs with Self-Consolidating Concrete and Galvanic Anodes
Paper number 18-03056, http://amonline.trb.org/2017trb-1.3983622/t022-1.3997225/217-1.3997628/18-03056-1.3991852/18-03056-1.3997632
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Abstract: Historically, the Virginia Department of Transportation (VDOT) has repaired chloride-contaminated reinforced concrete bridge substructure elements that contain vertical and overhead sections with either shotcrete or a conventional A3 (3,000 psi) or A4 (4,000 psi) concrete. This study investigated using self-consolidating concrete (SCC), which has a high flow rate, bonds well, has low permeability, and provides smooth surfaces, as another option. SCC can be placed in narrow areas and can fit the geometry of the element. The study also explored the use of galvanic anodes to control corrosion activity in SCC repairs at various locations. In VDOT's Lynchburg District and Staunton District, SCC repairs were made with and without the use of galvanic anodes. This provided a means for determining the benefit of using the anodes. The needed repair areas were determined by visual observation and sounding. After 7 years of service, SCC repair areas with and without anodes did not exhibit corrosion activity; small vertical cracks were evident in the SCC but did not affect performance. The anodes provided protection to the steel immediately adjacent to the repair areas. However, they did not protect the more remote unrepaired concrete areas. These unrepaired areas now require additional repairs.

The study recommended that in the future half-cell potential measurements, rather than sounding, be used to identify the needed repair areas. Progression of corrosion demonstrates the necessity of removing all chloride-contaminated concrete adjacent to the reinforcement, as anodes in the repair area will provide protection only in a narrow area around the patch.

First Application of UHPC Bridge Deck Overlay in North America
Paper number 18-06205, http://amonline.trb.org/2017trb-1.3983622/t003-1.4001637/846-1.4001659/18-06205-1.3990887/18-06205-1.4001662
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Abstract: Deterioration of existing bridge decks, which usually originates with the deck cracking on the top surface, is a common problem in North America. It causes frequent repair of the decks to limit further damage resulting from water/chloride ingress. Superior engineering and durability properties facilitate the use of ultra-high performance concrete (UHPC) as an attractive alternative for a deck overlay and minimize deck deterioration. Recently developed UHPC thixotropic mix designs enable UHPC overlay to be used on decks with slope and meet specific crowning requirements. The use of this UHPC with 3.25% of steel fibers was successfully evaluated under laboratory conditions. The feasibility of applying this technology in the field was then investigated on a small bridge for the first time in North

America in May 2016. This paper presents the details about the laboratory evaluation, field implementation of UHPC overlay, and lessons learned from this first UHPC overlay project in North America.

Bridge Inspection and Management

Development and Implementation of the 3-D Bridge App for Collection and Retrieval of Bridge Inspection and Management Information

Paper number 18-05137, http://amonline.trb.org/2017trb-1.3983622/t003-1.4001637/253-1.4001896/18-05137-1.3991795/18-05137-1.4001899

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Abstract: To increase the efficiency and reliability of bridge inspections, the Michigan Department of Transportation (MDOT) worked closely with a Michigan Technological University research team to develop a three-dimensional (3D) model-based data entry application for mobile tablets to aid inspectors in the field. The 3D BRIDGE App does this by enabling inspectors to enter element-level bridge condition data using 3G/4G network-enabled tablet devices. The system collects information from MDOT's bridge management database, and then generates and renders an interactive 3D model of the desired bridge. The bridge inspector is able to record the locations and attributes of new defects in an element-level form by touch interaction and manipulation of the 3D model. By utilizing previously existing defects, the application also allows for bridge inspectors to better visualize and edit past inspection data in future inspections, creating a defect timeline charting the severity and extent of the problem. Inspectors can also take pictures of the defects using the tablet's camera, as well as record comments, creating a location-specific chain of evidence through each inspection. The application also runs on desktop computers and all resulting data may be uploaded to the department's bridge management database, allowing results to be integrated into bridge management workflows to provide better understanding of the overall condition of bridge infrastructure.

Bridge Inspection Protocol Using UAV Data

Paper number 18-00122, http://amonline.trb.org/2017trb-1.3983622/t003-1.4001637/423-1.4001800/18-00122-1.3991555/18-00122-1.4001807

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Abstract: The use of Unmanned Aerial Vehicles (UAVs) or Aircraft Systems (UASs), commonly known as drones, has significantly increased over recent years in the field of civil engineering. In detail, the need

for a more efficient and cost-effective alternative for bridge inspection, has risen due to the increased interest from bridge owners. The primary goal of this paper was to evaluate the efficiency of a drone as a supplemental bridge inspection tool. To complete this study, a glulam girder with a composite concrete deck bridge was selected in the state of South Dakota (SD), and a drone, a DJI Phantom 4, was utilized to perform the bridge inspection. Based upon the literature review, an inspection protocol with a drone was developed, in order to efficiently identify damage on the bridge. A drone-enabled inspection was performed following the protocol, and resulting findings were compared to those available in the past inspection report provided by SD Department of Transportation (SDDOT). This study details drone-enabled inspection principles and relevant considerations to obtain optimum data acquisition. A key finding demonstrated throughout this project is that different types of structural damage on the bridge were identified using the drone.

A GUI-Based Tool Identifying Cost-Effective and Rapid Concrete Repair Techniques for Bridges
Paper number 18-05458, http://amonline.trb.org/2017trb-1.3983622/t003-1.4001637/423-1.4001800/18-05458-1.3997880/18-05458-1.4001803
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Abstract: Every second, millions of Americans depend on a vast U.S. infrastructure that extends from coast to coast and is exceeding its design life. Concrete is a principal component of many transportation structures. While highly durable, a variety of processes degrade and damage concrete. Replacement is expensive and many cases warrant repair instead of replacement. Since many damage processes are progressive, early and properly timed repairs can reduce costs. An overall lifetime cost of ownership approach to selection and design of repairs has merit, but requires good information about costs and outcomes. There is a possibility that effective timing and application of repairs can be of great benefit to maintenance activities – including calculating lifetime costs and identifying rapid techniques that allow for expedited designs of repairs and minimizing repair times. This paper presents the results of a project aimed at the challenge in implementing comprehensive repair and maintenance practices in a state DOT's bridge inventory. Challenges arise from the number of available repair techniques and specialization of the repairs according to special conditions and the type of component. To mitigate this problem and arrive at the best solution, this paper reports on the assembly and development of an automated computer-based graphical user interface (GUI) tool. The tool incorporates an easily accessible database of cost-effective and rapid concrete repair techniques that a user can access using a simple menu-driven GUI. The Concrete Repair GUI software will allow the user to arrive to the most effective type of repair technique by properly identifying the concrete failure type and analyzing the damage to that particular structure.

Culvert and Stream Maintenance

CIPP and Spray-On Liner Culvert Rehabilitation: A Review of Water Quality Impacts and Current Construction Specifications

Paper number 18-01125, http://amonline.trb.org/2017trb-1.3983622/t006-1.4000109/208-1.4000481/18-01125-1.3998036/18-01125-1.4000486

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Abstract: Cured-in-place-pipe (CIPP) and spray-on liners are used to rehabilitate damaged culverts because they can be less expensive than other pipe repair technologies. Study objectives were to: (1) compile and summarize known CIPP and spray-on lining surface water contamination incidents; (2) provide an overview of water quality impact studies on CIPP and spray-on liners; (3) compare and contrast current transportation agency construction practices. The literature was reviewed for contamination incidents and water quality impact studies. Construction documents and perspectives were obtained from 32 DOTs. Twelve CIPP surface water contamination incidents were found while none were found for spray-on liners. CIPP incidents were attributed to the release of uncured resin, manufacturing byproducts, and waste to surface waters. Four states conducted water quality impact field studies for CIPP, while only 1 state examined spray-on liners. Studies revealed that CIPP installations released resin ingredients, solvents, and manufacturing byproducts. Chemicals were detected in water samples for up to 88 days. Although no water quality impacts were found from field tests of cementitious and polyurea spray-on liners, impacts to water quality were found in laboratory tests. Many (22) states had CIPP construction guidance while only three had spray-on liner guidance. Construction requirements included thetemporary use of materials at the culvert openings to limit chemical release; water testing before and after liner installation; and the capture and authorized release of wastewater.The report provides a list of recommended construction specifications to minimize risks to water quality.

