Chapter VI – PAVEMENT EVALUATION AND DESIGN

SECTION 601 – FUNDAMENTAL CONCEPTS OF PAVMENT EVALUATION AND DESIGN

Sec. 601.01 Introduction

One of the State of Virginia's largest assets, if not the largest asset, is the highway network system. The Virginia Department of Transportation (VDOT) is responsible for maintaining the third largest roadway network in the United States encompassing over 53,000 miles. VDOT's Materials Division's Pavement Design and Evaluation (PD&E) Section is responsible for the review and comment on new and rehabilitated pavement structures around the state. PD&E assists the districts in the overall management of Virginia's highway construction program by providing guidance, technical assistance and training.

An important function in pavement management is project level analysis of existing roadway sections. Project level analysis is the inspection of existing pavements to determine the causes of deterioration and to assess the current condition. Once project level analysis has been conducted, then the most reliable pavement design can be performed. For new construction and rehabilitation projects, the combining of existing condition data, future traffic projections, soil subgrade properties and paving material properties will ensure a proper pavement design. This analysis and design should apply not only to pavement reconstruction and rehabilitation projects, but to routine and preventative maintenance projects as well.

The purpose of this document is to provide guidelines for VDOT's pavement engineers in conducting project evaluations and pavement designs on Major (Interstate, Primary, Urban and High-Volume Secondary) Roadways and Minor (Low-Volume Secondary and Sub-Division) Roadways. The amount of pavement evaluation required will be dependent on the scope of the project; the pavement design process will depend on the roadway classification (Interstate, Primary or Secondary). This document covers design considerations for routine maintenance, rehabilitation and construction activities performed by VDOT. However, it does not preclude from consideration new and innovative pavement techniques.

Sec. 601.02 Project pavement Evaluations

Major Roadway project evaluation process is a two-step procedure: Step 1 – Preliminary Pavement Analysis and Design, Step 2 – Detailed Pavement Evaluation and Design. Major Roadways consist of Interstate, Major and Minor Arterial, and Major and Minor Collector routes. Step 1 occurs during the project-scoping phase of a construction-funded project being managed by the Location and Design Division. Step 2 occurs after the scoping phase during the Planning, Specifications and Estimating (detailed design) development.

The details for these evaluations are provided in the following sections.

(a) Preliminary Pavement Evaluation

Step 1 is the preliminary pavement analysis and design. This process will occur once the District Materials Engineer has been notified that a project requires a pavement design. Ideally, the Location and Design Section will notify the District Materials Engineer prior to establishing a preliminary construction estimate. With pavement items being a large percentage of the overall construction cost, a good initial estimate will aid L&D in requesting construction funds. At the preliminary evaluation and design phase of a project, the PD&E Section will provide technical assistance to the District Pavement Engineer. To conduct the preliminary pavement evaluation, the District Pavement Engineer should conduct 4 tasks. These tasks are:

Task 1. Data Gathering
Task 2. Field Data Collection
Task 3. Preliminary Recommendation
Task 4. Determine Need for Detailed Pavement Evaluation

Figure 1 shows the process flow for the preliminary pavement evaluations.

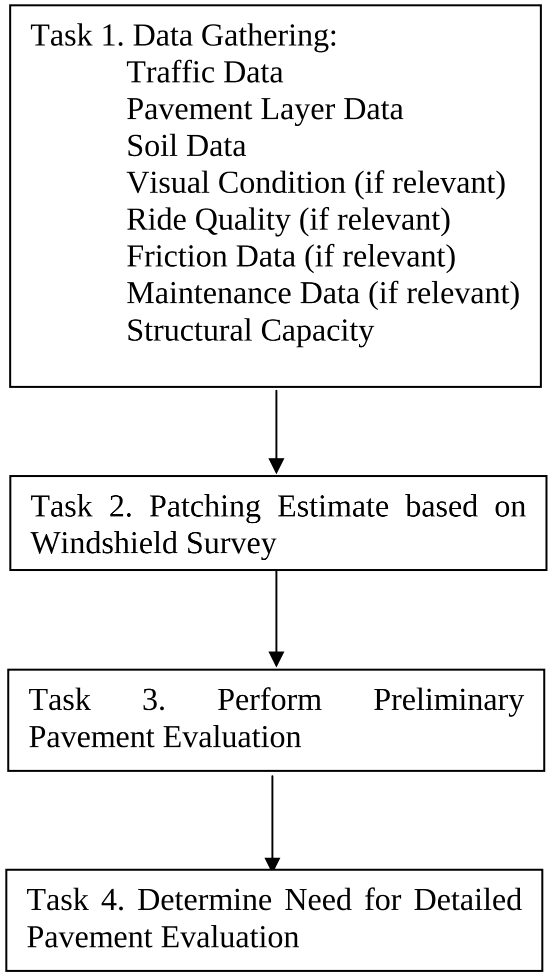


Figure 1 - Preliminary Pavement Evaluation Process Flow

Task 1. Data Gathering

For construction projects where existing pavement may be utilized, data should be gathered prior to performing a preliminary evaluation. If available and relevant to the project, the Pavement Engineer should gather:

Traffic Data (AADT, ESAL Factor, % Trucks, etc.),
Pavement Layer Data (Materials, Thickness', Year Constructed)
Soil Condition Data (Type and Strength),
Visual Condition Data,
Ride Quality Data,
Structural Capacity Data,
Friction Data, and
Maintenance Data (including dates and types of rehabilitation).

Much of this data may be contained in HTRIS; however, the data must be validated prior to conducting the analysis. It is important to remember that for projects that include the widening of an existing pavement, realignment of a roadway (where a portion of the existing pavement is used), or other projects where the existing pavement is part of the final design, the existing pavement must be evaluated and addressed in the final pavement recommendation.

Task 2. Patching Estimate From Windshield Survey

For a preliminary evaluation, minimal field data collection is required. The Pavement Engineer should perform a limited visual survey on the pavement surface and drainage structures (i.e. curb and gutter, ditches, underdrains).

Where the existing pavement may be utilized, proper patching of deteriorated pavement is necessary at the time of maintenance/rehabilitation. The Pavement Engineer should estimate the amount of full-depth and partial depth patching required by performing a windshield survey. Approximate areas of pavement experiencing alligator cracking, rutting and localized failures should be used to estimate patching types and quantities. Refer to SECTION 603 for guidance in determining patching type based on distresses observed.

Note:

Full-Depth Patches are defined as removing all Portland Cement Concrete (PCC) / AC material – surface mix, intermediate mix and base mix by milling, carbide grinding or saw cutting, but not the granular or stabilized base/sub-base unless determined necessary by the field engineer.
Partial Depth Patches are defined as removing a portion of the total PCC/AC thickness by milling or carbide grinding.

In addition, the Pavement Engineer should consider the pavement drainage conditions and their effects on the current pavement condition and potential rehabilitation alternatives. This will include, but not be limited to:

Curb and gutter condition;
Curb reveal;
Shoulders;
Side ditches;
Underdrains; and
Medians.

Finally, the Pavement Engineer should note any other pertinent information related to the project that may affect the final pavement design. Examples are poor roadway geometry (excessive cross-slope, excessive crown, etc.), guardrail height, bridge clearances, etc. While the Pavement Engineer is not responsible for measuring or assessing these items, general knowledge of these items will assist in developing pavement options.

Task 3. Preliminary Recommendation

Upon completion of the field data collection and data analysis, the Pavement Engineer will develop a preliminary pavement recommendation.

Subtask 3.1. Data Analysis

For each project, a minimal amount of data analysis should be required. The Pavement Engineer should:

Calculate the cumulative number of ESALS (if necessary) based on available traffic data;

Calculate the required structural capacity using the procedures given in SECTION 604;

Determine the preliminary pavement improvement or potential improvements (overlay, new construction, reconstruction, etc.).

This analysis should be conducted to ensure a good initial construction estimate as well as to inform the Location and Design Section of possible pavement requirements for the project.

Subtask 3.2. Preliminary Pavement Report

Once the data analysis is completed, the Pavement Engineer will prepare a preliminary pavement report. This report will document the project's description, pavement structure, traffic levels, surface condition, and recommended improvement or improvement options.

Based on the recommended improvement or improvement options, a cost estimate can be developed by the project manager. If several improvement options are available and the project meets the life cycle cost analysis (LCCA) requirements outlined in SECTION 607.02, then a LCCA should be performed.

Task 4. Determine Need for Detailed Pavement Evaluation (Non-Construction Program Projects)

Once the preliminary pavement evaluation is complete, the Pavement Engineer must determine if the project requires a Detailed Pavement Evaluation. This task applies to projects not in the Six-Year Improvement Program (SYIP). Projects in the SYIP will be subject to a detailed pavement evaluation.

For routine maintenance activities a detailed project level analysis will not be required. These activities include:

Crack Sealing;
AC Overlay (1.5") based on AASHTO Pavement Design (no additional structure is required, overlay required to improve ride or friction characteristics only);
AC Overlay (2.0") based on AASHTO Pavement Design (less than 5% of the pavement surface requires patching);
Surface Treatment (less than 5% of the pavement surface requires patching); and
Patching (less than 5% of the pavement surface requires patching).

For those projects that require more than 5% patching or require a structural capacity improvement based on the preliminary data analysis conducted in Subtask 3.1, then a Detailed Pavement Evaluation should be conducted.

(b) Detailed Pavement Evaluation

The detailed pavement evaluation will serve several purposes. First, the evaluation will refine the preliminary pavement recommendation. Second, the Pavement Engineer will be able to provide a better construction estimate to aid in allocating funds within the district. And third, the final pavement recommendation will aid the highway designer in developing construction documents (plans, specifications, etc.). This evaluation will help ensure proper improvements and designs to VDOT's assets.

To conduct a detailed pavement evaluation, the following tasks should be performed:

- Task 1. Records Review
- Task 2. Traffic Data Analysis
- Task 3. Pavement Data Collection and Analysis
- Task 4. Maintenance and Rehabilitation Design/New Design
- Task 5. Final Report
- Task 6. Project File Submittal to Pavement Design and Evaluation Section

Figure 2 shows the process flow for the detailed pavement evaluations.

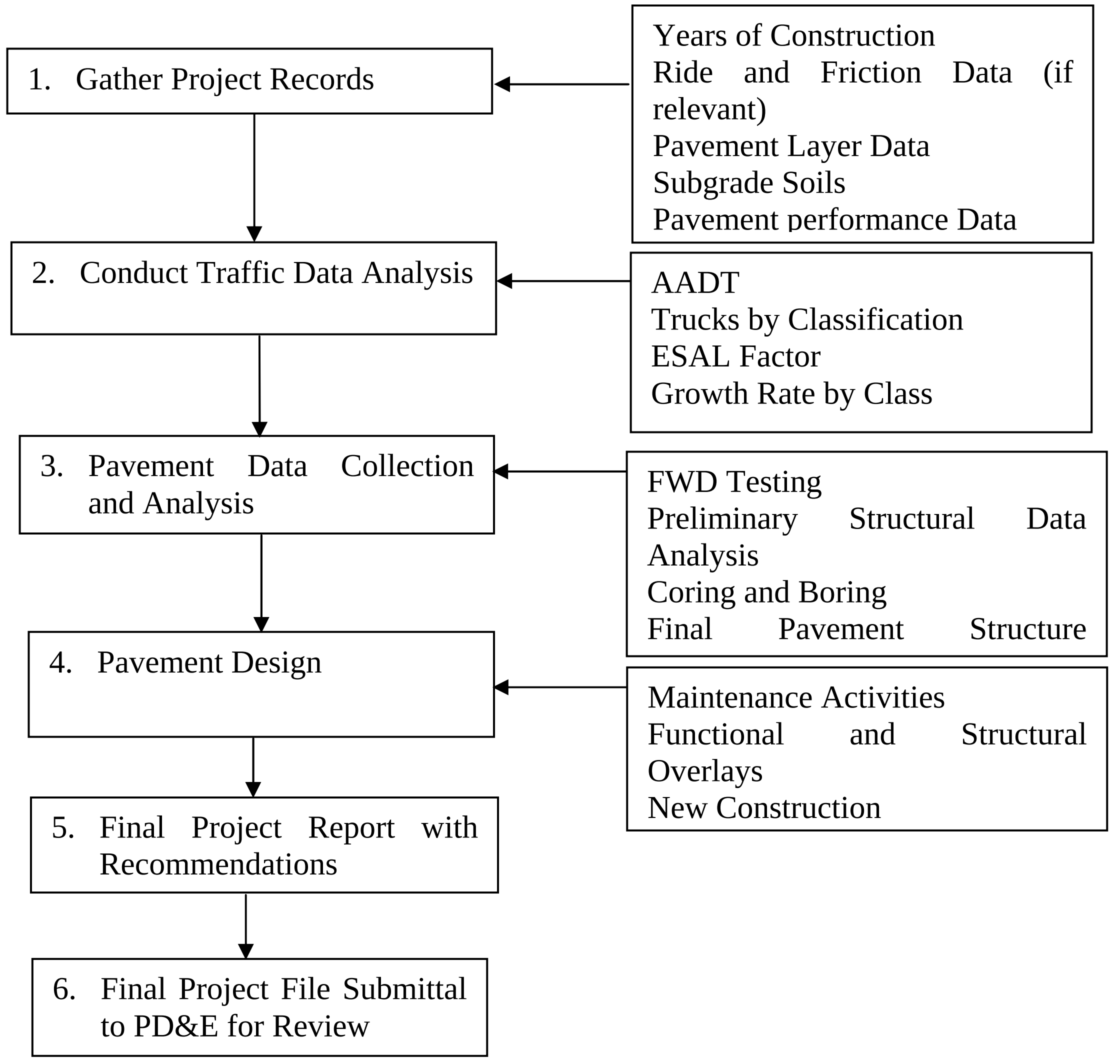


Figure 2 - Detailed Pavement Evaluation Process Flow

<u>Task 1. Records Review</u>

As performed in the preliminary evaluation, the Pavement Engineer should conduct a record review to update and expand the data previously gathered. This review will concentrate on construction history, maintenance history, and pavement performance data (current and historical). For new construction projects, Task 1 can be omitted.

