Utilizing Pavement Evaluation Data in Rehabilitation Design in MDSHA

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ABSTRACT

Maryland State Highway Administration (MDSHA) has implemented a pavement rehabilitation design approach that attempts to utilize pavement evaluation data and current pavement design procedures. There are numerous different mechanisms and testing equipment currently utilized to evaluate the existing structural and functional condition of roadway pavements. In the same manner, there are many different analysis approaches and design theories that are used in the pavement industry to develop the pavement design strategies for new roadways and the rehabilitation of existing roadways. The majority of the pavement rehabilitation design approaches are based primarily on test site empirical equations or on the experience of the individuals responsible for the construction management of the project. In addition, most of the known existing rehabilitation design approaches do not typically utilize current pavement evaluation techniques to assist in rehabilitation design.

MDSHA utilizes pavement evaluation data collected from deflection testing, ride quality testing, surface friction testing, ground-penetrating radar testing, and pavement surface distress testing to contribute to the development of our pavement rehabilitation strategies. The pavement evaluation data collected is used along with the procedures in the "1993 AASHTO Guide for Design of Pavement Structures" to develop pavement rehabilitation strategies. This paper documents MDSHA's attempt to utilize pavement evaluation data to select rehabilitation strategies based on the most effective pavement engineering design, considering cost to the administration, practicality of construction, and benefit in terms of service life provided to pavement network.

INTRODUCTION

Maryland State Highway Administration (MDSHA) is responsible for approximately 16,362 lane miles of roadway. Currently, approximately 60% of the pavement network is comprised of flexible pavements, 36% is portland cement concrete pavement resurfaced with hot mix asphalt (composite pavements), and less than 5% are rigid pavements. A large portion of the pavement roadway network of MDSHA has a significant traffic volume. The environmental and geological regions of Maryland lend themselves to a wide range of agricultural and industrial commerce. Maryland has three distinct regions that have different traffic and geology/soil conditions. The eastern shore portion of Maryland is dominated with agricultural based commerce and traffic. The soil conditions on the eastern shore are dominated by sandy soils. The central portion of Maryland is strongly metropolitan in business with a high percentage of industrial type traffic motivated by the water ports. This central portion of Maryland is a peidmont area dominated by silty clays, clays, and micaceious silts. The western portion of Maryland is dominated by logging, extractive industries (coal, stone, etc.), and agriculture based commerce as well as several major trucking routes that highly influence the traffic mix. The western portion of Maryland is characterized by rocky and silty soils. Although Maryland is a small state, there is a wide range of existing soil and geological conditions, as well as unique traffic volume and weight trends, that the MDSHA pavement design engineer needs to possess knowledge of in order to make accurate pavement recommendations.

MDSHA is currently structured into two separate functions for the purpose of completing and maintaining construction projects, Planning/Design and Operations. The MDSHA Administrator is responsible for overseeing and directing both functions to ensure that MDSHA goals are achieved. Each function is completed by the efforts of several offices. There are separate divisions under each office that complete more specific tasks related to the completion of construction projects. The Pavement Division of MDSHA falls under the Office of Materials and Technology (OMT). The OMT is responsible for the design and quality of all materials placed in MDSHA projects. The Pavement Division is responsible for the design of all pavement structures in MDSHA projects. In addition, the Pavement Division is responsible for the data processing and analysis of all the network level data collection for MDSHA roadways and pavement management system (PMS).

Other Maryland state agencies, the Federal government, Counties, Cities, and other local municipalities are responsible for the remaining roadways in Maryland. Frequently in these cases, these other agencies seek the assistance of Pavement Division with regard to pavement recommendations. Therefore, in addition to the workload of MDSHA construction projects, the pavement engineers in the Pavement Division are often asked to assist and review other agency's pavement construction projects. Based on the work completed over the last several years and the existing transportation budget, the Pavement Division is responsible for approximately 250 to 300 pavement design recommendations a year, from MDSHA projects alone.

MDSHA developed a pavement design guide to provide a comprehensive set of procedures and policies to assist our pavement design engineers in developing recommendations for new construction and pavement rehabilitation projects. The purpose of the document is to provide MDSHA pavement designers a guide to developing pavement recommendations that are consistent and accurate across all pavement engineers. The goal is to supply pavement engineers the guidance to have the ability to provide pavement recommendations that are based on the most effective engineering design considering cost to MDSHA, practicality of construction, and benefit in terms of service life provided to the MDSHA pavement network. The Pavement Division currently utilizes the 1993 "AASHTO Guide for Design of Pavement Structures" and its subsequent revisions as the framework for its pavement design procedure. The MDSHA Pavement Design Guide utilizes a majority of the AASHTO Guide for design analysis and has made modifications to that procedure based on local knowledge, available pavement data, material knowledge, past experiences, and knowledge and resource base of pavement engineers.