Investigation of Engineered Cementitious Composite for Culvert Repair

Paper number 18-03118, http://amonline.trb.org/2017trb-1.3983622/t003-1.4001637/317-1.4001857/18-03118-1.3996008/18-03118-1.4001866

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Abstract: Corrugated metal pipe culverts are distressed at the inverts because of abrasion and corrosion. Concrete has been used to repair the inverts in thicknesses of about 4 inches. Environmentalists object to such thicknesses because of restriction to the water flow. This study investigated engineered cementitious composite (ECC) in thicknesses of 1 inch or less above the crest of the corrugated metal pipe. ECC contains short polyvinyl alcohol fibers and exhibits very tight numerous cracks that prevent the infiltration of solutions from within the pipe. ECC is used in the invert and along the side where

water rises most of the time. Biaxial geogrids were used to reinforce the thin ECC and to keep the concrete from sliding along the sides. Initially in the laboratory in small batches, ECC with locally available materials and regular sand was developed and placed in culvert samples that had geogrid attached. Then, as a preparation for actual culvert repairs, ECC was prepared in a truck mixer and placed in large culvert samples at a district office of the Virginia Department of Transportation. Since some of the culverts are coated with asphalt, in an actual deteriorating asphalt-coated culvert, a 6-foot section was repaired to ensure that ECC could perform well with minimal cracking. With the geogrid and the screws, ECC was attached to the metal culvert, and after weeks of observation, it appeared to stay in place.

Finite Element Modeling and Analysis of Early-Age Cracking Risk of Cast-in-Place Concrete Culverts

Paper number 18-00760, http://amonline.trb.org/2017trb-1.3983622/t022-1.3997225/318-1.3997566/18-00760-1.3991689/18-00760-1.3997602

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Abstract: Extensive cracking was found in several cast-in-pace concrete culverts in Alabama that can decrease the long-term durability of the culverts. Early-age stress development in concrete is influenced by temperature changes, modulus of elasticity, stress relaxation, shrinkage, thermal coefficient of expansion, and the degree of restraint. The objective of this study is to determine means to mitigate early-age cracking in culverts by evaluating the cracking risk. Finite-element analysis was used to model the early-age stress by accounting for the following factors: construction sequencing, support restraint, concrete constituents, temperature effects, and the time-dependent development of mechanical properties, creep/relaxation, and drying shrinkage. Experimental results from restraint to volume change tests with rigid cracking frames were used to verify the accuracy of the finite-element analysis. A parametric study was performed to quantify the effect of changing joint spacing, joint type, construction sequence, concrete coefficient of thermal expansion, placement season, and concrete type on the early-age cracking risk. The finite-element model results revealed that the use of the following measures will reduce the risk of early-age cracking in cast-in-place concrete culverts: lower coefficient of thermal expansion concrete, contraction joints, sand-lightweight concrete or all-lightweight concrete, and scheduling the casting of the culvert wall to minimize the difference in its placement time relative to its previously cast base. Alternatively, to minimize the contribution of thermal effects on cracking risk, the construction schedule should be developed to avoid concrete placement during hot weather conditions.

Alternative Stream Channel Maintenance at Bridges in Ohio: Outcomes of a Participatory Research Project

Paper number 18-05087, http://amonline.trb.org/2017trb-1.3983622/t001-1.4002183/355-1.4002304/18-05087-1.3991645/18-05087-1.4002307

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Abstract: The Ohio Department of Transportation (ODOT) maintains >44,000 bridges statewide. Annually, hundreds of maintenance projects are undertaken by county maintenance crews to mitigate the effects of stream channel scour and sediment aggradation that impacts the structural integrity and conveyance capacity of many bridges. Current maintenance practices have limitations and often provide only temporary resolution to the maintenance issue. As a result, ODOT sought out research to identify alternative maintenance practices that are: 1) more sustainable (i.e. reduce long-term maintenance frequency), 2) environmentally sensitive, 3) economical, and 4) readily implementable by county maintenance crews. Reconnaissance was conducted to identify representative sites with typical maintenance problems to serve as case study examples. Based on literature review and experience of the research team, a range of alternative maintenance practices were identified. Potential solutions were further refined as researchers worked with ODOT staff to inventory equipment available for construction, identify construction materials that could be obtained with reasonable effort, and assess skills sets of ODOT maintenance crews. Proposed maintenance projects were presented to ODOT staff and subsequently revised during multiple iterations of a participatory design process. Flow altering devices (e.g. vanes, w-weirs, etc.) commonly used in the field of stream restoration and "softer" bank stabilization materials were selected for further investigation. The following paper describes typical maintenance problems at bridge crossings, outlines historical maintenance practices in Ohio, provides information on alternative practices implemented through the research effort, and provides details on a pilot project that was implemented by county maintenance crews.

Gravel Road Maintenance

Applying Large-Scale Optimization to Evaluate Pavement Maintenance Alternatives for Low-Volume Roads Using Genetic Algorithms

Paper number 18-01478, http://amonline.trb.org/2017trb-1.3983622/t022-1.3997225/343-1.3997556/18-01478-1.3991659/18-01478-1.3997563

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Abstract: Over the last decade, significant progress has been made to customize the maintenance policies of low-volume roads (LVRs) to the available local needs and resources. The application of low-cost treatments and surface repairs are extensively employed to reduce the annual maintenance costs. Colorado Department of Transportation (CDOT) applies chip seals and thin overlays as the only available treatment options applied to LVRs. However, the effectiveness of these treatments depends mainly on the existing condition of pavements. Some surface treatments and light rehabilitations provide only short-term effectiveness, and state DOTs make unnecessary expenditures when applying these

strategies. The multi-year optimization techniques support decision makers with a set of optimal maintenance activities to achieve specific pavement performance targets within reasonable budgets. This study applies large-scale optimization to compare between the current CDOT maintenance policy and an alternative strategy recommended for low-volume paved roads in Colorado. Genetic algorithms were applied in the optimization models because they are capable to resolve computational complexity of optimization problems in a timely fashion. The optimized maintenance alternatives were comprehensively investigated for a LVRs network in Colorado over a specific planning horizon. The specific optimization constraints and limitations prevailing LVRs are addressed and introduced in the problem formulation of optimization process. The results of both performance and cost analysis emphasize the effectiveness of the proposed maintenance strategy compared to the followed one. The alternative policy provides much more benefit-cost saving while preserving the overall pavement performance of the network. This approach is expected to be efficient to quantify the mid and long-term financial impact of different treatment policies applied to LVRs within modest resources.