By reviewing "As-Built" construction plans and history information in HTRIS (if available), the following data should be collected:

- Years of Construction (original and resurfacing),
- Pavement Ride Quality (if relevant),
- Pavement Surface Friction (if relevant),
- Pavement Layer Materials, and
- Subgrade Soil Types and Strengths.
- Pavement Performance History (LDR, NDR, CCI), if available.

With use of the HTRIS, the Pavement Engineer should be able to obtain current pavement performance data and historical performance data, which will be beneficial in Task 4.

Task 2. Traffic Data Analysis

Unlike the preliminary pavement evaluation, a more detailed traffic data analysis is required. For the preliminary evaluation, the Pavement Engineer will gather available traffic data from the HTRIS and/or possibly District Traffic Engineering or Transportation Planning Sections. This data may only consist of average daily traffic counts, but may not contain information on the number and types of trucks using the roadway. For the detailed evaluation, more accurate data may be required depending on the information used for the preliminary evaluation and the preliminary pavement recommendation.

Traffic data to be collected should include:

Average Annual Daily Traffic
Number of Trucks by Classification
ESAL Factor by Classification
Traffic Growth Rate
Truck Weights (if available from weigh station)

In the event some or all of this information is not available, the Pavement Engineer should request the Traffic Engineering Section to conduct at least a 12 hour traffic study and to provide an estimate of the daily (24-hour) traffic. This study should provide an estimate of the AADT, percent trucks, and classification of trucks using the roadway.

Once traffic data are collected, the Pavement Engineer will conduct a traffic analysis for the pavement design period. The purpose of this analysis will be to determine the required structural capacity for the pavement based on the expected/forecast traffic loading (cumulative ESALS). If the pavement requires an overlay, the Pavement Engineer will calculate the cumulative ESALS to date (years since last Major Rehabilitation) and ESALS to failure for the current pavement structure. The last Major Rehabilitation is generally defined as a pavement action where the net increase in pavement structure is at least 2.0" for flexible pavements and concrete pavement restoration (CPR) for rigid and composite pavements. The cumulative ESALS to date and ESALS to failure will be used to calculate the structural condition factor (C_x) due to traffic. The structural condition factor is reported on a 0 to 1 scale and is used to determine the remaining life of the pavement (0 – 100%).

Task 3. Pavement Data Collection and Analysis

Under Task 3, the Pavement Engineer should perform the following data collection and analysis activities:

Subtask 3.1. Falling Weight Deflectometer Testing
Subtask 3.2. Preliminary Structural Data Analysis
Subtask 3.3. Pavement Coring and Subgrade Boring
Subtask 3.4. Final Pavement Structural Analysis
Subtask 3.5. Patching Survey

Subtask 3.1. Falling Weight Deflectometer Testing

The purpose of FWD testing (Figure 3) is to assess the existing structural condition of the pavement and strength of the subgrade soils. FWD testing can be conducted on flexible, rigid and composite pavements. The amount and specifics of the testing for each type of pavement is contained in SECTION 602 of this document.

Figure 3 - Falling Weight Deflectometer

Subtask 3.2. Preliminary Structural Data Analysis

Upon completion of FWD testing, the Pavement Engineer will perform a section analysis of the data. This may be done by using the cumulative sums of deflection method outlined in Appendix J of the *1993 AASHTO Guide for the Design of Pavement Structures*. The Pavement Engineer will determine homogeneous sections of pavement and subgrade strength based upon deflection response as depicted in Figure 4. These homogeneous sections will be identified for pavement coring and possibly subgrade boring to determine the actual pavement structure. In addition, these sections will be used as analysis units in Task 4. A more detailed description of this process is contained in SECTION 602.

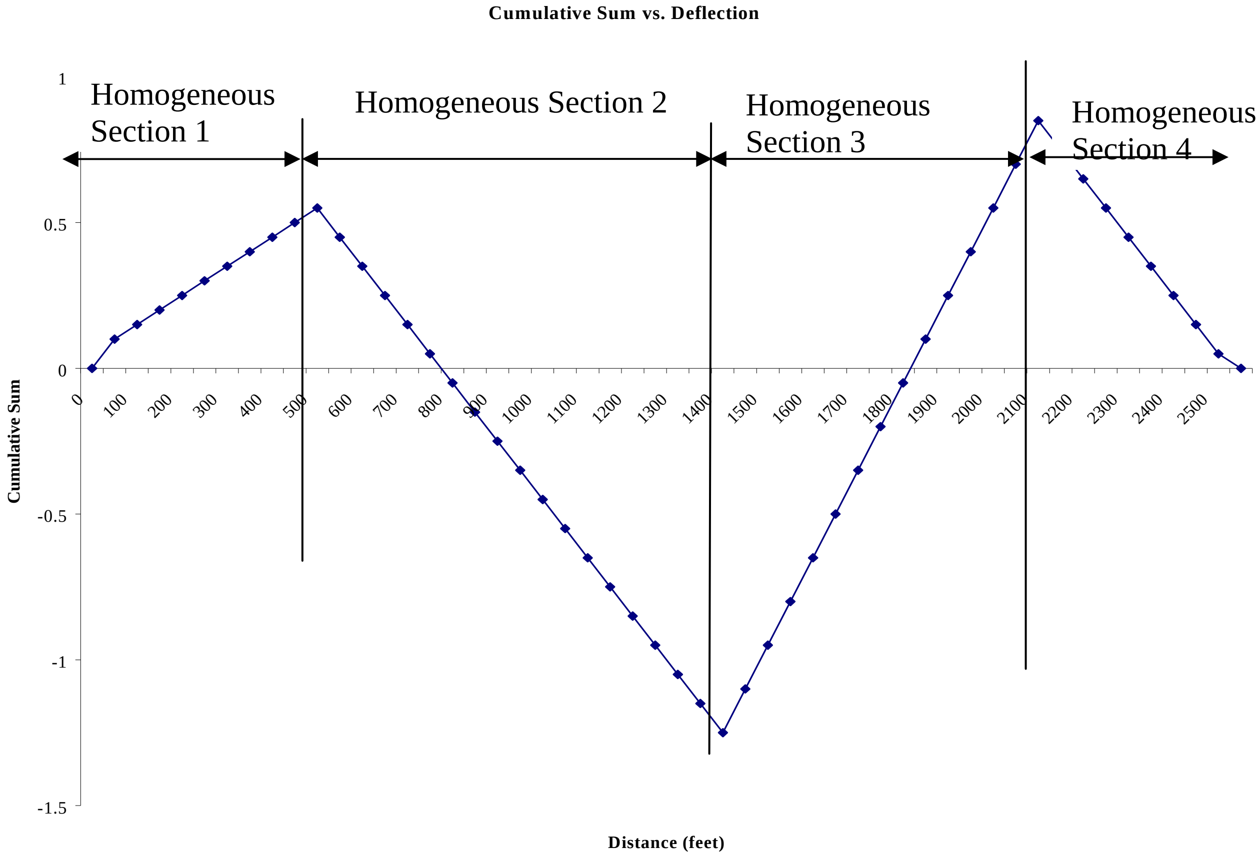


Figure 4 - Example of Cumulative Sums Deflection

Subtask 3.3. Pavement Coring and Subgrade Boring

Once pavement coring and boring locations has been identified in Subtask 3.2, the Pavement Engineer will arrange the coring and boring operations. For the pavement coring, the following should be recorded:

- pavement material types,
- thickness and
- visual condition.

For the subgrade borings, a visual classification of the materials, moisture contents of the material, depth to water table, blow counts and retrieval of a bulk sample should be conducted. For investigating existing pavements, borings to a depth of 4 feet should be performed. Adequate material should be recovered from the borings for possible resilient modulus testing and laboratory classification. Please refer to other sections of the Manual of Instructions for more information on coring, boring and laboratory testing.

Subtask 3.4. Final Pavement Structural Analysis

Once the exact pavement structure and subgrade is known, the Pavement Engineer will conduct a final pavement structural analysis using the FWD data collected in Subtask 3.1. Please refer to

SECTION 602 for guidance on structural analysis. This analysis will be used to determine the existing structural capacity of the pavement. For flexible pavements, the Pavement Engineer will determine:

Effective Structural Number (SN_{eff})
Layer Moduli and
Resilient Modulus of the Subgrade.

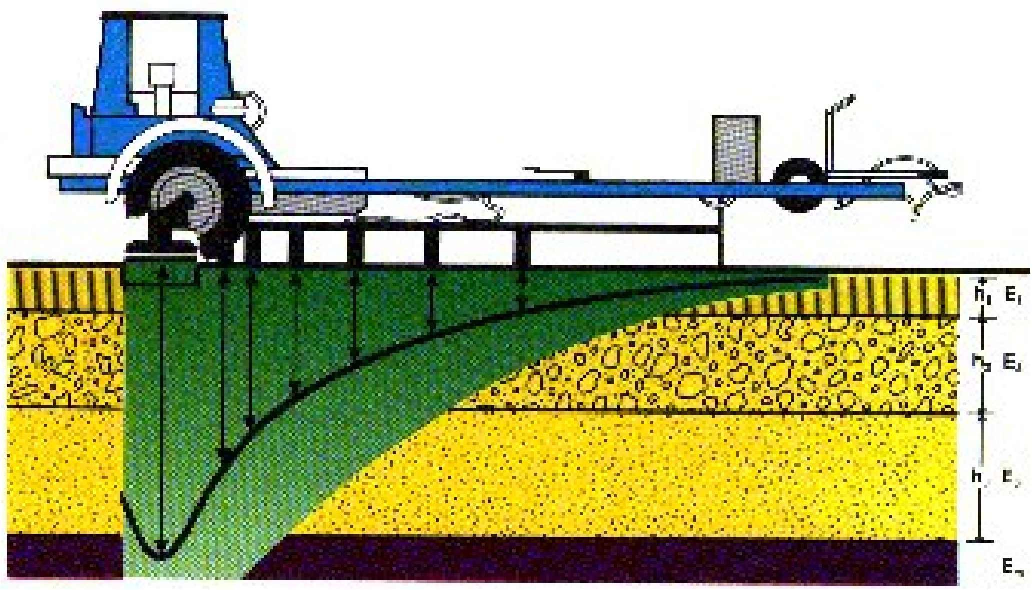


Figure 5 – Deflection Basin Collected with Falling Weight Deflectometer

For rigid pavements, the Pavement Engineer will determine:

Elastic Modulus of the PCC
Composite Modulus of Subgrade Reaction
Load Transfer at Cracks and Joints and
Potential for the Presence of Voids.

For composite pavements, the Pavement Engineer will determine:

Elastic Modulus of the PCC
Composite Modulus of Subgrade Reaction
Resilient Modulus of the Subgrade.
Load Transfer of Cracks and Joints and
Potential for the Presence of Voids.

These results will be used to design the future improvement of the roadway. SECTION 604 contains guidelines and recommendations for pavement analysis and designs.

Subtask 3.5. Patching Survey

For projects where the existing pavement will be incorporated into the final pavement design, the Pavement Engineer should determine the amount of full-depth and partial depth patching required. For projects where the existing pavement will be demolished, this subtask can be omitted.

The amount of patching should be based on guidelines provided in SECTION 603 and the engineer's judgment. Please remember, if the total AC thickness is 8 inches and the final pavement recommendation calls for removing and replacing 2", then partial depth patches may not be required. Note:

> Full-Depth Patches are defined as removing all PCC/AC material – surface, intermediate and base mixes, etc., by milling, carbide grinding or saw cutting, but not the granular or stabilized base/sub-base unless determined necessary by the field engineer.
> Partial Depth Patches are defined as removing a portion of the total PCC/AC thickness by milling or carbide grinding.

Guidelines for determining patch locations and types for PCC and AC surfaces are contained in SECTION 603.