In the simplest of terms, the goal of the MDSHA pavement engineer is to assess the structural and functional needs of a roadway and develop pavement rehabilitation recommendations that will meet a desired service life at a specified minimum ride quality and structural capacity. In order to determine the structural and functional needs of a roadway, specific pavement engineering design tasks, like those shown below need to be accomplished:

- Data Collection
- Data Analysis
- Develop Rehabilitation Techniques
- Material Design
- Selection of Rehabilitation Strategy

The data collection effort involves the gathering of historical information of the roadway as well as existing pavement and subgrade conditions. The data collection efforts include the following tasks: records review, site inspections, visual condition survey, functional condition data collection, and structural condition data collection. The data analysis efforts involve assessing the functional and structural condition of the existing roadway and subgrade in terms of useful life for design and material selection tasks. Data analysis efforts include identifying uniform sections, material strengths, existing distress types, and the existing pavement performance. Developing rehabilitation techniques involve selecting repair and rehabilitation techniques to correct existing distress and meet the structural and functional demands of the roadway. Material design involves the selection of materials to meet the structural and functional demands of the roadway. The selection of a rehabilitation strategy for construction is based on the most effective engineering design considering cost to MDSHA, practicality of construction, and benefit in terms of service life provided to the MDSHA pavement network. The remaining portion of this paper provides an overview of MDSHA's approach to incorporate pavement evaluation data in the pavement rehabilitation design process.

DATA COLLECTION

The MDSHA collects pavement evaluation data on both a network level and project level basis. Annual MDSHA network level data collection includes ride quality, rutting, and friction for all directional miles under the responsibility of MDSHA. Our network level data collection equipment includes an Automated Roadway Analyzer (ARAN) vehicle from Roadware in addition to skid testing equipment. The ARAN vehicle is used to collect both ride quality and rutting performance data. The ARAN vehicle is also used to collect right of way digital video and downward digital video for automated distress identification analysis. Our project level data collection includes pavement material structure and thickness determination, non-destructive deflection testing, and ride quality testing. The project level data collection equipment required to collect this level of data includes high-speed profilers, falling weight deflectometer (FWD), ground penetrating radar (GPR), drilling/coring rigs, and manual visual surveys.

Visual Condition Survey

A project level visual pavement condition survey is completed for all pavement rehabilitation recommendations developed by the MDSHA Pavement Division. Technicians and engineers follow procedures outlined in the Army Corps of Engineers PAVER procedure and ASTM D 6433 to collect project level pavement visual condition data. This procedure involves calculating a 0 to 100 pavement condition index (PCI) of the pavement by identifying the quantity of predefined pavement distress types and severities. Each project is divided into numerous sections and sample units and a technician or engineer then surveys a statistically significant number of representative sample units. The type, quantity, and severity of each distress identified in a sample unit is used to develop the 0 to 100 condition index.

The distress quantities from the sample units can be extrapolated to estimate the total amount of distress throughout the entire project. Both the PCI and extrapolated distress quantities are utilized in the MDSHA pavement rehabilitation design procedures.

MDSHA utilizes the ARAN vehicle and its downward digital video to collect network level pavement visual survey information. In 2001, MDSHA initiated and successfully implemented an effort to process the network data collected from the digital video through an automated distress identification process to identify the quantity and severity of linear cracking. This process uses software called WiseCrax, developed by Roadware, to electronically identify cracking severity and quantity in the downward digital video. MDSHA staff process the data through the automated distress identification process and then perform quality assurance checks on the analysis to verify results. The results of the task fuel our pavement management system that utilizes an optimization algorithm to develop MDSHA's goals for pavement system preservation that include budget, lane miles resurfaced, and benefit in terms of service life. This automated distress identification process will be added to MDSHA's routine annual network level data collection efforts.

Ride Quality and Rutting

The ARAN vehicle is utilized to collect approximately 10,000 directional miles ride quality and rut data of the MDSHA pavement network each year. The ride quality data collected by the ARAN vehicle in both the inner and outer wheel path of the roadway is converted into an International Roughness Index (IRI) value. Rut data is collected utilizing up to 37 sensors across the width of the pavement. The ARAN vehicle collects a transverse profile once every 10 feet. Rut data can be reported in various formats in a specific length of road including average rutting, maximum rutting, and percentage of rutting greater than a half inch. MDSHA currently collects IRI and rut data in the outer lane for all MDSHA roads in both directions. This network level data not only fuels our pavement management system, but is also extremely critical in the policies, guidelines, and procedures in the pavement rehabilitation design process. MDSHA also has two high-speed profilers that are used on a project level collection basis for quality assurance testing.

Material Type and Thickness Determination

MDSHA has the ability to use four in-house pavement and soil drilling crews and several contract resources are available to assist in identifying pavement structure and thickness. These crews have the ability to obtain material samples from pavement layers and to measure material layer thickness through the use of either auger or cores. MDSHA has several consultants under contract with the ability to provide ground penetrating radar testing to provide subsurface material thickness and quality characterization. MDSHA has employed these resources to obtain pavement layer thickness and material characterization on several projects in the past and plan to continue to utilize and develop an increased use of this technology in the future.

Friction Testing

MDSHA collects roadway friction values using in-house skid trailers as part of the annual network level pavement data collection in accordance with ASTM E 274. MDSHA collects friction values every three tenths of a mile in the outer most lane in both directions of travel for approximately 10,000 directional miles each year. The skid trailers are also used to collect friction values on various project level assignments as needed.