An Optimization Model to Select Unpaved Roads for Chemical Treatments as Dust Suppressants

Paper number 18-05467, http://amonline.trb.org/2017trb-1.3983622/t022-1.3997225/244-1.3997610/18-05467-1.3991812/18-05467-1.3997613

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Abstract: This study developed a model to select the optimum sections of unpaved roads for chemical treatments as dust suppressants within limited budget. In the state of Wyoming, more than 12,000 miles of roads are unpaved. Wyoming being a leading producer of coal, and oil and gas, means its unpaved roads have more traffic that result in significant dust emissions. To reduce this dust emission, Wyoming currently uses CaCl2 and MgCl2as dust suppressants. Because the budget is limited, all these 12,000 miles of unpaved roads cannot be treated every year. A Previous study concluded that traffic volumes, percent passing through #200 sieve and annual rainfall have significant impact on generating dust. Considering these factors, this study developed a model that identifies which unpaved roads should be traeted within a limited budget using a linear integer optimization technique. As a case study, this model was successfully implemented on a small network of 27 unpaved roadway segments.

Use of Real-Time Dust Monitoring and Surface Condition to Evaluate Success of Unpaved Road Treatments

Paper number 18-06624, http://amonline.trb.org/2017trb-1.3983622/t022-1.3997225/343-1.3997556/18-06624-1.3991656/18-06624-1.3997557

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Abstract: Fugitive dust from unpaved roads creates human health hazards, degrades road surfaces, and increases the cost of road maintenance. As a result, many different chemical treatments are applied to unpaved roads in an attempt to control dust and stabilize the wearing course. However, investigations of the effectiveness of these treatments have often been poorly planned or executed. The objective of this study was to use a combination of real-time dust monitoring and objective road condition evaluations to assess the success of two chemical treatments for a period of 19 months post-application, in order to provide quantitative information in support of road management decisions. Both durablend-C™ and EnviroKleen® reduced dust by up to 99% relative to the untreated control during the monitoring period. Linear models of dust production indicated that road treatment and humidity explained most of the variation in dust over time, and quantitative data from the vehicle-mounted particulate monitor were consistent with qualitative observations of dust conditions. Road sections treated with either product developed less rutting and fewer potholes than the untreated control. Overall, the combination of real-time dust monitoring and surface condition evaluation was an effective and efficient approach for generating quantitative data on endpoints of interest to road managers.

Estimation of Gravel Roads Ride Quality Through Android-Based Smartphone

Paper number 18-04288, http://amonline.trb.org/2017trb-1.3983622/t024-1.3995637/677-1.3995762/18-04288-1.3991164/18-04288-1.3995763

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Abstract: This study demonstrated the ability of smartphone sensors in evaluating gravel roads conditions. Seventy gravel roads with various conditions, surface materials, and geometric features were included in this study. The carried analysis was based on signals demodulation and wavelet transformation to reduce the effect of many external factors (i.e., speed dependency, engine vibrations, and suspension system) that may affect the obtained measurements. It was found that the acquired signals from a smartphone accelerometer can reflect the actual conditions of a gravel road. In addition, the location and the severity of surface deteriorations like potholes could be identified. A regression model (R^2=0.78) based on the acquired signals from smartphones was developed to predict the overall rating of gravel roads condition according to the Riding Quality Rating Guide (RQRG) system. An initial validation analysis, conducted on new 35 gravel roads, showed that this model was able to return reasonable ratings. Also, the statistical analysis showed that any difference between the predicted and the actual ratings of less than 1.3 was not significant. The proposed methodology can be considered a baseline for building a low cost crowdsourcing platform that helps local agencies in managing their inventory of gravel roads.

Performance-Based Design Method for Gradation and Plasticity of Granular Road Surface Materials

Paper number 18-05314, http://amonline.trb.org/2017trb-1.3983622/t022-1.3997225/343-1.3997556/18-05314-1.3991658/18-05314-1.3997561

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Abstract: Granular-surfaced roads frequently experience severe surface damage and degradation, which adversely affects traffic safety and significantly increases maintenance costs. The importance of the gradation and plasticity of granular-surfaced road materials have long been recognized. However, very few studies have focused on quantifying the effects of gradation and plasticity on the resulting mechanical performance of granular roadways. In this study, extensive laboratory tests and statistical analyses were conducted to quantify the effects of variations in gradation and plasticity on the mechanical performance of granular road surface materials. A performance-based design method was developed using Fuller's model to replace the commonly used arbitrary gradation band specifications. To validate the performance of the proposed method, field test sections were constructed then tested and monitored through a seasonal freeze-thaw period. Compared to existing gradation band specifications, the laboratory and field test results demonstrated that the newly proposed method is more closely tied to performance and can be used to develop specifications with more precise targets. To help secondary roads agencies implement the proposed method while also recycling existing surface materials, a Microsoft Excel gradation optimization program was developed to determine the mixing ratios of existing roadway aggregate and up to three new quarry materials to come closest to the theoretical gradation for optimum performance. A complete set of testing, design, and construction procedures is also recommended to provide more cost-effective solutions to building or reconstructing granular-surfaced road systems.

Maintenance Worker Safety

Impact of Temporary Portable Work Zone and Personal Lighting on Vehicle Speeds in Nighttime Highway Preservation Projects

Paper number 18-05510, http://amonline.trb.org/2017trb-1.3983622/t004-1.4001281/463-1.4001457/18-05510-1.3997512/18-05510-1.4001458

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Abstract: Every year thousands of people are killed or injured in work zone crashes in the US due to excessive speed, distraction, inattentiveness, or low visibility. Many highway construction, maintenance, and pavement projects occur at night when the traffic volume is low, creating less congestion and delay

to the traffic. During nighttime operations, however, ability of drivers to see workers is diminished. High speed roadways with low visibility make an unsafe and dangerous situation for both motorists and workers. In this paper the impact of additional temporary lighting on vehicle speed in highway work zones was investigated. In addition, the impact of wearing personal lighting equipment was also examined during paving operations. Two common types of lighting equipment, a light tower and a balloon light, were set up in work zones and a personal, wearable light was used during two paving projects on Oregon highways. Traffic speed and other vehicle and lighting data were collected on different nights when the lighting equipment was turned on and also when it was turned off. The research findings indicate that both additional temporary roadway lighting and personal lighting help to make workers more visible to motorists and equipment operators. Although a temporary light leads to slightly higher vehicle speeds, it makes the work zone and workers more visible for motorists and equipment operators. Statistical analysis revealed that there is no difference between mean vehicle speed with and without personal lights turned on. Personal, wearable lights are highly recommended for workers who are located away from large equipment and other light sources.

Assessing Driver Understanding and Responses to a Visual and Audible Work Zone Intrusion Alarm System

Paper number 18-04557, http://amonline.trb.org/2017trb-1.3983622/t023-1.3996143/393-1.3996907/18-04557-1.3996911/18-04557-1.3996912

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Abstract: Oldcastle Materials and ARTIS, LLC joined forces to develop an innovative work zone intrusion detection and alarm system. The system flashes LED lights and emits an audible alarm if an intrusion is detected. TTI conducted a study to assess how motorists approaching a simulated work zone with an alarm system interpreted the lights/alarm and responded to them.

A demographically-balanced group of 63 participants drove an instrumented vehicle around a test course created at the Texas A&M University RELLIS Campus. Several vehicle operating measures were recorded, and participants were asked questions at the end of the study to understand their thoughts about what the alarm meant and what a driver should do in response to the alarm.

Overall, very few statistically significant changes in vehicle operating measures were recorded when the alarm system was activated, suggesting that the system did not have an adverse effect on driver behavior. Participant responses to questions indicated a common perception that the alarm was initiated to get them to slow down, which is one of the desired outcomes of the system. However, many of the participants perceived the alarm as a police or emergency vehicle presence nearby, and believed that they should have pulled over and stopped when the alarm activated. Based on these findings, the researchers recommended that the audible alarm be modified to provide short bursts (less than one second long) to differentiate it from emergency response sirens.