Task 4. Pavement Design

Upon completion of Task 3, the Pavement Engineer will develop a pavement design for the project. In general, a project will require one or more of the following:

Maintenance Activities
Functional Overlay
Structural Overlay
Full-depth Base Widening
Reconstruction/New Construction

Maintenance Activities

For projects requiring a maintenance improvement, the Pavement Engineer will specify the maintenance to be performed. Maintenance activities may include, but not be limited to:

Partial Depth Patches,
Full Depth Patches,
Crack Sealing,
Surface Treatment (Slurry Seal, Micro surfacing, Chip Seal, etc.),
Joint Sealing,
Joint Cleaning, and
Slab Stabilization.

The maintenance activity(s) designed should be based upon some of the following roadway attributes:

Pavement Distress,
Pavement Type,
Maintenance Activity Performance
Traffic Level and
District Preferences (chip seal vs. slurry seal).

It will be the responsibility of the Pavement Engineer to investigate these attributes.

Functional and Structural Overlays

For projects requiring a functional or structural improvement, the Pavement Engineer will perform pavement designs as well as specify any maintenance to be performed. The pavement designs are to be based on current AASHTO procedures. (Except Secondary Roads may use "The Pavement Design Guide for Subdivision and Secondary Roads in Virginia." For higher-volume Secondary Roads, the use of AASHTO is encouraged.) The Pavement Engineer will use data collected in Task 3 to determine the current pavement condition and future requirements based on anticipated traffic. Where possible the Pavement Engineer should develop multiple alternatives for a project in order to perform life cycle cost comparisons. If the existing pavement may be removed, then the Pavement Engineer should refer to Section 606 on Pavement Type Selection. If the pavement is to remain in place, the Pavement Engineer should consider changing maintenance approaches (more vs. less patching), changing overlay thickness, changing milling thickness, changing materials, etc. For rigid pavements, concrete pavement restoration (CPR) may include joint/crack patching, grinding, dowel bar retrofit, etc. When CPR is considered by the pavement engineer, a 10-year design life should be used. The specifics on pavement design are contained in SECTION 604; the specifics on life cycle cost analysis are contained in Section 607.

<u>Task 5. Final Report</u>

For each project, the Pavement Engineer will prepare a final report to document the technical approach and recommendations. This report will contain the following:

Section 1 - Specific Location of the Project
Section 2 - Existing Pavement Information (Rehab and Widening/Capacity Improvement Projects)
- Subsection 2.1 - Pavement Structure
- Subsection 2.2 - Pavement Condition based on Ride Data (IRI), Structural Capacity (FWD Testing Results), and Visual Condition (Distress Survey)

Section 3 - Soils Information based on Soils Report - Unsuitable Materials, Select Material, etc.
- Subsection 3.1 - Unsuitable Materials at Subgrade
- Subsection 3.2 - Unsuitable Materials in Cut Areas
- Subsection 3.3 - Shrinkage Factors for Excavation
- Subsection 3.4 - Slope Design
- Subsection 3.5 – Rock at Subgrade and in Cut Areas

Section 4 – Traffic Analysis Summary
- Subsection 4.1 – General Information (AADT for Design Year, Growth Rate, Truck Percentage, Truck Classes, ESAL Factor)
- Subsection 4.2 – Cumulative ESAL Computations

Section 5 – Pavement Recommendations
- Subsection 5.1 – Mainline Roadway
- General Description of Pavement Design
- Parameters/Assumptions used in Pavement Design (Mr, CBR, Design Life, Reliability, etc.)
- Description of Patching (Quantity required, locations, quantity to remove, Patching Material and Specifications)
- Description of Pavement Design Cross Section with Notes
- Drainage Considerations (subsurface drainage – see Section 604)

Shoulder Design Details (see Section 604)
Subsection 5.2 – Connecting Roadways, Ramps, etc. (same as outlined above)
Section 6 – Sources of Material

Not all report sections will be required for all projects. It is the responsibility of the Pavement Engineer to determine what sections are to be included in the final report. Much of this information will be contained in separate appendices attached to the report. This information may include:

Detailed Structural and Functional Condition Data (Section 2)
Detailed Soils Information (Section 3)
Detailed Traffic Analysis (Section 4)
Pavement Design Parameters (Section 5)

Section 3 is not intended to replace the Soils Report, but summarize the information for the project designer(s).

The final recommendation will provide details on the materials to be used, material thickness, maintenance, etc. If necessary, the Pavement Engineer will provide any special provisions for construction and pavement cross sections. The main purpose of this report is to aid District Location and Design personnel in preparing project plans and contract documents.

Task 6. Project File Submittal to PD&E for Review and Comment

Once the District Pavement Engineer has obtained approval from the District Materials Engineer, the project file may be submitted to the Materials Division's Pavement Design and Evaluation Section for review and comment. Projects that have a construction estimate over $2 million at time of Preliminary Field Inspection meeting should be submitted. As a quality assurance step, this review should be obtained prior to the incorporation of pavement designs in the final project plans.

Whether a project report is submitted or not to PD&E, all Districts should use the following Pavement Recommendation Project File Format for their own review. This format will aid PD&E in the review of the projects by providing the right information at the right time. Additionally, this will provide complete design information for projects when it is needed for future reference. As a minimum, if applicable to the project, the file will contain:

- Cover Memo
- Pavement Design/Rehabilitation Report with Appendices
- General Pavement Details
- Project Preliminary Plans
- Printouts from Pavement Design Software properly labeled
- Traffic Analysis
- Existing Pavement Condition Surveys (Applies to Rehab Projects and Widening/Capacity Improvement Projects)

Once received by PD&E, the proper reviews will be conducted and comments obtained. Then, the Materials Division will forward the pavement designs to the Location and Design Division's Administrator with a letter concurring or disagreeing with part or all of the recommendations.

This letter will include carbon copies to the District Materials Engineer and others as specified by the District Pavement Engineer.

SECTION 602 – FALLING WEIGHT DEFLECTOMETER TESTING AND ANALYSIS GUIDELINES

Sec. 602.01 Introduction

One of the most difficult exercises for a pavement engineer is analyzing deflection data collected with a falling weight deflectometer. While FWDs have been in use for over 20 years, the methods to process the data are far from perfect. Engineers, educators and researchers are constantly trying to develop new analysis approaches that will provide data results that match field conditions with laboratory results.

Although most of the development has been in the field of pavement research, several software tools are available for production data processing and analysis. The purpose of this document is to provide guideline for engineers to follow when setting up FWD testing on a project and for analyzing results. Additional information on analyzing the testing results can be found in the document titled "MODTAG – User's Manual and Technical Documentation."

FWD data analysis is not an easy process, but with practice and experience engineers will be able to evaluate and determine how to use the FWD results.

Sec. 602.02 FWD Testing - Flexible Pavements

For flexible pavements, falling weight deflectometer (FWD) testing is used to assess the structural capacity of the pavement and estimate the strength of subgrade soils. In addition to the structural capacity, the elastic modulus for the surface, base and subbase layers can be determined.

(a) FWD Testing Pattern

The FWD testing pattern selected for a project should be related to the project's size and layout. The Pavement Engineer should consider the number of lanes to be tested, total length of the project, and any unusual circumstances that would require a change in the testing pattern.

Project Layout

The project layout will influence the FWD testing pattern. For projects where the pavement is to be repaired in each direction, then travel lanes in each direction should be tested. Typically, this should be the outside travel lane. For projects where only one direction will be repaired and more than two lanes exist, then testing should be conducted on the outside lane and possibly inside lane. The inside lane should be tested if:

- Pavement structure is different than the outside lane,
- More load related distress is present as compared to the outside lane, or
- Heavy truck traffic uses the lane (lane is prior to a left exit).

For projects that contain multiple intersections, the FWD testing may not be possible due to traffic. However, where possible testing should be conducted at approaches and leaves to an intersection.

Project Size

The size of a project will influence the test spacing. The project size is determined by the directional length of pavement to be repaired, not necessarily the centerline length. For example, a project that has a centerline distance of 1 mile and will be repaired in two directions has a directional length of 2 miles. Therefore, the test spacing should be based on two miles. Table 1 contains guidelines based on project size, test spacing, and estimated testing days. A testing day is defined as 200 locations tested.

Project Size (miles)	Test Spacing (feet)	Approximate Number of Tests	Testing Days
0 – 0.5	25	75	½ Day
0.5 – 1.0	50	90	½ Day
1.0 – 2.0	50	175	1 Day
2.0 – 4.0	100	175	1 Day
4.0 – 8.0	150	200	1 to 1 ½ Days
> 8.0	200	>200	> 1 ½ Days

Table 1 Flexible Pavement Test Spacing Guidelines

For two or three lane bi-directional roadways not separated by a median, the testing should be staggered by one-half the test spacing. See Diagram 1 for clarification. For projects that are separated by a median, a staggered testing pattern is not required.

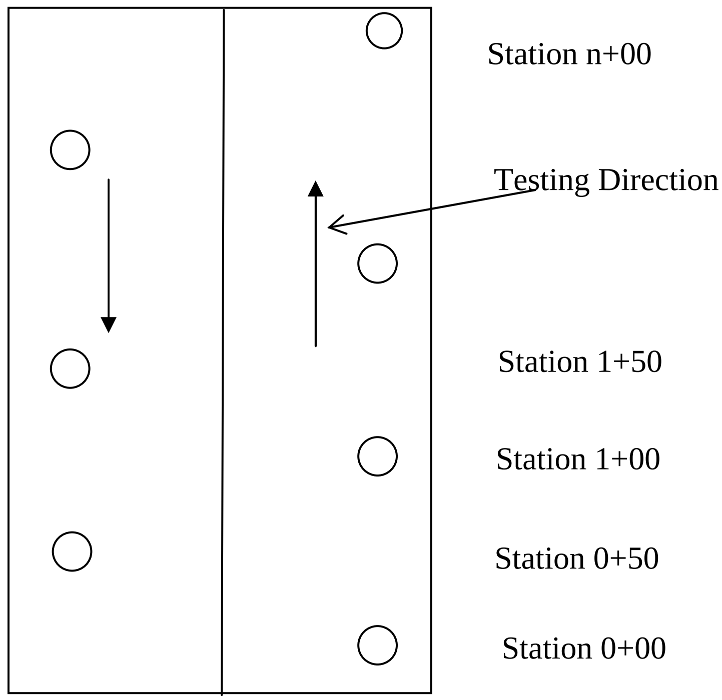


Diagram 1 - Staggered Testing Pattern

Basin Testing Location

For flexible pavements, FWD testing should be conducted in the wheel path closest to the nearest shoulder. This type of testing is known as basin testing since deflection measurements from all sensors may be used; refer to Figure 5. The purpose of this testing is to characterize the structural condition of the pavement where damage due to truck loading should be the greatest. For the outside lanes, testing should be conducted in the right wheel path. For inside lanes, testing should be conducted in the left wheel path.

(b) FWD Drop Sequence

Drop sequences vary based on pavement type and the type of information being gathered. Drop sequence is defined as the order in which impulse loads are applied to the pavement. This includes the "seating drops" and the recorded impulse loads. Below is the recommended drop sequence for basin testing on flexible pavements:

Two Seating Drops at 12,000 pounds
Four Recorded Drops at 6,000 pounds
Four Recorded Drops at 9,000 pounds
Four Recorded Drops at 12,000 pounds
Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data. By performing multiple drops at a location, the pavement will react as a homogeneous structure as well as reduce the errors in measurement. Additionally, by recording and analyzing data from four different load levels, the Pavement Engineer can determine if the materials on the project are stress sensitive (non-linearly elastic), if a hard bottom (water table, bedrock or extremely stiff layer) is present, and if compaction/liquefaction is occurring in the subgrade.

(c) FWD Sensor Spacing

FWD sensor spacing to record pavement deflection data is dependent on the pavement type as well as the testing purpose (load transfer testing vs. basin testing). For basin testing on flexible pavements, the recommended spacing is given below:

0 in., 8 in., 12 in., 18 in., 24 in., 36 in., 48 in., 60 in., and 72 in.

If the FWD is only equipped with seven sensors, then the measurement at 48 in. and 72 in. would be omitted.

(d) Surface Temperature Measurement

Ideally, the pavement temperature will be recorded directly from temperature holes at each test location as the FWD test is being performed. While this is the preferred approach for research projects, it is not practical for production level testing (network level or maintenance and rehabilitation projects). Therefore, for production level testing the economic and practical approach is by measuring the surface temperature at each test location. This can be easily done using an infrared thermometer. The FWD can automatically measure and record the pavement surface temperature to the FWD file. If the FWD is not equipped with an Infrared thermometer, then the FWD operator can use a hand held thermometer and record the temperature to a file. By measuring and monitoring the surface temperature during testing, the FWD operator can suspend testing if the pavement becomes too hot.

Sec. 602.03 FWD Testing - Jointed Concrete Pavements

For rigid pavements, falling weight deflectometer (FWD) testing is used to assess the structural capacity of the pavement, estimate the strength of subgrade soils, assess load transfer at joints, and detect voids at joints. In addition to the structural capacity, the elastic modulus for the surface, base and sub-base layers can be determined.

(a) FWD Testing Pattern

The FWD testing pattern selected for a jointed concrete pavement project should be related to the project's layout, project size, and slab length. The Pavement Engineer should consider the number of lanes to be tested, total number of slabs, length of the project, and any unusual circumstances that would require a change in the testing pattern.