Deflection Testing

MDSHA owns and operates a Dynatest Model 8002 falling weight deflectometer (FWD). This FWD is used to obtain structural data on all project level collection needs. MDSHA does not perform network level structural testing. The FWD testing is used to characterize the strength of subgrade and pavement structure as well as of load transfer efficiency of joints and cracks. MDSHA has several consultant contracts in place with the ability to provide FWD services when demand for testing on pavement rehabilitation design production warrants. With the current pavement recommendation demands, the MDSHA FWD is usually in operation approximately 125 test days a year, dependent on weather and precipitation variations. That type of production demand results in approximately 125,000 test points and 375,000 recorded drops per year.

DATA ANALYSIS

MDSHA has attempted to make the best use of all of the pavement evaluation collected in the development of pavement rehabilitation design recommendations. In order to make beneficial design recommendations from the pavement evaluation data collected, the data has to be processed and presented in a format that is needed to make pavement engineering decisions. The MDSHA Pavement Design Guide has documented procedures and processes to complete the data analysis of both the network and project level pavement evaluation data collection.

A pavement system has two basic service lives; a structural life and a functional life. The structural life of a pavement is based on the quality and strength of the individual pavement layers to support the existing and expected traffic volume and vehicle weight. The functional life of a pavement is based on its ability to provide an expected level of ride quality and safety to the travelling public. For some pavement types, these two lives follow very similar deterioration curves and duration. For other pavement type cases, the pavement structure may be able to support expected traffic volumes for an indefinite number of years, but the ride quality and safety conditions are much shorter in duration. This scenario results in functional improvements necessary to a roadway to provide ride quality and/or safety improvements at much higher frequency than structural improvements. This is especially true in MDSHA on composite pavements (rigid pavement overlaid with HMA).

Therefore, both a structural and functional analysis of a pavement needs to be completed in a construction project. The resulting analysis of both structural and functional life, will provide the information necessary for pavement design engineers to make rehabilitation decisions based on the most effective engineering design considering cost to MDSHA, practicality of construction, and benefit in terms of service life provided to the MDSHA pavement network.

Structural Analysis

Deflection data and material type / thickness data is the required information for performing a structural analysis of an existing pavement structure. All the information needed for structural analysis is collected as part of MDSHA project level data collection. The MDSHA pavement rehabilitation design process is based on the engineering principles and procedures in the "1993 AASHTO Guide for Design of Pavement Structures." The effective structural capacity of the existing pavement structure is the primary goal of structural analysis in pavement rehabilitation design, following the current 1993 AASHTO Pavement Design Guide.

The basic concept of deflection testing is to simulate typical traffic loads and monitor the deflection response of the pavement structure from that load. Measured surface deflections resulting from a known load are used to estimate material strength properties of a pavement structure based in linear elastic theory of materials. The primary data collected from deflection testing is a measured vertical load and pressure and the resulting deflections in the pavement surface measured at radial distances from the load. The largest deflection from the load occurs under the load plate and typically decreases outwardly from the load plate. Deflections under the load plate provide an indication of the material properties of all the layers in the pavement structure at that location. As recorded deflections move further away from the load plate, the data is representative of the layers deeper into the pavement structure with less influence from the layers near the surface. The strength of all pavement layers above the subgrade and the strength of the subgrade are two critical results of structural analysis needed in the 1993 AASHTO Pavement Design Guide and the current MDSHA pavement design process.

The structural analysis of deflection data involves evaluating the measured load and resulting deflections to determine the material properties of the pavement structure. A typical "forward" material calculation requires knowledge of the material properties and the deflection is estimated based on the applied load. The use of deflection data requires a "back" calculation method because the deflections and load are known and the material properties are estimated. This method of obtaining the material response and estimating the material properties is called "backcalculation."

There are several backcalculation software applications available on the market today. MDSHA currently uses the backcalculation algorithms in the AASHTOWare DARWin software, which is based on the AASHTO deflection analysis procedures. The AASHTO deflection analysis procedures do not produce individual pavement layer moduli, only a composite modulus for all layers. Other software applications are required if individual pavement layer strengths are desired. The most used software application by MDSHA for the estimation of individual pavement layer strength is MODULUS, developed by Texas A&M University. The MODULUS algorithm attempts to match the collected deflection basins with a database of deflection basins with known layer moduli. The accuracy of the backcalculated layer moduli is based on the percent sensor error between the measured deflection and the predicted deflection from the MODULUS algorithm. There are several other backcalculation software applications for available on the market today. Some applications perform an iterative process to estimate the layer modulus, others use the database approach and match measured deflections, while others use a finite element analysis approach to solve for individual layers.