Simulator and Field Study of Truck-Mounted Automated Flagger Assistance Devices in Missouri

Paper number 18-01188, http://amonline.trb.org/2017trb-1.3983622/t023-1.3996143/393-1.3996907/18-01188-1.3991595/18-01188-1.3996917

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Abstract: Automated flagger assistance devices (AFADs) are designed to improve worker safety by replacing flaggers who are typically located near traffic approaching a work zone. In this study, a new AFAD developed by the Missouri Department of Transportation (MoDOT) was investigated by a driving simulator study and a field study. The MoDOT AFAD configuration, involving STOP/SLOW paddles, Red/Yellow lights, and a changeable message sign (CMS), was incorporated onto a truck-mounted attenuator for operator protection. Driver behavior measures, including approach speed, initial braking location, full stop distance, reaction time, and intervention rate, were used to measure the effectiveness of AFAD as compared to a human flagger. In the driving simulator study, the AFAD and its alternative designs significantly reduced average approach speeds (7.7 to 8.9 mph) and increased the distance at which the approaching vehicle came to a complete stop (24 to 48 feet). In the field study, the AFAD was able to slow vehicle approach speeds (4.20 mph less), stop vehicles farther back than a flagger (11.4 feet), and release traffic quicker than flaggers (1.3 seconds less). Each study was followed by a survey that captured driver preferences and understanding. The results from both surveys showed that drivers understood AFADs reasonably well and preferred AFADs over human flaggers, especially for the MoDOT AFAD configuration. Overall, the AFAD has potential to improve the safety of work zones and workers.

Evaluating Work-Zone Intrusion Alert Technology: Recommendation for Future Development

Paper number 18-00603, http://amonline.trb.org/2017trb-1.3983622/t023-1.3996143/393-1.3996907/18-00603-1.3996919/18-00603-1.3996920

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Abstract: Roadway construction and maintenance workers are often exposed to substantial safety risks resulting in part from working in close proximity to live traffic. As a result of this hazardous work environment, 1,435 roadway construction and maintenance workers in the US died while they were on duty between 2003 and 2014, averaging about 115 fatalities per year. Vehicles intruding into work zones are linked to approximately 8% of work zone fatalities. Approximately 50% of fatalities recorded between 2011 and 2014 were attributed to vehicles hitting a worker in the work zone. Past studies suggest that implementing safety technologies in work zones could have prevented many of those fatalities. Unfortunately, the construction industry is historically known to be resistant to change and slow in technology adoption. One reason for the industry's conservative approach towards new safety technologies is the lack of scientifically-based evaluation studies on the effectiveness of such technologies. To help improve adoption potential, the researchers developed and implemented a five-

step evaluation protocol for assessing work zone intrusion alert technologies (WZIATs). The evaluation study focused on three commercially available intrusion alert technologies: SonoBlaster, Intellicone, and Worker Alert Technology (WAS). The study demonstrated that a rigorous scientific evaluation process for WZIATs can be developed and implemented. In addition, WZIATs showed they have the potential to play a significant role in improving highway worker safety, and recommendations are provided to improve the effectiveness of WZIATs.

Effects of Mounting Height, Offset Distance, and Number of Light Towers on Drivers' Visual Performance and Discomfort Glare in Work Zones

Paper number 18-04997, http://amonline.trb.org/2017trb-1.3983622/t023-1.3996143/429-1.3996885/18-04997-1.3991547/18-04997-1.3996890

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Abstract: Portable light towers are a significant source of glare to motorists entering a work zone. Although existing research has evaluated the effect of light tower orientation on visibility and glare, the effects of mounting height, offset distance from the roadway, and number of light towers on visual performance and discomfort glare are yet to be reported. Understanding these relationships can help in developing illuminating guidelines for work zones that can reduce glare for drivers. The goal of this paper to understand the effect of mounting height, offset distance to the roadway, and number of light towers on drivers' visual performance and discomfort glare. Participants drove through a realistic work zone and evaluated portable light towers in varying mounting heights, offset distances, and number of light towers. Results indicated that the mounting height and offset distances play a critical role in affecting the driver's visual performance and discomfort glare rating. Portable light towers, irrespective of wattage and lumen output, at less than 20 ft. mounting height and closer to the roadway result in decreasing driver visual performance and increasing their discomfort glare. Portable light towers should be mounted at a height of at least 20 ft. and balloon light towers with higher wattage (4,000 W and greater) and lumen output (400,000 lumens and greater) should be located at an offset distance of at least 10 ft. from the roadway.

Risk Factors Affecting Crash Injury Severity by Work Zone Area

Paper number 18-05849, http://amonline.trb.org/2017trb-1.3983622/t023-1.3996143/421-1.3996894/18-05849-1.3996895/18-05849-1.3996896

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Abstract: Work zones include before work area, at taper approach area, and adjacent to work area. The geometric, traffic control aspects, traffic operations, and driver's maneuverability differ within each work zone area. Therefore, the risk of getting involved in a crash and factors that contribute to these crashes varies by areas in work zones. The focus of this research is to examine and identify factors that contribute to crash injury severity in these work zone areas. Five years (2010-2014) of crash data for the

state of North Carolina was obtained from the Highway Safety Information Systems (HSIS) and used in this research. Four partial proportional odds models were developed using SAS as the data was violating the parallel lines assumption. The results obtained indicate that the risk of getting involved in a work zone crash in the taper approach area is higher on roads with rigid, flexible post barrier medians. Further, the risk of getting involved in a work zone crash in the adjacent to work area is higher in extreme weather conditions, on roads with rigid and flexible post barrier and curb medians, speed limit between 26 mph - 45 mph, interstates and US routes. However, the risk of getting involved in severe injury crashes in the before work area is higher on roads with flexible post barrier medians but lower on roads with semi-rigid post barrier medians. Such findings from this research will assist the practitioners to take precautionary measures and reduce risk of getting involved in a crash by implementing safety countermeasures in work zone areas.

Applications of Lidar and Connected Vehicle Data to Evaluate the Impact of Work Zone Geometry on Freeway Traffic Operations

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Abstract: Extensive literature exists regarding recommendations for lane widths, merging tapers, and work zone geometry to provide safe and efficient traffic operations. However, it is often infeasible or unsafe for inspectors to check these geometric features in a freeway work zone. This paper discusses the integration of LiDAR (Light Detection And Ranging)-generated geometric data with connected vehicle speed data to evaluate the impact of work zone geometry on traffic operations. Connected vehicle speed data can be used at both a system-wide (statewide) or segment-level view to identify periods of congestion and queueing. Examples of regional trends, localized incidents, and recurring bottlenecks are shown in the data in this paper. A LiDAR-mounted vehicle was deployed to a variety of work zones where recurring bottlenecks were identified to collect geometric data. In total, 350 directional miles were covered, resulting in approximately 360 GB of data. Two case studies, where geometric anomalies were identified, are discussed in this paper: a short segment with a narrow lane width of 10-10.5 feet and a merging taper that was about 200 feet shorter than recommended by the Manual on Uniform Traffic Control Devices. In both case studies, these work zone features did not conform to project specifications but were difficult to assess safely by an inspector in the field due to the high volume of traffic. The paper concludes by recommending the use of connected vehicle data to systematically identify work zones with recurring congestion and the use of LiDAR to assess work zone geometrics.

Pavement Repair and Rehabilitation

This section includes papers on crack sealing and filling, chip seals and fog seals, overlays, and concrete.