Project Layout

The project layout will influence the FWD testing pattern. For projects where the pavement is to be repaired in each direction, then travel lanes in each direction should be tested. Typically, this should be the outside travel lane. For projects where only one direction will be repaired and more than two lanes exist, then testing should be conducted on the outside lane and possibly inside lane. The inside lane should be tested if:

Pavement structure is different than the outside lane,
More load related distress is present as compared to the outside lane, or

Heavy truck traffic uses the lane (lane is prior to a left exit).

For projects that contain multiple intersections, then FWD testing may not be possible due to traffic. However, where possible testing should be conducted at approaches and leaves to an intersection.

Slab Length and Project Size

The number of jointed concrete slabs in a project will determine test spacing. For projects with short slab lengths, it may not be practical to test every slab (basin and joint testing). For projects with longer slab lengths, every slab may be tested.

In addition to slab length, the size of a project will influence the test spacing. The project size is determined by the directional length of pavement to be repaired, not necessarily the centerline length. For example, a project that has a centerline distance of 1 mile and will be repaired in two directions has a directional length of 2 miles. Therefore, the test spacing should be based on two miles. Table 2 contains guidelines based on project size, approximate slab length, test spacing, and estimated testing days. A testing day is defined as 175 locations tested (joints, corners and basins).

Project Size (miles)	Slab Length	Basin Test Spacing (no. of slabs)	Joint/Corner Spacing (no. of slabs)	Approximate Number of Tests	Testing Days
0 - 0.5	< 20’	Every 6th Slab	Every 2nd J/C	115	1 Day
	20’ – 45’	Every Slab	Every J/C	175	1 Day
	> 45’	Every Slab	Every J/C	120	1 Day
0.5 – 1.0	< 20’	Every 9th Slab	Every 3rd J/C	180	1 Day
	20’ – 45’	Every 2nd Slab	Every 2nd J/C	175	1 Day
	> 45’	Every Slab	Every J/C	300	1 ½ - 2 Days
1.0 – 2.0	< 20’	Every 12th Slab	Every 4th J/C	250	1 – 2 Days
	20’ – 45’	Every 4th Slab	Every 2nd J/C	300	1 ½ - 2 Days
	> 45’	Every 2nd Slab	Every 2nd J/C	270	1 ½ - 2 Days
2.0 – 4.0	< 20’	Every 15th Slab	Every 5th J/C	380	1 ½ - 3 Days
	20’ – 45’	Every 6th Slab	Every 4th J/C	380	1 ½ - 3 Days
	> 45’	Every 4th Slab	Every 2nd J/C	450	2 – 3 ½ Days
4.0 – 8.0	< 20’	Every 20th Slab	Every 10th J/C	220	1 ½ - 3 Days
	20’ – 45’	Every 8th	Every 4th J/C	470	2 ½ - 4 ½

Project Size (miles)	Slab Length	Basin Test Spacing (no. of slabs)	Joint/Corner Spacing (no. of slabs)	Approximate Number of Tests	Testing Days
		Slab			Days
	> 45’	Every 6th Slab	Every 3rd J/C	590	2 ½ - 4 ½ Days
> 8.0	< 20’	Every 20th Slab	Every 10th J/C	450	3 Days
	20’ – 45’	Every 10th Slab	Every 5th J/C	650	3 ½ - 4 Days
	> 45’	Every 8th Slab	Every 4th Slab	500	3 Days

Table 2 Joint Concrete Pavement Test Spacing Guidelines

Testing Location

For jointed concrete pavements, three types of FWD testing are generally conducted – basin, joint, and slab corner testing. Each test provides information on the structural integrity of the pavement.

Basin Testing

For jointed concrete pavements, basin testing should be conducted near the center of the slab (See Diagram 2). This testing provides information on the elastic modulus of the PCC and strength of base materials and subgrade soils.

Joint Testing

For jointed concrete pavements, joint testing should be conducted in the wheel path closest to the free edge of the slab (See Diagram 2). Typically, for the outside lanes, testing will be conducted in the right wheel path. For inside lanes, testing should be conducted in the left wheel path. If more than two lanes exist and the middle lanes are to be tested, then the nearest free edge must be determined. This testing provides information on joint load transfer – how well a joint, either through aggregate interlock and/or dowel bars, can transfer a wheel load from one slab to an adjacent slab.

Corner Testing

For jointed concrete pavements, corner testing should be conducted at the slab’s free edge corner (See Diagram 2). Typically, for the outside lanes, testing will be conducted in the right corner edge of the slab. For inside lanes, testing should be conducted in the left corner edge of the slab. If more than two lanes exist, then the middle lanes should only be tested if pumping is suspected in the middle lanes. The Pavement Engineer will determine if pumping is present and if testing should be conducted. Unless otherwise directed by the Pavement Engineer, corner testing shall be conducted on the leave side of the joint where voids are typically located. This testing provides information on the possibility for the presence of voids under a slab corner.

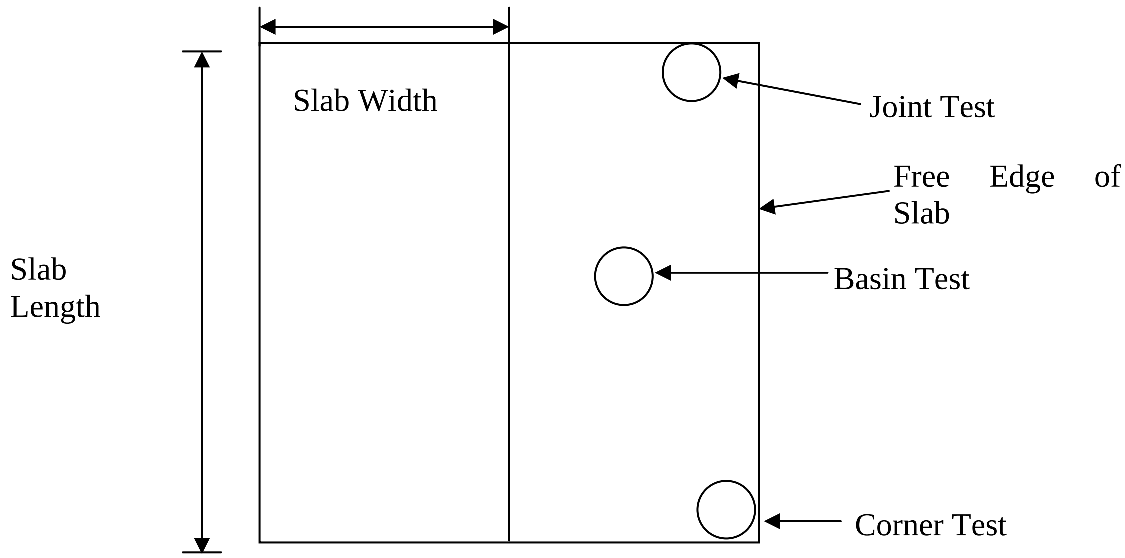


Diagram 2 - JPC Testing Pattern

(b) FWD Drop Sequence

When collecting pavement structure data, the correct drop sequence is required. Drop sequences vary based on pavement type and the type of information being gathered. Drop sequence is defined as the order in which impulse loads are applied to the pavement. This includes the “seating drops” and the recorded impulse loads.

Basin Testing

Below is the recommended drop sequence for basin testing on jointed concrete pavements:

Two Seating Drops at 12,000 pounds
Four Recorded Drops at 6,000 pounds
Four Recorded Drops at 9,000 pounds
Four Recorded Drops at 12,000 pounds
Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data. By performing multiple drops at a location, the pavement will react as a homogeneous structure as well as reduce the errors in measurement. Additionally, by recording and analyzing data from four different load levels, the Pavement Engineer can determine if the materials on the project are stress sensitive (non-linearly elastic), if a hard bottom (water table, bedrock or extremely stiff layer), and if compaction/liquefaction is occurring in the subgrade.

Joint Testing

Below is the recommended drop sequence for joint testing on jointed concrete pavements:

Two Seating Drops at 12,000 pounds
Four Recorded Drops at 6,000 pounds
Four Recorded Drops at 9,000 pounds
Four Recorded Drops at 12,000 pounds

Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data.

Corner Testing

Below is the recommended drop sequence for corner testing on jointed concrete pavements:

Two Seating Drops at 12,000 pounds
Four Recorded Drops at 9,000 pounds
Four Recorded Drops at 12,000 pounds
Four Recorded Drops at 16,000 pounds

In order to use the AASHTO procedure for the detection of voids, three different load levels are required; therefore, at each test location the FWD will need to perform 11 drops and record three sets of deflection and impulse load data

(c) FWD Sensor Spacing

FWD sensor spacing to record pavement deflection data is dependent on the pavement type as well as the type of testing. For jointed concrete pavements, three types of testing are performed – joint, corner and basin.

Basin Testing

For basin testing on jointed concrete pavements, below is the recommended spacing:

0 in., 8 in., 12 in., 18 in., 24 in., 36 in., 48 in., 60 in., and 72 in.

If the FWD is only equipped with seven sensors, then the measurement at 48 in. and 72 in. would be omitted.

Joint Testing

For joint testing on jointed concrete pavements, only two sensors are required. Below is the required spacing:

0 in. and 12 in.

The sensors are to be placed on each side of the joint and are to be 6 inches from the joint (See Diagram 3).

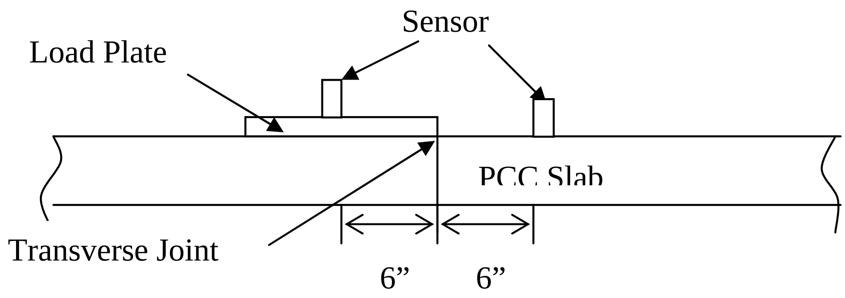


Diagram 3 - Joint Load Transfer Testing Sensor Spacing

(d) Surface Temperature Measurement

Ideally, the pavement temperature will be recorded directly from temperature holes at each test location as the FWD test is being performed. While this is the preferred approach for research projects, it is not practical for production level testing (network level or maintenance and rehabilitation projects). Therefore, for production level testing the economic and practical approach is by measuring the surface temperature at each test location. This can be easily done using an infrared thermometer. The FWD can automatically measure and record the pavement surface temperature to the FWD file. If the FWD is not equipped with an Infrared thermometer, then the FWD operator can use a hand held thermometer and record the temperature to a file. By measuring and monitoring the surface temperature during testing, the FWD operator can suspend testing if the pavement becomes too hot.

Sec. 602.04 FWD Testing - Composite Pavements

For composite pavements, falling weight deflectometer (FWD) testing is used to assess the structural capacity of the pavement and estimate the strength of subgrade soils as well as assess the load transfer at underlying joints. In addition to the structural capacity, the elastic modulus for the surface, base and subbase layers can be estimated.

(a) FWD Testing Pattern

The FWD testing pattern selected for a project should be related to the project’s size and layout. The Pavement Engineer should consider the number of lanes to be tested, total length of the project, and any unusual circumstances that would require a change in the testing pattern. In addition, the AC overlay thickness should be considered. If the thickness is less than four inches, then the load transfer of the underlying PCC joints may be performed.

Project Layout

The project layout will influence the FWD testing pattern. For projects where the pavement is to be repaired in each direction, then travel lanes in each direction should be tested. Typically, this should be the outside travel lane. For projects where only one direction will be repaired and more than two lanes exist, then testing should be conducted on the outside lane and possibly inside lane. The inside lane should be tested if:

Pavement structure is different than the outside lane,

More load related distress is present as compared to the outside lane, or
Heavy truck traffic uses the lane (lane is prior to a left exit).

For projects that contain multiple intersections, then FWD testing may not be possible due to traffic. However, where possible testing should be conducted at approaches and leaves to an intersection.

Project Size

The size of a project will influence the test spacing. The project size is determined by the directional length of pavement to be repaired, not necessarily the centerline length. For example, a project that has a centerline distance of 1 mile and will be repaired in two directions has a directional length of 2 miles. Therefore, the test spacing should be based on two miles. Table 3 contains guidelines based on project size, test spacing, and estimated testing days if load transfer testing is not performed. If load transfer testing is desired, then the appropriate spacing should be determined in the field. As a guideline, please refer to Joint/Corner Spacing column in Table 2. A testing day is defined as 200 locations tested.

Project Size (miles)	Test Spacing (feet)	Approximate Number of Tests	Testing Days
0 – 0.5	25	75	½ day
0.5 – 1.0	50	90	½ Day
1.0 – 2.0	50	175	1 Day
2.0 – 4.0	100	175	1 Day
4.0 – 8.0	150	200	1 to 1 ½ Days
> 8.0	200	>200	> 1 ½ Days

Table 3 Composite Pavement Test Spacing Guidelines

For two or three lane bi-directional roadways not separated by a median, the testing should be staggered by one-half the test spacing. See Diagram 4 for clarification. For projects that are separated by a median, a staggered testing pattern is not required.