The process of developing pavement layer properties from deflection data requires knowledge of the art/science of analyzing loads and deflections and a good understanding of pavement engineering and material properties. The MDSHA Pavement Division's process for checking deflection data quality, developing material properties for pavement rehabilitation design, and quality checks of the analysis are detailed in the MDSHA Pavement Design Guide. The AASHTOWare pavement design software (DARWin), the backcalculation analysis software MODULUS 5.1, and several in-house software applications are currently utilized to complete the structural analysis. The following outline provides an overview of the structural analysis approach used for deflection data:

1.0 Quality Assurance of Deflection Data
- 1.1 Non-Decreasing Deflections
- 1.2 Out of Range Errors
- 1.3 Error Comments

2.0 Pre-process Deflection Data
- 2.1 Select Deflection Load (drop height/s)
    - Normalize Deflection Data
- 2.2 Composite Modulus Plots
    - Non-linear Soils
    - Erroneous Sensor Readings
    - Select # of Sensors to Analyze

2.3 Select Distinct Sections
- Recorded Distinctions: Test Type, Lane, and Field Comments
- Sensor/Deflection vs. Station
- Cumulative Sum

3.0 Analysis of Deflection Data

3.1 Flexible Standard Calculations:
- Resilient Modulus of the Subgrade
- Composite Modulus of Pavement Layers Above Subgrade
- Effective Structural Number
- Individual Layer Coefficients
- Temperature Correction Factor

3.2 Rigid/Composite Standard Calculations:
- Slab Bending Factor / AC Compression Factor
- Load Transfer Efficiency (LTE)
- Void Detection
- Area Method
- Radius of Relative Stiffness
- Modulus of Subgrade Reaction
- PCC Elastic Modulus

3.3 Backcalculation Software
- Use Modulus, WESDef, Modcomp, EverCalc, or other tools

4.0 Quality Control of Deflection Analysis

4.1 Percent Sensor Error

4.2 Layer Moduli Reasonable Ranges

4.3 Data Reasonableness Checks

5.0 Reporting/Summary of Deflection Data Analysis Results

A portion of the structural analysis involves review and analysis of the visual survey data. Several of the distress types recorded in the visual survey are indicative of the structural capacity of the existing pavement structure. The load induced distress types and locations can be compared to the results of the deflection analysis for an overall structural analysis of the roadway improvement project. In cases where the pavement structure, load transfer efficiency, and subgrade strength varies throughout the length of the project, the types of visual distress should mimic the same section trends. The analysis of the visual distress survey will be described in further detail under the functional analysis section of this paper, but the results are also used in the structural analysis of an existing pavement structure.

Functional Analysis

Visual condition survey, rutting, friction, and ride quality data are all used for performing a functional analysis of an existing pavement structure. Most of the information needed for functional analysis is collected as part of MDSHA network level data collection with the exception of the visual condition survey. The functional analysis portion of the MDSHA pavement rehabilitation design process is based on pavement engineering principles and MDSHA historical pavement performance data. Performance trends and business plan goals are the tools used to make material decisions with regard to the functional condition of a roadway improvement project.

Visual Condition Survey Analysis

The visual condition survey results are used to populate an in-house developed software program to convert the surveyed distress results into PCI values and extrapolated distress quantities. The PCI value is converted into a condition factor for each section within the limits of a project. The condition factor is then applied to the numerical value of the original structural capacity of the pavement structure to determine the effective structural capacity of the existing pavement. This process is shown in the following equations:

$$SC_{eff} = SC_o * C_x$$

where:

SC_o = Original structural capacity of the pavement section at the time of the last improvement.
SC_{eff} = Effective structural capacity of the pavement section at the time of evaluation.
C_x = Condition Factor from visual condition analysis (=< 1.0). To obtain C_x use the following equation:

$$Cx = (PCI / 100)^2 \quad > 0.65$$

where:

PCI = Average PCI for the analysis section.

The extrapolated distress quantities are used to estimate the quantity of patching necessary to improve the roadway to a level of service acceptable for pavement rehabilitation. Typically, not all distress types in a pavement section are repaired through patching. Utilizing the extrapolated distress quantities provides the ability to evaluate several different pre-overlay repairs. Engineers evaluate the impact of pre-overlay repairs such as patching and milling to improve the condition of a pavement. Prior to advertisement of a project, a formal patching survey is completed to establish the final patching quantity.

Rutting Analysis

Rutting, friction, and ride quality data are stored and viewed in MDSHA software developed in-house to provide the pavement engineer the ability to evaluate the historical and current performance of the roadway under investigation. The network level data collected with the ARAN vehicle is evaluated along with the rutting quantity identified in the project level data collected in the visual condition survey. The following are several ways to view the network level rutting data to evaluate the pavement performance:

- Average, minimum, and maximum rutting for entire project limits on the roadway.
- Average, minimum, and maximum rutting for specific limits on the roadway.
- Percentage of measured intervals with rutting greater than 0.5”.

The various forms in which rutting data can be presented can be graphed versus station or mile point or on a map to identify trends and sections that are performing at varying levels. When rutting trends are compared to other functional analysis results and structural analysis results, a clearer evaluation of the pavement performance can be developed for the pavement rehabilitation design.

Friction Analysis

Friction data that is stored and viewed in an in-house MDSHA developed software program can provide the pavement engineer the ability to evaluate the historical and current performance of the roadway under investigation. The network level data collected with the skid trailers is evaluated along with the polished aggregate and bleeding identified in the project level data collected in the visual condition survey. The following are several ways to view the network level friction value data to evaluate the pavement performance:

- Average, minimum, and maximum friction values for entire project limits on the roadway.
- Average, minimum, and maximum friction values for specific limits on the roadway.

- Average, minimum, and maximum friction values statewide.