Economic Analysis of Pavement Preservation Techniques

Paper number 18-00843, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/725-1.3997743/18-00843-1.3991087/18-00843-1.3997746

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Abstract: This paper summarizes the research study conducted to develop and implement a methodological framework, using an economic analysis technique, to evaluate the cost-effectiveness of the three different preventive maintenance treatments applied in Texas: chip seals, microsurfacing, and thin overlays. The analysis is based on a stochastic evaluation of the effective life and cost of +14,000 maintenance and rehabilitation projects built from 1994 to 2015. The effect of the traffic loads, traffic volume, and roadway type was also evaluated. The life-cycle cost of the preventive maintenance techniques was obtained using a Monte Carlo Simulation. Among the principal results, it was found that chip seals are the most cost-effective treatments and present the lower life-cycle cost variability. The effective life of all three treatments was found to be quite similar. Additionally, it was found that the chip seals and microsurfacing tend to present comparable life-cycle cost when using it on heavy trafficked roadways.

Improving Quantity Estimating for Pavement Rehabilitation and Resurfacing Using Mobile Lidar

Paper number 18-06403, http://amonline.trb.org/2017trb-1.3983622/t024-1.3995637/312-1.3996054/18-06403-1.3996058/18-06403-1.3996059

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Abstract: Repaving, rehabilitation and pavement maintenance are routine tasks of all state and local transportation agencies. Compared with traditional surveying techniques, vehicle-based mobile light detection and ranging (LiDAR) systems can be used to estimate material volumes needed for pavement rehabilitation and resurfacing in a cost-efficient manner. An innovative approach based on use of

mobile LiDAR data and geographic information system (GIS) analysis was developed to create 3-dimnesion raster representation of roadway surfaces. The research approach involved conducting a comprehensive technical evaluation of multiple mobile scanning systems to evaluate accuracy and precision of collected raster surfaces and required procedures to calibrate, collect and process LiDAR data. A testbed study site located along a 2.9-mile urban parkway in Anderson, South Carolina was used to investigate accuracy of high resolution raster surface modeling of the roadway paved surface. LiDAR data was collected by five mobile laser scanning (MLS) vendors. MLS data from each vendor was evaluated with regard to accuracy and precision of the raster surfaces. The resultant surfaces were compared between vendors and with a raster surface created from profile and 100-ft. cross section data obtained from traditional surveying methods. LiDAR produced more precise surface data and pavement material estimates as compared with traditional survey data averaged linearly over 100-ft increments. In comparing LiDAR data between compliant MLS vendors, average raster cell height differences averaged 0.21 inches, ranging from 0.01 to 0.63 inches, indicating LiDAR data has considerable potential for creating accurate pavement material volume estimates.

Universal Method to Measure Water Infiltration into Asphalt Pavements Independent of Pavement Preservation Surface Treatment

Paper number 18-01230, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/422-1.3997881/18-01230-1.3995950/18-01230-1.3997886

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Abstract: In recent years, greater focus has been placed on pavement preservation treatments, where one of the primary goals is to seal an existing pavement (especially cracks) to preserve it from further oxidation (i.e. decrease its permeability). The industry needs the ability to measure the effectiveness of these surface treatments; a single universal method that could be used for this purpose would be ideal, especially if traditional asphalt pavement surfaces could also be evaluated or field and laboratory measurements successfully related. This paper's objective is to present a simple permeameter device, the Mississippi permeameter (MSP), for measuring water infiltration into asphalt pavements independent of the surface (e.g. dense graded asphalt (DGA), chip seal). In this paper, the MSP was evaluated against traditional field and laboratory permeameters (e.g. NCAT permeameter) on a range of surfaces from open graded friction course (OGFC) (most permeable) to DGA (most common) to chip and scrub seals (least permeable, roughest texture, most difficult to measure). The MSP provided measurements as reasonable as those of existing permeameters and was also successfully used to test chip and scrub sealed cracks, which is beyond existing permeameters' abilities. Additional refinements are needed for relating field and laboratory measurements, but the MSP concept appears promising and worth pursuing given the increasing pavement preservation focus.

Crack Sealing and Filling

Field Evaluation and Cost-Effectiveness of Crack Sealing in Flexible and Composite Pavements

Paper number 18-00328, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/356-1.3997896/18-00328-1.3991642/18-00328-1.3997906

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Abstract: One of the most common methods to treat longitudinal and transverse cracks is Crack Sealing (CS), which is categorized as a preventive maintenance method. Field performance and cost-effectiveness of this treatment widely vary depending on pavement conditions and installation of the material. The objective of this study was to evaluate the field performance and cost-effectiveness of CS in flexible and composite pavements in hot and wet climates such as Louisiana, and to develop a model that would quantify the expected benefits of CS given project conditions. To achieve this objective, 28 control sections that were crack-sealed between 2003 and 2010 were monitored for at least 4 years. These sections included flexible and composite pavements, sealed and unsealed segments, and varying traffic levels. The performance of these sections was evaluated in terms of the Random Cracking Index (RCI) and the Roughness Index (RI). Based on the results of this analysis, it was concluded that CS has a significant impact on random cracking only. When compared to untreated segments, CS extended Pavement Service Life (PSL) by two years. When compared with the original pavement, CS extended PSL by 5.6 and 3.2 years for flexible and composite pavements, respectively, if applied at the correct time. The cost-benefit analysis indicated that CS is cost-effective whether asphalt emulsion or rubberized asphalt sealant is used. A non-linear regression model was developed to predict the extension in PSL due to CS without the need of performance data based on the Annual Daily Traffic (ADT), pavement type, and prior pavement conditions.

Comparison of Field Performance of Crack Treatment Methods in Asphalt Pavement: Crack Filling Versus Crack Sealing

Paper number 18-01296, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/356-1.3997896/18-01296-1.3997900/18-01296-1.3997901

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Abstract: Crack sealing and filling treatment has always been an important consideration in order to prolong the life of pavement among all the pavement maintenance program. Crack sealing uses a router to cut the crack to provide a uniform rectangular reservoir for greater penetration of sealants and crack filling is simply inserting sealant without performing any modification to the crack walls. Most of the states in US have been using crack filling treatment for treating the cracks because of its cost-effectiveness and proper guidelines. However, the performance and cost-effectiveness history of crack sealing practice is not known or not well documented in comparison to the performance of crack filling.

This research study is intended to compare the field performance between crack sealing and filling treatment. The comparison includes four different roads in four districts which were selected based on the climate regions, Annual Average Daily Traffic (AADT), material and conditions. In order to have appropriate comparison the same hot pour sealant material and finishing technique was used. The treated sections in all four districts were regularly inspected once after a three month period of interval. In general, the results of this study indicated that crack sealing treatment exhibited excellent performance and observed to have on an average 37% more treatment effectiveness than crack filling treatment. Implementing with proper guidelines sealing technique is more cost effective practice in a long run compared to filling technique.

Cost-Effectiveness for Hot-Poured Asphalt Crack Sealants

Paper number 18-02259, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/356-1.3997896/18-02259-1.3997897/18-02259-1.3997898

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Abstract: Hot-poured crack sealants are among the most commonly used types of pavement treatment. The cost effectiveness of their application is site specific, based on pavement conditions, traffic, installation conditions, and treatment performance. This paper presents a scenario-based analysis aimed to determine when a sealant application is cost effective. Two treatments, rout and seal and clean and seal, are considered. The equivalent annual cost (EAC) approach and cost-to-benefit (C/B) ratio are both implemented. The paper developed an analytical equation for cost effectiveness of treatment compared with no treatment based on the EAC approach. The equation relates the additional service life required for a treatment to become cost effective considering pavement construction costs, treatment costs, and pavement life expectancy. According to the case considered, it was shown that sealing can be cost effective if it extends pavement life for more than one year for all cases. Cost-to-benefit ratio showed lower effectiveness of sealing as sealing may not provide immediate improvement to pavement condition. It was concluded that cost effectiveness of sealant treatment increases when proper hot-poured sealant is selected for specific projects. The equation developed is proposed to aid agencies in selecting the proper pavement treatment considering fund availability.