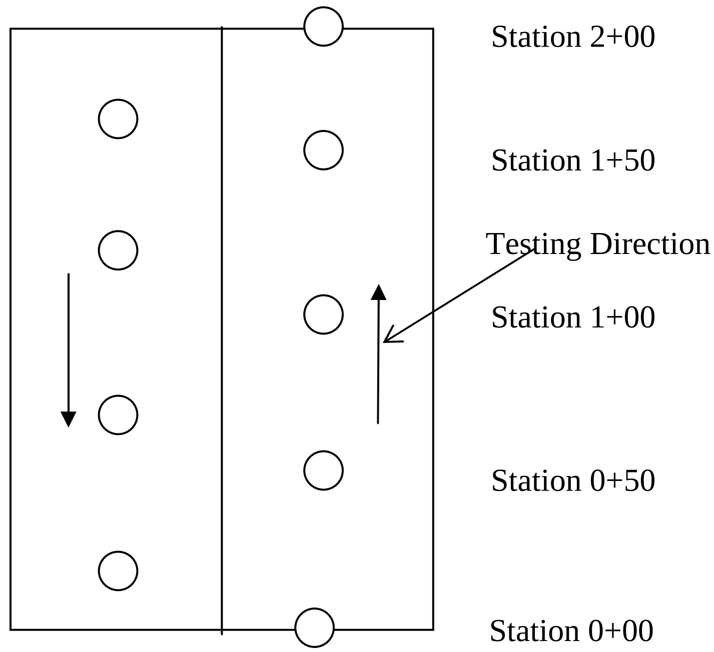


Diagram 4 - Staggered Testing Pattern

Testing Locations

For composite pavements, two types of FWD testing are generally conducted – basin and joint. Each test provides information on the structural integrity of the pavement.

Basin Testing

For composite pavements, basin testing should be conducted in the middle of the lane or near the center of the slab (See Diagram 4). This testing provides information on the elastic modulus of the AC, PCC and strength of base materials and subgrade soils.

Joint Testing

For composite pavements, joint testing should be conducted in the wheel path closest to the free edge of the slab (See Diagram 2). Typically, for the outside lanes, testing will be conducted in the right wheel path. For inside lanes, testing should be conducted in the left wheel path. If more than two lanes exist and the middle lanes are to be tested, then the nearest free edge must be determined. This testing provides information on joint load transfer – how well a joint, either through aggregate interlock and/or dowel bars, can transfer a wheel load from one slab to an adjacent slab.

FWD Drop Sequence

When collecting pavement structure data, the correct drop sequence is required. Drop sequences vary based on pavement type and the type of information being gathered. Drop sequence is defined as the order in which impulse loads are applied to the pavement. This includes the "seating drops" and the recorded impulse loads.

<u>Basin Testing</u>

Below is the recommended drop sequence for basin testing on composite pavements:

Two Seating Drops at 12,000 pounds
Four Recorded Drops at 6,000 pounds
Four Recorded Drops at 9,000 pounds
Four Recorded Drops at 12,000 pounds
Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data. By performing multiple drops at a location, the pavement will react as a homogeneous structure as well as reduce the errors in measurement. Additionally, by recording and analyzing data from four different load levels, the Pavement Engineer can determine if the materials on the project are stress sensitive (non-linearly elastic), if a hard bottom (water table, bedrock or extremely stiff layer), and if compaction/liquefaction is occurring in the subgrade.

<u>Joint Testing</u>

Below is the recommended drop sequence for joint testing on composite pavements:

Two Seating Drops at 12,000 pounds
Four Recorded Drops at 6,000 pounds
Four Recorded Drops at 9,000 pounds
Four Recorded Drops at 12,000 pounds
Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data.

<u>(c) FWD Sensor Spacing</u>

FWD sensor spacing to record pavement deflection data is dependent on the pavement type as well as the type of testing. For composite pavements, two types of testing are performed – joint, and basin.

<u>Basin Testing</u>

For basin testing on composite pavements, below is the recommended spacing:

0 in., 8 in., 12 in., 18 in., 24 in., 36 in., 48 in., 60 in., and 72 in.

If the FWD is only equipped with seven sensors, then the measurement at 48 in. and 72 in. would be removed.

<u>Joint Testing</u>

For joint testing on composite pavements, only two sensors are required. Below is the required spacing:

0 in. and 12 in.

The sensors are to be placed on each side of the joint and are to be 6 inches from the joint (See Diagram 5).

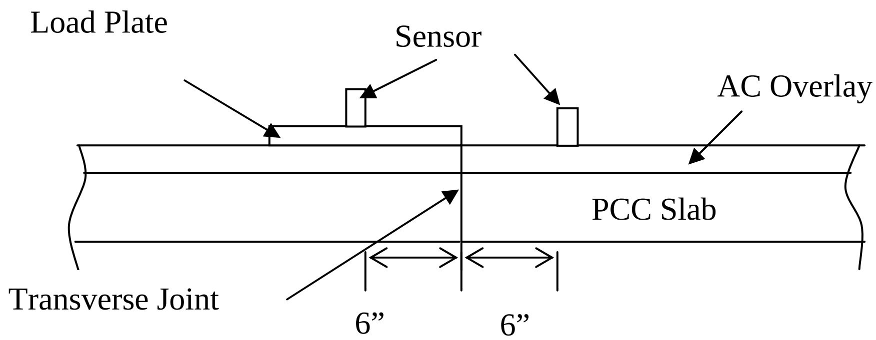


Diagram 5 - Joint Load Transfer Testing Sensor Spacing

(d) Pavement Temperature Readings

Ideally, the pavement temperature will be recorded directly from temperature holes at each test location as the FWD test is being performed. While this is the preferred approach for research projects, it is not practical for production level testing (network level or maintenance and rehabilitation projects). Therefore, for production level testing the economic and practical approach to determine the mid-depth pavement temperature is by measuring the surface temperature at each test location. This can be easily done using an infrared thermometer. The FWD can automatically measure and record the pavement surface temperature to the FWD file. If the FWD is not equipped with an Infrared thermometer, then the FWD operator can use a hand held thermometer and record the temperature to a file. Using temperature correlation models such as the BELLS3 equation, the mid-depth AC material temperature can be estimated.

Sec. 602.05 FWD Testing - Continuously Reinforced Concrete Pavements

For rigid pavements, falling weight deflectometer (FWD) testing is used to assess the structural capacity of the pavement and estimate the strength of subgrade soils. In addition to the structural capacity, the elastic modulus for the surface, base and sub-base layers can be determined.

(a) FWD Testing Pattern

The FWD testing pattern selected for a continuously reinforced concrete pavement project should be related to the project’s layout and project size. The Pavement Engineer should consider the number of lanes to be tested, total number of slabs, length of the project, and any unusual circumstances that would require a change in the testing pattern.

Project Layout

The project layout will influence the FWD testing pattern. For projects where the pavement is to be repaired in each direction, then travel lanes in each direction should be tested. Typically, this should be the outside travel lane. For projects where only one direction will be repaired and more than two lanes exist, then testing should be conducted on the outside lane and possibly inside lane. The inside lane should be tested if:

Pavement structure is different than the outside lane,
More load related distress is present as compared to the outside lane, or
Heavy truck traffic uses the lane (lane is prior to a left exit).

For projects that contain multiple intersections, then FWD testing may not be possible due to traffic. However, where possible testing should be conducted at approaches and leaves to an intersection.

Project Size

The size of a project will influence the test spacing. The project size is determined by the directional length of pavement to be repaired, not necessarily the centerline length. For example, a project that has a centerline distance of 1 mile and will be repaired in two directions has a directional length of 2 miles. Therefore, the test spacing should be based on two miles. Table 4 contains guidelines based on project size, test spacing (basins and cracks), and estimated testing days. A testing day is defined as 175 locations tested (cracks and basins).

Project Size (miles)	Basin Test Spacing (feet)	Crack Spacing (feet)	Approximate Number of Tests	Testing Days
0 – 0.5	25	25	150	1 Days
0.5 – 1.0	50	25	270	1 ½ Days
1.0 – 2.0	100	50	270	1 ½ - 2 Days
2.0 – 4.0	150	50	450	2 – 3 Days
4.0 – 8.0	150	75	650	2 ½ - 5 Days
> 8.0	200	150	680	4 Days

Table 4 Continuously Reinforced Concrete Pavement Test Spacing Guidelines

Testing Location

For continuously reinforced concrete pavements, two types of FWD testing are generally conducted – basin and crack. Each test provides information on the structural integrity of the pavement.

Basin Testing

For continuously reinforced concrete pavements, basin testing should be conducted near the center of the panel (See Diagram 6). This testing provides information on the elastic modulus of the PCC and strength of base materials and subgrade soils.

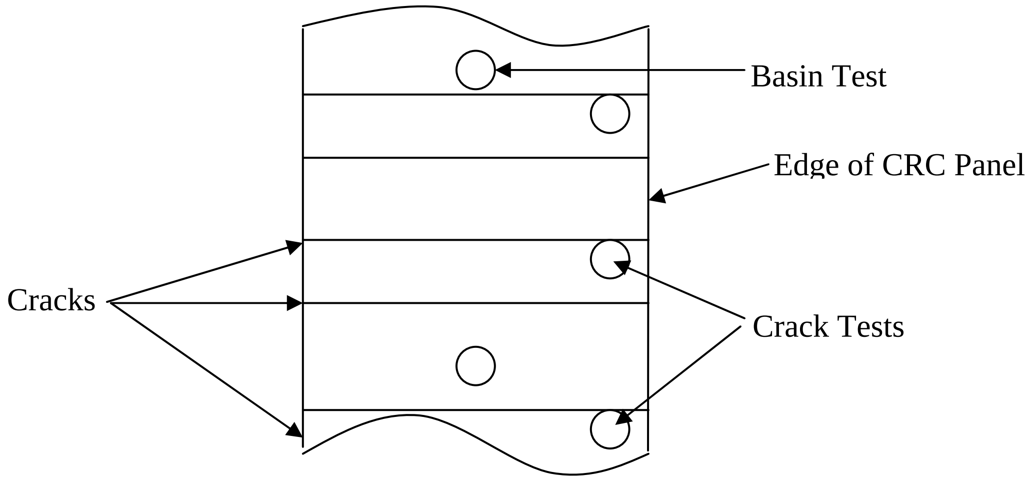


Diagram 6 - CRC Testing Pattern (one lane)

Crack Testing

For continuously reinforced concrete pavements, crack testing should be conducted in the wheel path closest to the free edge of the slab (See Diagram 6). Typically, for the outside lanes, testing will be conducted in the right wheel path. For inside lanes, testing should be conducted in the left wheel path. If more than two lanes exist and the middle lanes are to be tested, then the nearest free edge must be determined. This testing provides information on crack load transfer – how well a crack, either through aggregate interlock and/or steel reinforcement, can transfer a wheel load from one CRC panel to an adjacent panel.

(b) FWD Drop Sequence

When collecting pavement structure data, the correct drop sequence is required. Drop sequences vary based on pavement type and the type of information being gathered. Drop sequence is defined as the order in which impulse loads are applied to the pavement. This includes the "seating drops" and the recorded impulse loads.

Basin Testing

Below is the recommended drop sequence for basin testing on continuously reinforced concrete pavements:

Two Seating Drops at 12,000 pounds
Four Recorded Drops at 6,000 pounds
Four Recorded Drops at 9,000 pounds
Four Recorded Drops at 12,000 pounds
Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data. By performing multiple drops at a location, the pavement will react as a homogeneous structure as well as reduce the errors in measurement. Additionally, by recording and analyzing data from four different load levels, the Pavement Engineer can determine if the materials on the project are stress sensitive (non-linearly elastic), if a hard bottom (water table, bedrock or extremely stiff layer), and if compaction/liquefaction is occurring in the subgrade.

Crack Testing

Below is the recommended drop sequence for crack testing on continuously reinforced concrete pavements:

Two Seating Drops at 12,000 pounds
Four Recorded Drops at 6,000 pounds
Four Recorded Drops at 9,000 pounds
Four Recorded Drops at 12,000 pounds
Four Recorded Drops at 16,000 pounds

Therefore, at each test location the FWD will perform 14 drops and record four sets of deflection and impulse load data.

(c) FWD Sensor Spacing

FWD sensor spacing to record pavement deflection data is dependent on the pavement type as well as the type of testing. For continuously reinforced concrete pavements, two types of testing are performed – basin and crack.

Basin Testing

For basin testing on continuously reinforced concrete pavements, below is the recommended spacing:

0 in., 8 in., 12 in., 18 in., 24 in., 36 in., 48 in., 60 in., and 72 in.

If the FWD is only equipped with seven sensors, then the measurement at 48 in. and 72 in. would be omitted.

Crack Testing

For crack testing on continuously reinforced concrete pavements, only two sensors are required. Below is the required spacing:

0 in. and 12 in.

The sensors are to be placed on each side of the joint and are to be 6 inches from the joint (See Diagram 7).