The various forms in which friction values can be presented can be graphed versus station or mile point or on a map to identify trends and sections that are performing at varying levels. When friction value trends are compared to other functional analysis results, structural analysis results, traffic volumes, and vehicle accident trends, a clearer evaluation of the pavement performance can be developed for the pavement rehabilitation design. MDSHA has a study effort currently underway to investigate the requirement of a minimum final friction value for a completed resurfacing project. It is expected that the results of this study will influence our selection of pavement rehabilitation treatments and material selection for resurfacing projects.

Ride Quality Analysis

Ride quality data that is stored and viewed in an in-house MDSHA developed software provides the pavement engineer the ability to evaluate the historical and current performance of the roadway under investigation. The network level data collected with the ARAN vehicle is evaluated along with the ride quality opinion of the engineer during the project level data collected in the visual condition survey. The ride quality data is reported and analyzed in terms of IRI. The following are several ways to view the network level ride quality data to evaluate the pavement performance:

- Average, minimum, and maximum IRI values for entire project limits on the roadway.
- Average, minimum, and maximum IRI values for specific limits on the roadway.
- Average, minimum, and maximum IRI values statewide.

The various forms in which ride quality values can be presented can be graphed versus station or mile point or on a map to identify trends and sections that are performing at varying levels. When ride quality values trends are compared to other functional analysis results, structural analysis results, and pavement types, a clearer evaluation of the pavement performance can be developed for the pavement rehabilitation design.

Starting in July of 2001, all MDSHA advertised pavement projects had the opportunity for ride quality incentive and disincentive. This initiative partially originated from MDSHA's Pavement Division's effort to improve the ride quality of the network through improved pavement rehabilitation strategy and material selection. Each roadway improvement project has the ride quality incentive and full pay bands based on existing geometric conditions and the type of pavement rehabilitation strategy in the contract documents. MDSHA has made a conscious effort to couple pavement evaluation data and pavement rehabilitation strategy to improve pavement network ride quality.

DEVELOP PAVEMENT REHABILITATION TECHNIQUES

The selection of appropriate improvement pavement rehabilitation techniques is based, in part, on the results of the functional and structural condition of the pavement section. The results of the pavement data analysis are the criteria used by MDSHA to make selection decisions about pre-rehabilitation improvements and the type and thickness of the pavement rehabilitation. MDSHA has established a selection guideline to assist the pavement design engineer to identify the rehabilitation technique best suited to correct existing distress types and achieve functional and structural condition objectives. Pre-rehabilitation and rehabilitation techniques encompass all operations from partial-depth patching, grinding, functional HMA overlay to reconstruction. Initially several rehabilitation techniques are considered during the design phase and the best approach is selected based on the most effective pavement engineering design, considering cost to the administration, practicality of construction, and benefit in terms of service life provided to pavement network. Several rehabilitation techniques are often used within the limits of one project as part of the project pavement rehabilitation strategy to account for varying section performance.

The MDSHA pavement design guide provides assistance in the form of guidelines in the selection of the most appropriate pavement rehabilitation techniques as shown in Table 1. The table provides guidelines as to applicable functional classes and visual condition survey ranges of various rehabilitation techniques as well as expected service lives, maintenance of traffic demands, structural capacity requirements, and applicable uses. As seen in Table 1, the use of structural and functional analysis results are critical inputs in the decision of applicable pavement rehabilitation techniques in MDSHA.

More specific details about the pavement rehabilitation techniques are developed utilizing the structural and functional analysis results. These details involve the quantity and type of patching, the need and thickness of pavement removal (milling/grinding), as well as the need for wedge and level needs. Typically, patching operations precede all other construction operations within the existing roadway when considering criteria to determine the need for removal. Following that process, some distress types shall be repaired through patching and affect the total distress quantities used in the guidelines for removal criteria. Therefore, initial decisions about the need for patching need to be completed prior to making decisions about pavement removal. Decisions about the distress type and severity to patch vary by project and rehabilitation approach, but MDSHA has established at least a starting point guideline to be used in patching decisions. Tables 2 and 3 are used as guidelines to determine specific patching requirements. These guidelines can be customized to specific project conditions and demands.

Once patching decisions have been selected, the need for pavement removal (milling/grinding) can be determined. Table 4 gives MDSHA guidelines for milling/grinding. The thickness of patching should be evaluated following the determination of the need for removal process. The need for partial-depth patching could vary depending on the results of the removal selection process, especially in composite pavements. The thickness of the existing shoulders should be considered when determining the depth of removal. Shoulders with thin pavement structures may dictate minimum removal depths or the need for other alternative rehabilitation techniques.