Chip Seals and Fog Seals

Field Performance of Chip Seals for Pavement Preservation

Paper number 18-02655, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/ahd18-1.3997709/18-02655-1.3995642/18-02655-1.3997712

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Abstract: Over time, new pavements deteriorate due to the effect of traffic loads and the environment. If appropriate treatments are applied during the early stages of deterioration, it is possible to extend the service life of the pavement without incurring in costly rehabilitation or reconstruction activities. Chip seals are preservation treatments that can help protect the pavement structure, reduce the rate of

pavement deterioration, improve skid resistance and address minor surface problems. As part of the National Center for Asphalt Technology (NCAT) Pavement Preservation study, chip seal test sections were placed in a low traffic volume road (Lee County Road 159) in Auburn, Alabama. The location consists of a two-lane county road that provides dead end access to a quarry and an asphalt plant, resulting in a high percentage of heavy loads. At the time of treatment, the existing pavement was 14 years old and consisted of a 5.5 in. HMA layer over a 6.0 in. granular base. Treatments were applied in the summer of 2012 and have been in service for approximately 4.5 years. During this time, cracking, roughness, rutting and macrotexture data were collected weekly to evaluate pavement performance. The results determined that the performance of the treated sections is highly dependent on the initial condition of the pavement, particularly, the percentage of area cracked. Pavements that are treated while still in good condition tend to remain in that category for a longer time. Macrotexture may also be used to evaluate the functional performance of the chip seals.

Performance and Cost-Effectiveness of Chip Seal in Louisiana

Paper number 18-00550, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/725-1.3997743/18-00550-1.3997751/18-00550-1.3997752

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Abstract: Chip seal is a pavement maintenance technique typically applied on relatively low traffic roads with the aim to reduce the rate of deterioration and to defer the need for costly rehabilitation activities. This study aims at evaluating the short and long-term effectiveness of this treatment method in hot and humid climates such as Louisiana. Field performance of 24 pavement sections was used to evaluate the effects of chip seal on random cracking, roughness, rutting as well as on the overall condition of the pavement. Results showed that chip seal is very effective in controlling random cracking, but it had no significant effects on surface roughness. Pre-treatment conditions and the thickness of the Asphalt Concrete (AC) layer had significant effects on the performance of chip seals as well as on the extension of pavement service life. Pavements with AC layer thickness less than 4 in. exhibited an average service life extension of 2.6 years, whereas pavements with AC layer thickness greater than 4 in. had an average service life extension of 4.1 years. Results also showed that chip seal should not be applied to pavements with pre-treatment random cracking index (RNDM) values greater than 90 to ensure the positive effects of this maintenance activity. All the projects were found to be cost-effective, where the Benefit/Cost (B/C) ratios ranged from 1.1 to 11.3. Chip seal was more cost-effective when applied to pavements with fair to good pre-treatment conditions as compared to pavements with significant age-related distresses.

Chip Seal Aggregate Evaluation and Successful Preservation of Roads in Oregon

Paper number 18-04387, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/725-1.3997743/18-04387-1.3991086/18-04387-1.3997744

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Abstract: The Federal Highway Administration's Every Day Counts initiative focuses on saving time, resources and money. EDC has brought infrastructure preservation to the forefront of many conversations. Chip seals are a cost-effective pavement preservation strategy, but continued studies proving their performance benefits continue to be in high demand as agencies struggle to fund preservation programs. This study documents the effectiveness of chip seals when good materials, good construction and good agency oversight work together. Chips seals extend the service life of pavements an average of 5-6 years. This study gathers two years of field performance data (2014 to 2016) from chip seal projects constructed in Oregon. The data includes laboratory and field-testing to assess the chip seal materials used in construction and tracks the performance of the chip seal pavements, both emulsified asphalts and hot-applied asphalts. Findings show that chip seals enhance the surface texture properties and reduce the appearance of distresses over the two-year monitoring period for most sections.

Mechanistic Evaluation of Chip Seal

Paper number 18-04633, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/724-1.3997754/18-04633-1.3997764/18-04633-1.3997765

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Abstract: Chip seals are mostly constructed based on experience. However, it is difficult to evaluate the effects of pavement condition and materials type on chip seal performance based on experience only. This study used mechanistic procedure to evaluate chip seal performance for different types of materials and pavement conditions. Millings and virgin chips are compared to evaluate whether millings can be used in chip seal. It is observed that millings provide the same strength, surface texture, and skid resistance as virgin chips. It is also observed that there is an optimum value of surface texture for which maximum strength is obtained. Cohesive resistance decreases with mean texture depth whereas friction coefficient, skid resistance, and texture depth after chip seal increases with the increase of texture depth before chip seal.

Quantifying the Effect of Binder and Aggregate Application Rates on Chip-Seal Characteristics via Digital Image Processing and Sweep Tests

Paper number 18-05876, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/724-1.3997754/18-05876-1.3997755/18-05876-1.3997756

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Abstract: In an effort to improve understanding of the relationship between the binder/aggregate application rates and the final microstructure of chip seals, image processing techniques were used to quantify percent embedment (PE) and aggregate orientation. The loss of aggregates were measured at different binder/aggregate application rates using a modified version of the ASTM D7000 sweep test. The reasons behind the observed trends of aggregate loss with respect to the binder/aggregate application rates were explained by using the PE and aggregate orientations measured via digital image processing. A new parameter called "Theoretical Percent Embedment" was also introduced for proper analysis of application rates with respect to the cumulative aggregate loss from the sweep test. It was observed that the aggregates orient on their flattest side as the binder application rate increases and aggregate application rate decreases. Image analysis results clearly indicated that as the aggregate application rate increases, the 'lever and wedge' effect causes the aggregates to disorient from their flattest side, making them more prone to be picked by shear forces (e.g., the forces caused by the traffic). Therefore, it is important not to use too much aggregates in chip seal projects and there exists an optimum aggregate application rate to create the best microstructure that includes densely packed aggregates lying on their flattest side.

Evaluation of Using Line Laser Scanner to Improve the Measurement of Average Least Dimension in Chip-Seal Design Methods

Paper number 18-06373, http://amonline.trb.org/2017trb-1.3983622/t024-1.3995637/539-1.3995916/18-06373-1.3991370/18-06373-1.3995917

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Abstract: Chip seal, as the most widespread pavement preventive treatment, is regularly applied on existing pavements which are still in good structurally conditions to increase the pavement serviceability. The chief of effective parameters on chip seal performance is the binder application rate which directly governs the chip seal distresses, bleeding and raveling. How this rate is calculated mainly depends on the least dimension (LD) of aggregate particles. However, the available measuring methods of LD are slow, laborious, and subjective. This study presents the development of a new high-speed line laser scanner (LLS) prototype to measure the LD of particles more quickly and accurately. The LD of aggregate particles were also measured using a digital caliper and considered as control data. The repeatability and reliability of the developed LLS prototype were evaluated, as well as the speed of the prototype in calculating the LD of 100 aggregate particles. The findings indicate that the measurements of the developed prototype are highly correlated to those of the caliper. Additionally, it was found that the developed prototype is efficient and practically capable of calculating the LD of several particles simultaneously.