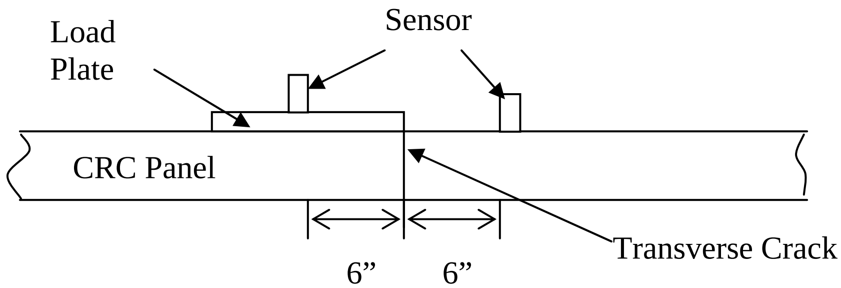


Diagram 7 - Joint Load Transfer Testing Sensor Spacing

(d) Pavement Temperature Readings

Ideally, the pavement temperature will be recorded directly from temperature holes at each test location as the FWD test is being performed. While this is the preferred approach for research projects, it is not practical for production level testing (network level or maintenance and rehabilitation projects). Therefore, for production level testing the economic and practical approach is by measuring the surface temperature at each test location. This can be easily done using an infrared thermometer. The FWD can automatically measure and record the pavement surface temperature to the FWD file. If the FWD is not equipped with an Infrared thermometer, then the FWD operator can use a hand held thermometer and record the temperature to a file. By measuring and monitoring the surface temperature during testing, the FWD operator can suspend testing if the pavement becomes too hot.

Sec. 602.06 FWD Data Processing

In order to process FWD data, many steps are required. These steps include gathering information on the pavement’s surface condition, conducting a preliminary analysis on the deflection data, performing pavement coring and subgrade boring operations, processing of all the data collected, and analyzing, interpreting and reporting on the data results. Each one of these steps has numerous tasks associated with them. These steps are detailed in the following sections.

(a) Pavement Surface Condition Survey

Prior to collecting any FWD data, the engineer should conduct a detailed pavement condition and patching survey. These surveys will help the engineer establish possible problem areas with the pavement and set-up the appropriate FWD testing plan. Testing could be concentrated in specific areas while other areas could be avoided completely. The pavement condition survey should:

- Identify distress type, severity, extent and exact location,
- Identify patched areas and areas that will probably require patching before or during the rehabilitation project, and
- Use same linear referencing system as FWD data collection.

Once these data are collected, the engineer can plot the results on a straight-line diagram. This will be extremely beneficial when other data are collected and analyzed.

(b) Preliminary Data Analysis

Once FWD data are collected, it is important to perform a preliminary analysis on the deflection data. Please refer to the "MODTAG – Users Manual and Technical Documentation" for further instruction on preliminary data analysis.

(c) Pavement Coring and Subgrade Boring

In order to conduct an analysis of FWD data, the exact pavement structure must be known. For most roadways, the exact structure is not known; therefore, pavement coring is required. Also, while the engineer may know what type of subgrade soils exists in the project area, it cannot be assured without boring the subgrade and extracting samples. These materials collected in field can be analyzed in the lab, and the lab results used to validate FWD Data Analysis results.

For the materials above the subgrade, the coring and boring crew should record:

Layer Materials – Asphalt, PCC, Granular, Cement Treated, etc
Layer Thickness – Thickness for each different layer
Layer Condition – AC material stripped, PCC deteriorated, granular material contaminated, etc.
Material Types – For AC Materials, identify various layer types

For the subgrade soils, the crew should obtain adequate material in order to determine the following material properties in the lab:

Soil classifications (gradations and Atterberg Limits)
Natural moisture content
Lab CBR
Resilient modulus (undisturbed or remolded)

(d) Full Data Processing

Once pavement condition data and materials data are collected, then the engineer can perform the data processing. The type of data processing depends on 1) pavement type – flexible, rigid or composite, and 2) testing performed – basin, joint load transfer, or corner void. Please refer to the "MODTAG-Users Manual and Technical Documentation" for further instructions.

(e) Data Analysis, Interpretation and Reporting

Except for operating the FWD processing programs, the data analysis and interpretation is the most difficult portion. Once the analysis and interpretation is completed, then the results must be presented in such a manner to be used in the pavement design programs. Please refer to the "MODTAG-Users Manual and Technical Documentation" for further information.

SECTION 603 – PATCHING SURVEY GUIDELINES

Sec. 603.01 Patching Survey

The Pavement Engineer should estimate the amount of patching required for a project. The amount of patching should be recorded in square feet in the field and converted to square yards and tons in the office. While in the field, the Pavement Engineer should determine if a patch should be full-depth or partial depth. Below are the definitions for full-depth and partial depth patches:

Full-Depth Patches are defined as removing all PCC/AC material – surface, intermediate and base mixes, etc., by milling, carbide grinding or saw cutting, but not the granular or stabilized base/sub-base unless determined necessary by the field engineer.

Partial Depth Patches are defined as removing a portion of the total PCC/AC thickness by milling or carbide grinding.

(a) Equipment and Supplies Needed

To perform a patching survey, the following equipment and supplies are needed:

Data Collection Sheets;
Pencil;
Clip Board;
Hard Hat;
Strobe Light;
Vehicle;
Map/Plan;
Marking Paint
Safety Vest; and
Measuring Wheel.

(b) Survey Procedure

Below are suggested steps to perform a patching survey:

1. Prepare data collection sheets to record type of distress, location, and type of patch. By performing this activity in the office, effort in the field can be concentrated on identifying locations that require patching.
2. Once the sheets have been prepared, go to the field with the equipment and supplies outlined above.
3. Establish the beginning of the project (paving joint, bridge joint, intersection, etc.) and mark Station 0+00 if no other stationing has been established. This stationing should be used to reference all field collected data (visual condition, coring/boring, FWD, etc.).
4. Walk the project and locate the areas requiring patching, milling or requiring a comment. If traffic control is being provided, traverse the pavement to assess the pavement condition and determine if patching, milling, etc. should be performed. If traffic control is not provided, then assess the pavement condition and determine if patching, milling, etc. should be performed from the shoulder. VDOT work zone safety procedures should be observed at all times. If walking the pavement is not possible due to safety or other reasons, the Pavement

Engineer should request video logging of the pavement in order to perform a patching survey using a computer work station.

5. Once complete, the data can be entered into an EXCEL or similar spreadsheet to calculate the amount and type of patching, as well as milling quantities.

For the preliminary analysis, only approximate pavement areas are required. For detailed analysis, more attention must be given to locating the patching and milling limits.

In addition, the Pavement Engineer should consider the pavement drainage conditions. This should include, but not be limited to:

Curb and gutter condition;
Curb reveal;
Shoulders;
Underdrains;
Side ditches; and
Medians.

Finally, the Pavement Engineer should note any other pertinent information related to the project. Examples are poor roadway geometry, guardrail heights, bridge clearances, etc.

Guidelines for Determining Patch Types and Locations for AC Surfaces					
Distress Type	Severity Level	Milling (1" - 2")			Comments
		No	Yes AC Material Thickness		
			> 6"	< 6"	
Alligator Cracking	1	None	None	None	
	2	Partial	Partial	Full	
	3	Full	Full	Full	
Rutting	1	None	None	None	
	2	Partial	None	None	
	3	Partial	Partial	Partial	If Subgrade problem, patch full depth to include replacing all materials and repairing subgrade
Linear Cracking	1	None	None	None	
	2	None	None	None	If crack is less than 1/2" wide and crack depth is less than 1/2 AC layer thickness, then crack fill.
	2	Partial	Partial	Partial	If the crack depth is greater than 1/2 AC layer thickness, then full depth patch.
Potholes/Failures/ Delaminations	N/A	Partial	None	None	Less than 6" in Diameter
	N/A	Partial	Partial	Full	Diameter is between 8" and 18"
	N/A	Full	Full	Full	Diameter is greater than 18"
Bumps/Sags	N/A	None	None	None	Causes low severity ride quality
	N/A	None	None	None	Causes medium severity ride quality
	N/A	Full	Full	Full	Causes high severity ride quality
Depression	N/A	None	None	None	Less than 1" deep
	N/A	Partial	None	None	Between 1" and 2" deep
	N/A	Full	Full	Full	Greater than 2" deep
Patches	N/A	None	None	None	Patch is in good condition and has little effect on ride quality
	N/A	Partial	Partial	Full	Patch is in fair condition (exhibiting Severity 1 LDR Distresses) or is effecting ride quality.
	N/A	Full	Full	Full	Patch is in poor condition (exhibiting Severity 2 or 3 LDR

Guidelines for Determining Patch Types and Locations for AC Surfaces					
Distress Type	Severity Level	Milling (1" - 2")			Comments
		No	Yes AC Material Thickness		
			> 6"	< 6"	
					distresses).
Joint Reflection Cracking	1	None	None	None	Load transfer greater than 70%
	2	Partial	None	Partial	Load transfer greater than 70%, use joint tape if AC layer thickness is less than 6" thick and milling will be performed
	3	Partial	Partial	Partial	Load transfer greater than 70%; patch to top of PCC Surface
Joint Reflection Cracking	1	None	None	None	Load transfer less than 70%
	2	Full	Full	Full	Load transfer is less than 70%; potential to reduce to partial depth patching, if needed.
	3	Full	Full	Full	Load transfer less than 70%

Guidelines for Determining Patch Types and Locations for Concrete Pavement Surfaces				
Distress Type	Severity			Comments
	Low	Medium	High	
Blow-Up	Full	Full	Full	
Corner Break	None	Full	Full	
Divided Slab	None	Full	Full	
Faulting	None	Full	Full	Consider grinding or undersealing the joint to remove fault.
Linear Cracking	None	None	Full	Consider grinding, undersealing or crack sealing for Low and Medium Severity.
Patching	None	**	Full	Replace in kind – Type I, II or IV
Pumping	None	None	Full	Consider undersealing to correct Pumping
Punchout	Full	Full	Full	Type II patch if punchout greater that 6' long
Spalling	AC	AC	Full	Clean out spalled area and replace with AC

Full Depth Patches may be Type I, II or IV depending on pavement type and patching area. Refer to special provision on PCC patching

If LTE (Load Transfer Efficiency) < 70% - AC patch is not recommended (Use PCC patch).
If Mr subgrade is weak - PCC patch required.
If Pumping is evident - PCC patch required.

SECTION 604 – GUIDELINES FOR USE OF THE 1993 AASHTO PAVEMENT DESIGN PROCEDURE

Sec. 604.01 Purpose

These guidelines are intended to aid professional staff knowledgeable in the field of pavement design and evaluation. Persons using these guidelines are responsible for their proper use and application in concert with the AASHTO "Guide for Design of Pavement Structures – 1993". The 1993 AASHTO Guide may be ordered by phone (800-231-3475) or via the internet (www.asshto.org). Virginia Department of Transportation and individuals associated with the development of this material cannot be held responsible for improper use or application.

Sec. 604.02 Flexible Pavement Design

In a true flexible system, the pavement lacks the inherent structural stiffness to resist the bending action of the applied load. Therefore, it merely distributes stresses to the subgrade and relies on the shearing resistance of the soils for its performance. As a consequence, the thickness design of a flexible pavement is based upon the concept of limiting the stress applied to the subgrade so that, under the worst environmental conditions, the subgrade soils' strength is not exceeded.

Generally, a flexible pavement is composed of a series of layers of granular and/or asphalt concrete materials, resting on compacted subgrade soil. The materials most effective in distributing the traffic loads to the subgrade are the base and subbase layers. The thickness of the asphaltic wearing surface may be relatively thin, such as with an asphalt surface treatment, in which case the granular materials provide the bulk of the pavement's load transfer capacity.

As a flexible pavement achieves higher stiffness, it acquires a greater ability to resist the bending action of the load and consequently approaches the limiting condition of the rigid pavement definition. In fact, an asphaltic concrete pavement with high stiffness could easily behave as a rigid slab and exhibit distress (failure) manifestations similar to those of a concrete pavement. In this case, the limiting horizontal strain at the bottom of the asphalt concrete layer must be considered in the pavement design process.

(a) Design Variables

Pavement Design Life

Highway Classification	Initial Construction Design (Years)	Overlay Design (Years)
Interstate	30	12
Divided Primary Route	30	12
Undivided Primary Route	20	10
High Volume Secondary Route	20	10
Farm to Market Secondary Route	20	10
Residential/Subdivision Street	20	10

Traffic Factors

Lane Distribution Factors

Number of Lanes Per Direction	VDOT Value for Pavement Design (%)
1	100
2	90
3	70
4 or more	60

Traffic Growth Rate Calculation

$GR = [AADT_f / AADT_i^{(1/(F-I))} - 1] \times 100$

Where:

GR = Growth Rate (%)

$AADT_f$ = Average annual daily traffic for future year

$AADT_i$ = Average annual daily traffic for initial year

I = Initial year for AADT

F = Future year for AADT

Future AADT Calculation

If an AADT and growth rate is provided, then a future AADT can be calculated using the following equation:

$AADT_f = AADT_I (1+GR/100)^{(F-I)}$

Where:

GR = Growth Rate (%)

$AADT_f$ = Average annual daily traffic for future year

$AADT_i$ = Average annual daily traffic for initial year (year traffic data is provided)

I = Initial year for AADT

F = Future year for AADT

ESAL Factors

When no site specific Weigh in Motion (WIM) or vehicle classification data are available to determine actual 18-kip Equivalent Single Axle Loads (ESAL) factors, use the following values:

Vehicle Classification	ESAL Factor (ESALs/vehicle)
Cars/Passenger Vehicles	0.0002
Single Unit Trucks	0.46
Tractor Trailer Trucks	1.05

If traffic classification or WIM data are available, use Appendix D of the *1993 AASHTO Design Guide for Pavement Structures* to determine ESAL factors.