Reasons to specify grinding over milling:

- only one lift is to be placed above removal area
- removing for poor ride conditions only
- removed pavement section is to be opened to traffic

Removal of the pavement by milling or grinding affects the existing condition of the pavement in addition to affecting the existing structural capacity of the pavement. Specific distresses are reduced or eliminated by removal of the pavement. Tables 5 and 6 provide information regarding the effect of pavement removal on distresses based on the visual PCI procedure. The PCI value, calculated from the visual survey, is based on the existing distresses in the roadway. The PCI value is then used as an indication of the effective structural capacity of the pavement structure. Pre-rehabilitation repairs alter the existing distresses and the PCI and therefore affect the existing structural capacity of the pavement structure. For example, if high severity alligator cracking were repaired with a full-depth patch, that distress would be changed to a low severity patch. Depending on the distress type and severity, pre-rehabilitation repairs may increase the PCI value and subsequently the structural capacity. Therefore, certain pre-rehabilitation repair strategies will influence the type and thickness of the pavement rehabilitation. A significant step in the pavement rehabilitation process is to re-calculate PCI for each sample unit based on the selected pre-overlay repairs. MDSHA has developed a software program that is used to re-calculate PCI based on pre-rehabilitation decisions. Patching and removal (milling/grinding) can both be completed as pre-rehabilitation repairs. In addition, the original structural capacity (SC_o) of the pavement is reduced as a result of milling or grinding.

Similar guidelines have been established for the need for wedge and level on roadway improvement projects. The use of a wedge/level layer is dictated by the amount the roadway elevation can be raised. If there are restrictions regarding the roadway elevation, removal (milling/grinding) should be the selected alternative. Otherwise if there are no roadway elevation restrictions, wedge/level is the preferred alternative. The MDSHA guidelines for wedge/level are presented in Table 7.

MATERIAL DESIGN

Selecting the appropriate material is the critical step in the design process after the appropriate pavement rehabilitation techniques have been developed. The proper rehabilitation strategy and design thickness for an improvement project is not effective if inferior or inappropriate material is selected. MDSHA exclusively uses hot mix asphalt (HMA) Superpave mix design approach for HMA use in roadway projects. MDSHA has developed guidelines to select the appropriate performance grade asphalt cement binder and gyratory compaction level based on the following:

- distress results of the visual condition survey,
- expected traffic volumes and weights,
- speed of traffic,
- quantity of material,
- pavement type, and
- location of the pavement structure.

MDSHA has also developed guidelines to select the appropriate HMA Superpave material type. The guidelines for Gap Graded mixes and high polish value stone mixes are general and are typically discussed with MDSHA internal experts in HMA and construction prior to placing them into contract documents. The following conditions need to be present prior to considering the selection of a Gap Graded HMA mix for the final pavement surface:

- 20,000 ADT (Two-way) in the design year, and
- ESAL category 4 or higher, and
- With a functional class of Freeway/Expressway or greater.

The following conditions need to be present prior to considering the selection of a High Polish HMA mix for the final pavement surface:

- ESAL category 3 or lower, and
- With a functional class of expressway/freeway or lower, and
- At least 1 of the following items:
    - 20,000 ADT (Two-way) in the design year, or
    - Skid Number values < 40, or
    - Greater than 25% of the mainline area is exhibiting polished aggregate as a distress.

SELECT PAVEMENT REHABILITATION STRATEGY

MDSHA uses an assortment of methods to select the pavement rehabilitation strategy that will be completed in the roadway improvement project. For most projects, the pavement design engineer performs a basic cost estimate based on material and construction costs. Those costs are compared to the service life and ride quality improvements provided by the various rehabilitation strategies. A decision is made based on the comparison and then provided to the respective engineering district to be discussed with the construction and engineering staff. From that discussion, it is believed that a pavement rehabilitation strategy is selected that utilizes all available pavement performance data and is based on the most effective pavement engineering design, considering cost to the administration, practicality of construction, and benefit in terms of service life provided to pavement network.

For large and highly political improvement projects, a formal life cycle costs analysis (LCCA) is conducted. MDSHA Pavement Division currently uses a probabilistic approach to life cycle cost analysis rather than the traditional deterministic approach. This approach allows for a range of construction and material cost used in the analysis rather than a discrete unit cost. The results of this approach provide the pavement engineer the probability of user and agency costs occurring over the analysis period. The probabilistic approach eliminates arguments over unit cost and future maintenance because a reasonable range is used that encompasses variations in the economy and construction costs.

In addition, MDSHA has put a tremendous amount of effort towards developing and calculating user costs involved in construction and rehabilitation projects. Various user delay costs are calculated to develop the overall user cost. These items include, but are not limited to the following: reduced speed costs, slow down costs, queue costs, idling costs, and acceleration costs. MDSHA has worked closely with FHWA to develop a LCCA approach that uses a probabilistic approach and incorporates detailed user delay costs.

CONCLUSIONS

MDSHA has invested time and effort in the development of a pavement design guide that takes full advantage of available pavement performance data. It is believed this guide will provide more logical and consistent pavement design recommendations that will result in a longer lasting and better riding pavement network.

REFERENCES

1. Maryland State Highway Administration (MDSHA), Office of Material and Technology, Pavement Division (2001) "MDSHA Pavement Design Guide."

2. American Association of State Highway and Transportation Officials (AASHTO), " 1993 AASHTO Guide for Design of Pavement Structures."