Performance-Graded Specifications for Asphalt Emulsions Used in Chip-Seal Preservation Treatments

Paper number 18-04652, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/724-1.3997754/18-04652-1.3997761/18-04652-1.3997762

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Abstract: This paper details the development of a framework for emulsion performance-grade (EPG) specifications for chip seal treatments. Chip seals are preservation surface treatments that are designed to improve the condition of the pavement surface while mitigating deterioration of the overall pavement structure. Asphalt emulsions used in chip seals often are selected based on factors that are not necessarily related to performance. Aggregate loss and bleeding have been identified as the most critical chip seal distresses that are related to binder performance. Storage stability, sprayability, and drain-out have been determined to be the most critical constructability concerns. For this study, binder and mixture test methods were identified to reflect the failure mechanisms for each critical distress type. The emulsion residue test methods that were identified to capture chip seal performance are the multiple stress creep and recovery test for bleeding and the dynamic shear rheometer frequency sweep test for low-temperature aggregate loss. The fresh emulsion test methods that were identified to capture chip seal constructability are the three-step shear test and storage stability test. The proposed EPG specifications for the fresh emulsion properties that are related to constructability were developed using statistical analysis of the binder test results. The proposed EPG specifications for the residual binder properties were developed by defining the temperature-independent relationships between the emulsion residue properties and mixture performance that correspond to each critical distress. Preliminary specification limits were then established based on the values of the binder properties that correspond to the critical mixture performance thresholds.

Related Research:

> **Low-Temperature Emulsion Performance-Graded Specification for Chip Seals**
> Paper number 18-01198, http://amonline.trb.org/2017trb-1.3983622/t004-1.4001281/714-1.4001321/18-01198-1.3991106/18-01198-1.4001342

Stripping Under Chip-Sealed Pavements in Minnesota

Paper number 18-00071, http://amonline.trb.org/2017trb-1.3983622/t024-1.3995637/809-1.3995652/18-00071-1.3990941/18-00071-1.3995662

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Abstract: In 2013, the Minnesota Department of Transportation (MnDOT) conducted a preliminary study that identified high air voids in underlying asphalt pavements as the main cause of stripping under chip seals. This paper details a research project sponsored by the Minnesota Local Road Research Board (LRRB) to follow-up on and extend the 2013 MnDOT study. The research included observation, testing, and analysis of 18 chip-sealed roadways in eight cities and counties in Minnesota. Field studies included surveys of pavement density (using ground- penetrating radar and nuclear gauge tests). Laboratory tests were also conducted to assess permeability, stripping, tensile strength ratio, asphalt film thickness, and mix properties. A major outcome of the research was the inability to verify the earlier MnDOT finding that high air voids were a cause of stripping under chip seals. The study also observed no direct relationship between incidence of stripping and asphalt pavement density and stripping. In addition, the study found no evidence to support correlations between incidence of stripping and site/supplier data (e.g. bituminous mixture, contractor, geographic location, or year of construction). Conclusions and recommendations from this broad, detailed exploration of stripping in chip sealed pavements are presented in the paper to inform city and county engineers on the use of chip seal treatments in municipal roadways.

Leaching Assessment of Eco-Friendly Chip-Seal Pavement

Paper number 18-04559, http://amonline.trb.org/2017trb-1.3983622/t004-1.4001281/606-1.4001407/18-04559-1.3997466/18-04559-1.4001414

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Abstract: The U.S. companies need to mine billions of tons of raw natural aggregates each year. In the same time, billions of scrap tires are disposed of in landfills every year, which makes the replacement of using natural aggregate with recycled and sustainable ones more beneficial to both industry and environment. This paper is part of a project that introduces a new eco-friendly chip seal by implementing the crumb rubber made of recycled tires as aggregates for such surface dressing. Crumb rubber as a partial or total replacement for the mineral aggregate was successfully implemented in the field using the traditional procedure and equipment. In this research, an extensive environmental impact study on the performance of the chip seal pavement surfaces in terms of leaching under different conditions was presented. The heavy metal leaching under different pH conditions including the simulated acid rain condition was evaluated and compared with conventional chip seal. Two types of rubber and two types of asphalt emulsions were studied individually as a material or as a part of chip seal specimens. This study revealed that the toxic heavy metals leached from the recycle rubber or rubberized chip seal were below EPA drinking water standards. In addition, a significant reduction of heavy metal leaching was recorded when rubber used with emulsion in a form of chip seal pavement under different pH conditions. Finally, the metal leaching in all types of samples including rubber, asphalt emulsion, and chip seal decreased with the increase in pH value.

Laboratory Performance of Fog Seal–Treated Open-Graded Friction Course Pavement

Paper number 18-03386, http://amonline.trb.org/2017trb-1.3983622/t020-1.3997695/422-1.3997881/18-03386-1.3991557/18-03386-1.3997882

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Abstract: Open graded friction course (OGFC) is a thin layer of permeable asphalt placed on a dense graded asphalt pavement intended for quick drainage of rainwater and good skid resistance, thus reducing traffic accidents and improving driving environment. However, high air voids and open aggregate structure make OGFC particularly vulnerable to raveling. Application of fog seal on slightly cracked OGFC is one of the preventive measures to extend service life of OGFC pavement. This study evaluated the effect of fog seal treatment on the performance of OGFC. A slightly raveled OGFC pavement was selected for fog seal treatment. Cores were taken from OGFC pavement lane and shoulder before and after fog seal application. Water permeability test, texture depth test and loaded wheel abrasion test were conducted to evaluate the performance of OGFC before and after the treatment. As expected, fog seal treatment reduced the permeability of OGFC. As fog seal application rate increased, permeability further decreased. Fog seal temporarily decreased the texture depth of OGFC, but the texture depth restored after the loaded wheel abrasion test. The results from the loaded wheel abrasion test showed that fog seal significantly deceased the abrasion loss, indicating fog seal could potentially improve the durability of OGFC and extend the service life of OGFC pavement.

Overlays

Design and Performance of Mixes for Use as an Ultrathin Overlay

Paper number 18-03417, http://amonline.trb.org/2017trb-1.3983622/t004-1.4001281/448-1.4001487/18-03417-1.3991521/18-03417-1.4001500

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Abstract: Friction loss is one of the most critical issues faced by agencies responsible for preserving a pavement structure. There are various methods used for surface treatments including seal coats, slurry seals, and ultra thin asphalt concrete overlays. Ultra thin overlays have increased in popularity due to their lack of noise and improved ride quality, as well as their reduced overall cost owing to the reduced layer thickness. This study had two major objectives: (i) determine the best mix type for use as an ultra thin overlay and (ii) evaluate the volumetric-based criterion that is currently used to determine the optimum binder content for mixes used in ultra thin overlays. The performance evaluation was conducted using laboratory techniques including the Hamburg Wheel Tracking Device and the Three Wheel Polishing Device. Out of the six potential gradations or aggregate structures that could be used

as an ultra thin overlay, three were found to be suitable based on the performance tests. It was also observed that the optimum binder content, as defined by the volumetric criterion, was also generally the optimum based on performance tests conducted in the laboratory.