ESAL Calculation

For the ESAL calculation, use Compound Growth Factors. Assume the Growth in the ESAL Factor is 0%.

Directional Split

For the directional split of truck traffic on a route, assume a 50/50 distribution unless information from Traffic Engineering or other sources are provided.

Reliability

	VDOT Value for Pavement Design	
Highway Classification	Urban	Rural
Interstate	95	95
Divided Primary Route	90	90
Undivided Primary Route	90	85
High Volume Secondary Route	90	85
Farm to Market Secondary Route	85	75
Residential/Subdivision Street	75	70

Serviceability

	VDOT Value for Pavement Design	
Highway Classification	Initial	Terminal
Interstate	4.2	3.0
Divided Primary Route	4.2	2.9
Undivided Primary Route	4.2	2.8
High Volume Secondary Route	4.2	2.8
Farm to Market Secondary Route	4.0	2.5
Residential/Subdivision Street	4.0	2.0

Standard Deviation

For flexible pavements, the standard deviation of 0.49 shall be used.

Stage Construction

This is an option in the Darwin pavement design program, select Stage 1 construction; as it is extremely rare that the funds are committed to a 2nd stage of construction at a set time in the future.

Material Information

Structural Layer Coefficients (New Design and Overlay)

Material	Typical Value
SM-9.0	.44
SM-9.5	.44

Material	Typical Value
SM-12.5	.44
IM-19.0	.44
BM-25.0	.44
SMA 9.5, SMA 12.5, SMA 19.0	.44
Graded Aggregate Base – 21A or 21B	.12
Cement Treated Aggregate Base	.20
Cement Treated Soil (i.e.- soil cement)	.18
Lime Treated Soil	.18
Rubblized Concrete	.18
Break and Seat/Crack and Seat Concrete	.25
Gravel	.10
Open Graded Drainage Layer – Bound	.10
Open Graded Drainage Layer – Unbound	0 – .10
All other soils and subgrade improvements	No Layer Coefficient

<u>AC Material Layer Thickness</u>

Material	Minimum Lift Thickness (in.)	Maximum Lift Thickness (in.)
SM-9.0	0.75	1.25
SM-9.5	1.25	1.5
SMA-9.5	1.25	1.5
SM-12.5	1.5	2
SMA-12.5	1.5	2
SMA-19.0	2	3
IM-19.0	2	3
BM-25.0	2.5	4
BM-37.5	3	6
Asphalt OGDL	2	3
Cement OGDL	4	4

<u>Drainage Coefficients (m)</u>

For most designs, use a value of 1.0. If the quality of drainage is known as well as the period of time the pavement is exposed to levels approaching saturation, then refer to Table 2.4 in the *1993 AASHTO Guide for the Design of Pavement Structures.*

<u>Design Subgrade Resilient Modulus</u>

Resilient Modulus values for a soil may be obtained from laboratory testing, correlations to other soil properties, and from FWD testing. While there are numerous sources, caution must be used when selecting a design resilient modulus. An analysis of all the soils data should be conducted prior to selecting a value.

Laboratory Testing Results

When laboratory testing is performed, an average Resilient Modulus (Mr) should not be used as the design Mr if the coefficient of variance (Cv) is greater than 10%. If the Cv is greater than 10%, then the Pavement Engineer should look at sections with similar Mr values and design those section based on that average Mr. If no sections clearly exist, then use the average Mr times 0.67 to obtain the design Mr. For those locations with an actual Mr less than the design Mr, then the Pavement Engineer should consider a separate design for that location or undercutting the area. More detailed procedures for using laboratory obtained Mr results will be contained in the future revision of this document.

Laboratory Correlations

If resilient modulus results are not available from laboratory testing, then use the following correlations:

For fine-grained soils with a soaked CBR less than 10, use the following equation to correlate CBR to resilient modulus (Mr):

Design Mr (psi) = 1,500 x CBR

For non fine-grained soils with a soaked CBR greater than 10, use the following equation:

$Mr = 3{,}000 \times CBR^{0.65}$

Typical values for fine-grained soils are 2,000 to 10,000 psi.
Typical values for coarse-grained soils are 10,000 to 20,000 psi.

FWD Testing Results

When FWD testing is conducted and the backcalculated resilient modulus is determined, use the following equation:

Design Mr = C x Backcalculated Mr

Where C = 0.33

Selecting Appropriate Mr Value

The design of flexible pavements is extremely sensitive to the design Mr value. The engineer must select the appropriate Mr value to ensure the pavement is not under or over designed. When no laboratory or FWD results are available, the engineer should use the Mr results based on the correlation to the CBR values. If results from FWD testing are available, then the engineer should use these results. CBR data can be used to validate the FWD results; material with a high CBR should have a high resilient modulus; material with a low CBR should have a low resilient modulus. If laboratory results exist and represent all of the soils to be encountered on the project, then these results should be used. If the results do not cover the entire project, then FWD results and laboratory correlations should supplement the laboratory results.

For all pavement designs, if the Design Mr is greater than 15,000 psi, then use a Design Mr value of 15,000 psi. This will prevent the over estimation of the subgrade strength which would lead to a potential pavement underdesign.

Shoulder Design

Typically, paved shoulders have a pavement structural capacity less than the mainline; however, this is dependent on the roadway. For Interstate routes, the pavement shoulder shall have the same design as the mainline pavement. This will allow the shoulder to support extended periods of traffic loading as well as provide additional support to the mainline structure. A full-depth shoulder (same design as the mainline pavement) is also recommended for other high-volume non-interstate routes that are likely to be widened within the life of the mainline pavement.

Where a full-depth shoulder is not necessary, the shoulder's pavement structure should be based on 2.5% of the design ESALs (minimum) for the project following the AASHTO pavement design methodology. A minimum of two AC layers must be designed for the shoulder in order to provide edge support for the mainline pavement structure. The AC layers must be placed on an aggregate or cement stabilized aggregate layer, not directly on subgrade, to provide adequate support and drainage for the shoulder and mainline pavement structures. To help ensure positive subsurface drainage, the total pavement depth of the shoulder should be equal to the mainline structure (i.e. mainline pavement structure thickness above the subgrade is 20 inches, shoulder pavement structure thickness above the subgrade is 20 inches).

Drainage Considerations

The presence of water within the pavement structure has a detrimental effect on the pavement performance under anticipated traffic loads. The following are guidelines to minimize these effects:

Standard UD-2 underdrains and outlets are required on all raised medians. UD-2 underdrains are intended to intercept water that may seep onto the pavement surface at the curb/pavement joint and create a safety hazard. Additionally, UD-2 underdrains can prevent water infiltration through or under the pavement structure. Refer to the current VDOT Road and Bridge Standards for installation details.

When Aggregate Base Material, Type I, Size #21-B is used as an untreated base or subbase, it shall be connected to a longitudinal pavement drain (UD-4) with outlets or day lighted (to the face of the ditch) to provide for positive lateral drainage on all roadways with a design ADT of 1,000 vehicles per day or greater. For super-elevated roadways where day lighting is used, only the lower/down side of the aggregate layer should be extended to the face of the ditch. (Refer to the current VDOT Road and Bridge Standards for installation details.) Other drainage layers can also be used. When the design ADT is less than a 1,000 vehicles per day, the Engineer must assess the potential for the presence of water and determine if sub-surface drainage provisions should be made.

When Aggregate Base Material, Size #21-A is used as an untreated base or subbase material, it should not be used to remove subsurface water by connecting it to a longitudinal underdrain.

Undercutting, transverse drains, stabilization, and special design surface and subsurface drainage installations should be considered whenever necessary to minimize the adverse impacts of subsurface water on the stability and strength of the pavement structure.

Standard CD-1 and CD-2 should be considered for use with all types of unstablized aggregates, independent of the traffic levels.

For roadways with a design ADT of 20,000 vehicles per day or greater, a stabilized drainage layer should be considered, placed on not less than 6 inches of stabilized aggregate material and connected to a UD-4 edge drain. Factors that may influence the selection of OGDL include constructability issues involving maintenance of traffic (e.g. multiple traffic shifts to complete pavement, etc.), numerous entrances that have to be maintained during construction, numerous intersecting streets, etc.

For additional information see Report Number FHWA-TS-80-224, Highway Sub-Drainage Design from the US Department of Transportation, Federal Highway Administration.

Sec. 604.03 Rigid Pavement Design

In a rigid pavement system, the pavement layer(s) is composed of materials of high rigidity and high elastic moduli which distributes a low level of stress over a wide area of the subgrade soil. Consequently, the major factor considered in the thickness design of rigid pavements is the structural strength of the pavement layers(s); i.e. – the concrete itself. Rigid pavements are classified into jointed and continuously reinforced. A jointed plain concrete pavement is an unreinforced pavement structure with joints at certain designated intervals to compensate for expansion and contraction forces and thermally induced stresses. Continuously reinforced concrete pavements, on the other hand, have been designed with sufficient reinforcement to eliminate the need for joints.

Design Variables

Pavement Design Life

Highway Classification	Initial Construction Design (Years)	AC Overlay Design (Years)	PCC Overlay Design (Years)
Interstate	30	10	30
Divided Primary Route	30	10	30
Undivided Primary Route	30	10	30
High Volume Secondary Route	30	10	30

Standard Deviation

For rigid pavements, a standard deviation of 0.39 shall be used.

Traffic Factors

Lane Distribution Factors

Number of Lanes Per Direction	VDOT Value for Pavement Design (%)
1	100
2	90
3	70
4 or more	60

Traffic Growth Rate Calculation

$GR = [(AADT_f / AADT_i)^{(1/(F-I))} - 1] \times 100$

Where:

GR = Growth Rate (%)

$AADT_f$ = Average annual daily traffic for future year

$AADT_i$ = Average annual daily traffic for initial year

I = Initial year for AADT

F = Future year for AADT

Future ADT Calculation

If an AADT and growth rate is provided, then a future AADT can be calculated using the following equation:

$AADT_f = AADT_I (1+GR/100)^{(F-I)}$

Where:

GR = Growth Rate (%)

$AADT_f$ = Average annual daily traffic for future year

$AADT_i$ = Average annual daily traffic for initial year (year traffic data is provided)

I = Initial year for AADT

F = Future year for AADT

ESAL Factors

When no site specific Weigh in Motion (WIM) or vehicle classification data are available to determine actual 18-kip Equivalent Single Axle Loads (ESAL) factors, use the following values:

Vehicle Classification	ESAL Factor (ESALs/Vehicle)
Cars/Passenger Vehicles	0.0002
Single Unit Trucks	0.59
Tractor Trailer Trucks	1.59

ESAL Calculation

For the ESAL Calculation, use Compound Growth Factors. Assume Truck Growth ESAL Factor is 0%.

Directional Split

For the directional split of truck traffic on a route, assume a 50/50 distribution unless information from Traffic Engineering or other sources are provided.

<u>Reliability</u>

VDOT Value for Pavement Design (%)

Highway Classification	Urban	Rural
Interstate	95	95
Divided Primary Route	90	90
Undivided Primary Route	90	85
High Volume Secondary Route	90	85

Serviceability

	VDOT Value for Pavement Design	
Highway Classification	Initial	Terminal
Interstate	4.5	3.0
Divided Primary Route	4.5	2.9
Undivided Primary Route	4.5	2.8
High Volume Secondary Route	4.5	2.8

Material Information

28-Day Mean PCC Modulus of Rupture (psi)

Typical Range – 600 to 800 VDOT Value for Pavement Design – 650

Use default value if actual value is not available. Where possible, use value base on historical data.

28-Day Mean PCC Modulus of Elasticity (psi)

Typical Range – 3,000,000 to 8,000,000 VDOT Value for Pavement Design – 5,000,000

Use default value if actual value is not available. Where possible, use value base on historical data.

Mean Effective k-value (psi/inch)

Typical Range – 50 to 500 VDOT Value for Pavement Design – 250

If the subgrade resilient modulus is known or obtained from correlation with CBR testing, then use the following equation:

k-value = Mr / 19.4

Caution must be used when selecting a design k-value based on resilient modulus and CBR. An analysis of all the soils data should be conducted prior to selecting a value. An average Resilient Modulus (Mr) should not be used as the design Mr if the coefficient of variance (Cv) is greater than 10%. If the Cv is greater than 10%, then the Pavement Engineer should look at sections with similar Mr values and design those section based on that average Mr. If no sections clearly exist, then use the average Mr times 67% to obtain the design Mr. For those locations with an actual Mr less than the design Mr, then the Pavement Engineer should consider a separate design for that location or undercutting the area.