Table 1: Pavement Rehabilitation Techniques

Rehab Technique	Pavement Type			Functional Class		Extended Lane Closure Required	Applicable PCI Range	Service Life (yrs)	Applicable Uses
	Rigid	Flexible	Composite	Interstate, Princ. Art.	All Others				
HMA Overlay	✔	✔	✔	✔	✔		> 25	8 - 12	• structural or functional improvement
PCC Bonded Overlay	✔			✔		✔	≥ 70	12 – 15	• PCC pavement in very good, sound condition • minimal to no pre-overlay required • structural overlay required
PCC Unbonded Overlay	✔	✔	✔	✔		✔	< 55	≥ 20	• PCC pavement in poor condition • structural overlay required • adequate vertical clearances
Rubblize and HMA Overlay	✔		✔	✔	✔	✔	< 55	15	• PCC pavement in poor condition • joint deterioration prevalent • removal of AC overlay required • adequate vertical clearances
Break & Seat and HMA Overlay	✔		✔	✔	✔	✔	≤ 70	12 - 15	• PCC pavement in fair to poor condition • Removal of AC overlay required
HMA Overlay with Saw & Seal	✔		✔	✔	✔		> 70	8 - 12	• joints in good working condition • load transfer > 70% on average • minimal joint patching exists or required • removal of AC overlay required
Ultra-Thin Whitetopping		✔	✔		✔	✔	> 55	< 10	• rutting exists throughout project limits (> 50% of the project length) • rutting resulting from material related problem • pavement structurally sound
In-place Recycled HMA		✔	✔	✔	✔		≥ 70	5 - 8	• minimal structural distress • minimal patching required • limited to approx. 3 inches in depth • good surface materials • not recommended for heavily oxidized material
Recycled HMA		✔	✔	✔	✔		> 25	8 - 12	• structural or functional improvement • good material to recycle • not recommended for heavily oxidized material

Rehab Technique	Pavement Type			Functional Class		Extended Lane Closure Required	Applicable PCI Range	Service Life (yrs)	Applicable Uses
	Rigid	Flexible	Composite	Interstate, Princ. Art.	All Others				
Concrete Pavement Restoration	✔			✔	✔		> 55	5 - 8	• joints in good condition • load transfer > 70% on average • no high steel problems • existing structure is adequate
AC Reconstruction	✔	✔	✔	✔	✔	✔	< 40	15	• significant structural improvement required • no allowance to increase grade • extensive (>40%) patching required
PCC Reconstruction	✔	✔	✔	✔	✔	✔	< 40	20	• significant structural improvement required • heavy truck loadings expected (potential to rut) • no allowance to increase grade • extensive (>40%) patching required
Pre-Overlay Techniques	✔	✔	✔	✔	✔				
Maintenance Treatments	✔	✔	✔	✔	✔				

Table 2: Patching and Joint Tape Guidelines for PCC Surfaces

Distress	Severity			Comments
	Low	Medium	High	
Blow-Up	Full	Full	Full	
Divided Slab	None	Full	Full	
Corner Break	None	Full	Full	
Durability	Full	Full	Full	
Faulting	None	Full	Full	Consider grinding or undersealing the joint to remove fault.
Linear Cracking	None	Partial	Full	Consider grinding, undersealing or crack sealing for Low and Medium Severity.
Patching	None	Full	Full	
Pumping	None	None	Full	Consider undersealing to correct Pumping
Punchout	Full	Full	Full	Type II patch if punchout greater that 6' long
Spalling	AC	Partial	Full	Clean out spalled area and replace with AC prior to overlay.

Type I PCC Patch is less than 15 feet in length
Type II PCC Patch is greater than 15 feet in length

Note: Joint sealant damage, lane/shoulder drop off, polished aggregate, popouts, RR Xing, Map Cracking, and shrinkage cracking are not patched.
If LTE < 70% then a flexible full-depth patch is not recommended (Use rigid patch).
If M_r subgrade is weak - PCC patch required.
If Pumping is evident - PCC patch required.

Table 3: Patching and Joint Tape Guidelines for AC Surfaces

		Milling (1" - 2")			Comments
Distress	**Severity**	**No**	**Yes**		
			AC Material Thickness		
			> 6"	**< 6"**	
Fatigue Cracking	**Low**	None	None	None	
	Medium	Partial	Partial	Full	
	High	Full	Full	Full	
Rutting areas < 500' long	**Low**	None	None	None	Soil/Subgrade could be cause for rutting.
	Medium	Partial	None	None	
	High	Partial	Partial	Partial	
Linear Cracking **Edge Cracking**	**Low**	None	None	None	If the crack depth is greater than ½ AC layer thickness, then use full-depth patch.
	Medium	Partial	None	None	
	High	Partial	Partial	Partial	
Potholes/Failures	**Low**	Partial	None	None	
	Medium	Partial	Partial	Full	
	High	Full	Full	Full	
Block Cracking **Slippage Crack** **Shoving** **Corrugation**	**Low**	None	None	None	Full-depth patching may be required if distress is significantly deep (>1/2 AC).
	Medium	Partial	None	None	
	High	Partial	Partial	Partial	
Depression **Bumps/Sags** **Swelling**	**Low**	None	None	None	Soil/Subgrade could be cause of depression, bumps/sags, and swelling.
	Medium	Partial	None	None	
	High	Full	Full	Full	
Patches	**Low**	None	None	None	
	Medium	Partial	Partial	Full	
	High	Full	Full	Full	
Joint Reflection Cracking LTE >70% - Good	**Low**	None	None	None	Potential to use Joint Tape (Type A Patch) remove to PCC
	Medium	Partial	Partial	Partial	
	High	Partial	Partial	Partial	
Joint Reflection Cracking LTE < 70% - Bad	**Low**	None	None	None	Patch with PCC.
	Medium	Partial	Partial	Partial	
	High	Full	Full	Full	