Performance of BCOA Pavements Under Accelerated Loading in Louisiana Condition

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Abstract: Bonded concrete overlay of asphalt (BCOA) has been widely used to repair aged asphalt concrete (AC) pavements with moderate distress. Due to the increasing costs of roadway maintenance, Louisiana has a great interest in determining if a thin bonded concrete overlay (usually 2 - 6 in.) is a suitable and cost-effective alternative to the current practice of roadway maintenance. In this study, two full-scale BCOA test sections having 4-in. and 6-in. Portland cement concrete (PCC) over an aged asphalt pavement structure were tested under accelerated pavement test (APT) loading under a typical southern Louisiana pavement condition. A heavy load simulation device – ATLaS30, equipped with a hydraulically-adjusted dual-tire wheel load, was used in the APT loading, and each section was loaded till a cracking failure was reached (i.e., all the slabs in loading path were cracked). As expected, the majority of load-induced cracks were not at a slab corner but along the wheel path (or longitudinal direction), presumably because the accelerated load in this study was applied along the centerline of the slabs. The load-induced tensile strains (measured at bottom of the slabs) also revealed a longitudinal cracking potential. The first wheel path cracks shown on the 4- and 6- in. BCOA sections, respectively, were observed after 477,400 and 6,382,000 estimated ESALs of loading. Overall, the 4-in. and 6-in. BCOA sections were estimated to have an equivalent pavement life of 1,468,000 and 8,210,000 ESALs, respectively. A surface depression as high as 0.35 in. (similar to the rutting of asphalt pavement) was found on the 4-in. BCOA section. Hammer sounding test indicated that the crack initiation of a BCOA slab could be coupled with a possible debonding at the slab-asphalt interface. Results of light falling weight deflectometer (LFWD) tests indicate that a LFWD modulus less than 60 ksi may indicate the occurrence of the debonding. Finally, a newly-developed SJPCP module in the Pavement ME software was employed to predict the performance of the BCOA sections of this study. The predicted results were discovered to be roughly comparable to the in-situ cracking performance of this study.

Environmental Benefits of Cold-in-Place Recycling

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Abstract: The conventional highway resurfacing technique, Mill and Overlay (M&O), partially removes the existing pavement and replaces it with asphalt derived from some recycled, but mostly virgin

materials. Cold-in-Place Recycling (CIR) is an alternative highway resurfacing method that partially mills the existing pavement and uses it beneath a thinner layer of new asphalt. CIR has become widely used for convenience and cost benefits, but the environmental impacts are poorly quantified.

The objective of this study was to quantify the environmental life cycle benefits of using CIR for highway resurfacing instead of M&O. Material quantities and equipment used for CIR, and what would have been used in M&O in the same project, were provided by contractors for nine highway resurfacing projects in Wisconsin. With this information, a life cycle assessment (LCA) tool was used to determine the relative environmental impacts of the two methods with energy consumption, water usage, and carbon dioxide emissions chosen as the metrics of the LCA.

Results show an average environmental savings of 22% in energy consumption and carbon dioxide emissions and 20% in water consumption associated with highway resurfacing when using CIR instead of conventional M&O. Environmental savings achieved by using CIR were found to be directly related to the reduction in volume of new HMA used, and to the reduction in transportation of materials to and from the site. Linear correlations that can be used to estimate savings of future CIR projects were derived.

Concrete

Modeling the Effect of the Drying Shrinkage and Cracking Prediction in Concrete Repair Systems

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Abstract: Deterioration of concrete will lead to a shorter service life for the concrete element, and hence for the entire structure. Continues maintenance and repair can extend the service life for a damaged concrete. The combination of drying shrinkage of the new applied repair and the restraint in the rapier system will often lead to cracking. Therefore, the restrained shrinkage in the repaired system due to applying the new repair material becomes a major concern in the repair concrete industry.
In this paper, the effect of drying shrinkage for the new applied repair material was modeled using COMSOL program. The common way to represent shrinkage strain in COMSOL is by heat transfer and moisture diffusion, while the developed model is using the strain module to apply the shrinkage strain on the repaired concrete system. Also, this model uses adaptive refinement techniques as a tester to detect the damaged element which represents the crack. The effect of the relative humidity gradient for the repair material through the depth was also considered. The model predictions showed a good agreement with the experimental results that were carried out by Beushausen and Alexander [1]. Finally, the developed model provides a useful tool for the engineers in repair industry to predict the possibility of cracking in the repair system due to the free drying shrinkage which helps to select the best repair materials for the specific conditions.

A New Method to Qualify the Cleanliness of Sawcut Joints in Concrete Pavement Construction

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Abstract: Sealed sawcut joints are a prevalent feature of jointed concrete pavement construction, which not only accommodate movement at the joint but theoretically should also prevent entry of moisture and incompressible debris. Presently, there is little or no definitive criteria for minimum sawcut joint cleanliness to ensure a durable bond between the sealant and the face of the joint well. There is a need of critical construction items for engineers to specify and for inspectors to determine if a sawcut joint is sufficiently clean for sealant installation in order to reduce the frequency of debonding failures. This paper reports on a new approach for inspection based on image analysis to characterize sawn surface cleanliness, with the ultimate aim of creating a database of roughness parameters which can serve as a basis for guidelines on minimum acceptable dirtiness levels at the time of sealant application. Images of different sawn surfaces were analyzed through the use of the Image J software where quantifiable surface characterization was obtained through the various parameters like roughness, profile height, skewness and kurtosis. Results indicated a decrease in roughness with an increase in dirtiness. The relationship of Image J parameters with dirtiness levels of joint surfaces was studied by varying the dirtiness level on different sawn surfaces. Implications of this study involve the relation of the image analysis parameters with bond strength and specification criteria to govern the quality of sealant installation under field conditions.

Roadside Maintenance

Comparative Analysis of Biodiesel Versus Petroleum Diesel Fuel Use in Off-Road Maintenance Equipment

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Abstract: Advocates for biodiesel claim that it is a clean, renewable, and cost effective fuel that provides economic and environmental benefits while easing the energy impacts of petroleum diesel. However, many of the claims presented in the popular press are often anecdotal in nature and frequently are not based on empirical data. The purpose of this paper is to present the results of a case study that comparatively analyzes the economic, energy, and environmental impacts of biodiesel versus petroleum diesel in off-road maintenance equipment. Using real world data, statistical comparisons of B20 versus petroleum diesel fuel use were performed on a fleet of backhoes, motor graders, and wheel loaders. Hypothesis testing was used to determine whether or not there was a statistically significant difference between B20 and petroleum diesel in fuel prices, fuel use rates, and emissions rates. Scatterplots of B20

versus petroleum diesel were developed for fuel prices, fuel use rates, and emissions rates to show how the two fuels are related to each other. Results indicated that there was no statistically significant difference between the national average prices of B20 and petroleum diesel; however, there were statistically significant differences between B20 and petroleum diesel for fuel use rates and emissions rates. Based on evidence in the case study, it was concluded that B20 has slightly higher economic and energy impacts than petroleum diesel, but B20 showed potential for lower emissions rates for certain air pollutants and greenhouse gases. Other considerations for using biodiesel in off-road maintenance equipment are presented.

Accommodation of Saltwater Temporary Pipelines on the Roadside

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Abstract: Drilling and completing oil and gas wells, particularly when using horizontal and hydraulic fracturing techniques, requires enormous amounts of water. Generally, it is cheaper for the industry to move fluids by pipeline than by truck, hence the interest in using permanent and/or temporary pipelines to transport water in areas where oil and gas developments take place. This paper describes temporary pipeline installation and operation practices and how they impact roadside maintenance activities as well as describes guidelines to install and operate temporary pipelines. A GIS database of temporary pipeline locations was developed from permits submitted to the Texas Department of Transportation between July 2011 and August 2016. General trends indicate temporary pipelines are typically 3, 4, 8, or 10 inches in diameter. Operators tend to favor certain highway segments to install temporary pipelines within the right of way. When multiple temporary pipelines are installed on segments repeatedly, this can impact maintenance operations. Several trends were observed that necessitate the development of guidelines for temporary pipelines. Many temporary pipelines were placed away from the right of way line, which creates conflicts with maintenance operations and results in some temporary pipelines being in the clear zone. Many temporary pipelines are not anchored in place and roll into the bottom of ditches or do not maintain a uniform alignment which impacts roadside maintenance.