Note:
1) Polished aggregate, bleeding, RR Xing, weathering, and lane/shoulder drop off are not patched.
2) Minimum patch size is generally 6 ft x 6 ft
3) Partial depth patching should not exceed 50% of the pavement in depth

Table 4: Pavement Removal (milling/grinding) Guidelines

Criteria	Depth of Removal
h_{ol} > proposed roadway elevation[1]	Overlay thickness
Medium and high severity rutting > 30% of the length	Depth of max rutting
Functional distress > 50% of area[2]	Depth of last surface layer[3]
> 30% of joints are medium or high severity joint reflection cracking	Depth of last surface layer[3]
Patching > 25% of area	Depth of last surface layer[3]
IRI > 170 in/mile for interstates	Depth of last surface layer[3]
IRI > 220 in/mile for non-interstates	Depth of last surface layer[3]

1 – If the removal and replacement thickness does not provide adequate structural capacity for the expected service life, additional discussion will needed to determine if a lower service life is acceptable. If not, this rehabilitation technique alternative should be eliminated from the viable alternatives.
2 – Functional distress consists of bleeding (sf), block cracking (sf), bumps/sags [(lf) * 6ft] = (sf), depression (sf), joint reflective cracking [(lf) * 6ft] = (sf), polished aggregate (sf), swell (sf), and weathering and raveling (sf).
3 – The depth of removal could be increased based on the depth of the cracks and the thickness of the existing HMA. It is not recommended to leave less than 1.5" of HMA material above PCC pavement. If less than 1.5" of HMA material will be left following required removal, all of the HMA material should be removed to the bare concrete surface.

Table 5: Pavement Distress Adjustments for AC Surfaced Pavements

Pre-Overlay Repairs for AC Surfaced Pavements			
Distress	**Partial Depth Patch**	**Full Depth Patch**	**Removal**
Alligator	Low patch	Low patch	-1 Severity
Bleeding	No	No	No Distress
Block	Low patch	Low patch	-2 Severity
Bumps/Sags	Low patch	Low patch	-2 Severity
Corrugation	Low patch	Low patch	-2 Severity
Depression	Low patch	Low patch	-1 Severity
Edge Cracking	Low patch	Low patch	-1 Severity
Joint Reflection	Low patch	Low patch	-1 Severity
Ln/Shld Drop	No	No	No
Linear Cracking	Low patch	Low patch	-1 Severity
Patch	Low patch	Low patch	-1 Severity
Polished Agg.	No	Low patch	No Distress
Pothole	Low patch	Low patch	-1 Severity
RR Crossing	No	No	No
Rutting	Low patch	Low patch	-2 Severity
Shoving	Low patch	Low patch	-2 Severity
Slippage	Low patch	Low patch	No Distress
Swell	Low patch	Low patch	-1 Severity
Weathering	No	No	No Distress

Table 6: Pavement Distress Adjustments for PCC Surfaced Pavements

Pre-Overlay Repairs for PCC Surfaced Pavements			
Distress	**HMA Patch**	**PCC Patch**	**CPR**
Blow-up	Low patch	Low patch	Low patch
Corner Break	Low patch	Low patch	Low patch
Divided Slab	Low patch	No Distress	No Distress
"D" Cracking	Low patch	Low patch	Low patch
Faulting	Low patch	Low patch	Low patch
Joint Seal Damage	No	No	Low Severity
Shoulder Drop off	No	No	No
Linear Cracking	Low patch	Low patch	Low patch
Patch – Large and Small	Low patch	Low patch	Low patch
Polished Aggregate	No	No	No Distress
Popouts	No	No	No Distress
Pumping	Low patch	Low patch	Low patch
Punchouts	No	Low patch	Low patch
RR Crossing	No	No	No
Scaling	No	No	No Distress
Shrinkage Cracks	No	No	No Distress
Spalling, Corner	Low patch	Low patch	Low patch
Spalling, Joint	Low patch	Low patch	Low patch

Table 7: Applications for Wedge/Level Layer

Criteria	Comments
Patching > 25% of project area	Full-depth and partial-depth
Any severity rutting > 30% of area	Based on length not area
Joint tape is used with a single HMA lift[1]	
Designed elevation increase in roadway[2]	Superelevation or cross slope
> 30% of joints are medium or high severity joint reflection cracking	Compared to total # of joints
IRI > 170 in/mile for interstates	
IRI > 220 in/mile for non-interstates	

1 – The existing composite or rigid pavement is structurally adequate ($SC_{eff} >= SC_f$). The wedge/level layer is intended to provide an additional layer between the joint tape and the final HMA overlay layer, resulting in two lifts of HMA between the joint tape and the final roadway surface.
2 – If a significant increase in elevation is required (>2.0"), then the 19.0 mm should also be used in combination with the 9.5 mm for wedge/level.