If the k-value is obtained from backcalculation, then use this value.

If the k-value (based on backcalculation or subgrade resilient modulus) is larger than 500, then use 500 as the design value.

Subdrainage Coefficient

For most designs, use a value of 1.0. If the quality of drainage is known as well as the period of time the pavement is exposed to levels approaching saturation, then refer to Table 2.4 in the *1993 AASHTO Guide for the Design of Pavement Structures.*

Load Transfer Factors

New Pavement Designs and Unbonded PCC Overlays with Load Transfer Devices

	VDOT Value for Design	
Pavement Type	Asphalt Shoulder	Tied PCC Shoulder or Wide Lane
Jointed Plain	3.2	2.7
Continuously Reinforced	3.0	2.6

Overlays Designs on Existing Pavements

For AC overlays on existing PCC pavements and bonded PCC overlays, determine the appropriate J-Factor based on the load transfer efficiency determined from joint/crack testing.

Pavement Type	Load Transfer Efficiency	Design J-Factor
Jointed Plain	> 70%	3.2
	50 – 70%	3.5
	< 50%	4.0
Jointed Reinforced	> 70%	3.2
	50 – 70%	3.5
	< 50%	4.0
Continuously Reinforced		2.4 (working cracks repaired with CRCP)

Shoulder Design

Typically, paved shoulders have a pavement structural capacity less than the mainline; however, this is dependent on the roadway. For Interstate routes, the pavement shoulder shall have the same design as the mainline pavement. This will allow the shoulder to support extended periods of traffic loading as well as provide additional support to the mainline structure. A full-depth shoulder (same design as the mainline pavement) is also recommended for other high-volume non-interstate routes that are likely to be widened within the life of the mainline pavement.

Two types of shoulders are designed for Portland cement concrete highways – full-width concrete shoulders, narrow-width concrete section with an asphalt concrete extension, or an asphalt shoulder. For full-width concrete shoulders, the pavement shoulder shall have the same design as the mainline pavement. This will allow the shoulder to support extended periods of traffic loading as well as provide additional support to the mainline structure.

A narrow-width concrete section with an asphalt concrete extension shoulder is constructed when a wide concrete lane (14 feet) is part of the mainline pavement. Twelve feet of the fourteen-foot wide slab is part of the outside travel lane, the remaining two feet is striped and designated as part of the shoulder. The two-foot section of concrete has the same structure as the twelve-foot section; therefore, no separate pavement design is necessary. For the asphalt concrete portion of the shoulder and other asphalt concrete shoulders not located on Interstates or high-volume routes, the shoulder's pavement structure should be based on 2.5% of the design ESALs (minimum) for the project following the AASHTO pavement design methodology. A minimum of two AC layers must be designed for the shoulder. The AC layers must be placed on an aggregate or cement stabilized aggregate layer, not directly on subgrade, to provide adequate support and drainage for the shoulder structure. To help ensure positive subsurface drainage, the total pavement depth of the shoulder should be equal to the mainline structure (i.e. mainline pavement structure thickness above the subgrade is 20 inches, shoulder pavement structure thickness above the subgrade is 20 inches). When the asphalt shoulder is constructed on an Interstate or high-volume roadway, the depth of the asphalt layers shall be the same as the depth of the Portland Cement Concrete slab.

Drainage Considerations

The presence of water within the pavement structure has a detrimental effect on the pavement performance under anticipated traffic loads. The following are guidelines to minimize these effects:

Standard UD-2 underdrains and outlets are required on all raised medians. UD-2 underdrains are intended to intercept water that may seep onto the pavement surface at the curb/pavement joint and create a safety hazard. Additionally, UD-2 underdrains can prevent water infiltration through or under the pavement structure. Refer to the current VDOT Road and Bridge Standards for installation details.

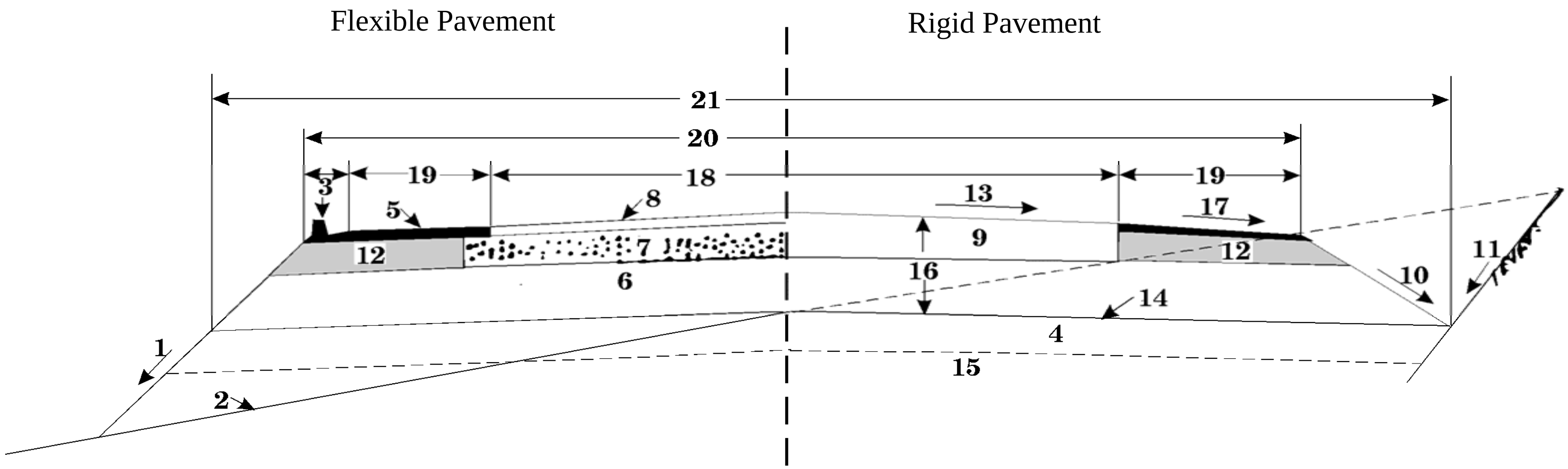
When Aggregate Base Material, Type I, Size #21-B is used as an untreated base or subbase, it shall be connected to a longitudinal pavement drain (UD-4) with outlets or day lighted (to the face of the ditch) to provide for positive lateral drainage on all roadways with a design ADT of 1,000 vehicles per day or greater. For super-elevated roadways where day-lighting is used, only the lower/down side of the aggregate layer should be extended to the face of the ditch. (Refer to the current VDOT Road and Bridge Standards for installation details.) Other drainage layers can also be used. When the design ADT is less than a 1,000 vehicles per day, the Engineer must assess the potential for the presence of water and determine if sub-surface drainage provisions should be made.

When Aggregate Base Material, Size #21-A is used as an untreated base or subbase material, it should not be used to remove subsurface water by connecting it to a longitudinal underdrain.

Undercutting, transverse drains, stabilization, and special design surface and subsurface drainage installations should be considered whenever necessary to minimize the adverse impacts of subsurface water on the stability and strength of the pavement structure.
Standard CD-1 and CD-2 should be considered for use with all types of unstablized aggregates, independent of the traffic levels.

For roadways with a design ADT of 20,000 vehicles per day or greater, a stabilized drainage layer should be considered, placed on not less than 6 inches of stabilized aggregate material and connected to a UD-4 edge drain. Factors that may influence the selection of OGDL include constructability issues involving maintenance of traffic (e.g. multiple traffic shifts to complete pavement, etc.), numerous entrances that have to be maintained during construction, numerous intersecting streets, etc.

For additional information see Report Number FHWA-TS-80-224, Highway Sub-Drainage Design from the US Department of Transportation, Federal Highway Administration.



1.	Fill Slope	12.	Shoulder Base
2.	Original Ground	13.	Pavement Cross Slope
3.	Curb or Curb and Gutter	14.	Subgrade
4.	Select Material or Prepared Roadbed	15.	Roadbed Soil
5.	Shoulder Surfacing	16.	Pavement Structure
6.	Subbase	17.	Shoulder Cross Slope
7.	Base Course	18.	Travel Lanes
8.	Surface Course	19.	Shoulder
9.	Pavement Slab	20.	Roadway
10.	Ditch Front Slope	21.	Roadbed
11.	Cut Slope		

Diagram 8 – Pavement Definitions

SECTION 605 – ASPHALT CONCRETE MIX SELECTION GUIDELINES

Sec. 605.01 Purpose of Guidelines

The guidelines provided herein are intended to aide the user in recommending mix types for asphalt overlays of flexible and rigid pavement, and new construction based on specific traffic and environmental conditions expected. These guidelines should be used as part of, or in conjunction with an engineering analysis of the pavement section. These guidelines are not intended to address pavement distress mechanisms, structural inadequacy of the pavement, existing pavement defects or other types of pavement deficiencies. It is the responsibility of the user to conduct an analysis/evaluation of the existing or expected pavement conditions prior to using this guide. Failure to do so could significantly affect the performance and service life of the materials and mixes selected.

These guidelines are applicable to VDOT projects. While the guidelines could be used for non-VDOT work with similar conditions, experience and engineering judgment should be exercised for such application.

These guidelines indicate the general highway conditions under which each mix should be used. Generally, a single mix type is used for all lanes in a single direction of a roadway. The asphalt binder type ESAL (Equivalent Single Axle load) range is based on an expected service life and is used in conjunction with the mix type's nominal maximum aggregate size in this guide. Traffic speed, vehicle types and volume should also be considered in the selection of a mix type. These considerations may warrant the use of a stiffer binder. Experience and judgment should be used in selecting the appropriate mixes to be used. Each District may implement a simple guide chart to eliminate those mixes that are not needed in their area.

Sec. 605.02 – Description of asphalt Concrete mixes

Numerous asphalt mixes are used in Virginia. These mixes are designed to perform different functions within the pavement structure. Mixes vary based on nominal maximum aggregate size, aggregate gradation, asphalt binder content and other variables just to name a few. The following sections describe common asphalt mixes used in Virginia.

(a) Dense Graded Mixes

Dense graded mixes, also known as SUPERPAVE™, are asphalt mixes with a uniform distribution of aggregate sizes along the maximum density line. These mixes can be "fine" or "coarse" graded depending on whether the aggregate gradations are above or below the maximum density line. Dense graded mixes are identified based on the nominal maximum aggregate size. The nominal maximum aggregate size is defined as one sieve size larger than the first sieve to retain more than 10 percent aggregate as shown in the design range specified in Section 211.03, Table II-13 of the Road and Bridge Specifications. [It is important to note that while Virginia uses US Customary units for constructing projects, asphalt mixes are identified based on the metric sieve equivalent (i.e. 9.5mm, 12.5mm, 19.0mm and 25.0mm).] Three different families of dense graded mixes are used in Virginia – surface, intermediate and base. A description of each family and the associated asphalt mix(s) are provided in the following section.

(1) Surface Mixes

Surface mixes serve as both functional and structural layers of the pavement structure. Surface mixes are directly exposed to traffic and the environment. They must provide a smooth, stable, safe (i.e. skid resistance) riding surface, and promote surface water drainage. In addition, they serve to prevent the entrance of excessive quantities of water into the underlying HMA layers, bases and subgrade. The surface layer normally contains the highest quality materials. In most instances, only one surface mix lift will be placed on a project. VDOT has three predominant dense graded surface mixes. Surface mixes are given the SM-XY.Z designation in contracts, specifications and special provisions where SM stands for surface mix and XY.Z denotes the nominal maximum aggregate size.

SM-9.0 This mix is a 'fine' (3/8 inch (9.5 mm) nominal maximum aggregate size) surface mix generally placed at 1 inch (25 mm) thickness. This mix is generally used in subdivisions and low volume pavements with little or no heavy vehicle traffic (trucks, buses) as a final riding surface. This mix should never be placed directly on aggregate base material; it is recommended to be placed on a minimum of 2 inches (50 mm) of a larger nominal maximum aggregate surface, intermediate or base mix.

SM-9.5 This mix is a 'fine' to 'medium' (3/8 inch (9.5 mm) nominal maximum aggregate size) surface mix generally placed at 1 ½ inches (40 mm) thickness. SM-9.5 mixes usually result in low water permeability values. This mix tends to be less susceptible to segregation than the SM-12.5 mix type described below. **SM-9.5 surface mixes can be considered the desired surface mix and are recommended for most final surface applications**.

SM-12.5 This mix is a 'medium' to 'coarse' (½ inch (12.5 mm) nominal maximum aggregate size) surface mix generally placed at 2 inches (50 mm) thickness. Depending on the aggregate gradation, this mix is more suited for roadways that need additional structural capacity to handle traffic loads. This mix tends to have higher permeability values when compared to a SM-9.5.

(2) Intermediate Mix

The intermediate mix, sometimes called binder course, consists of one or more lifts of structural asphalt concrete placed below the surface layer. Its purpose is to distribute traffic loads so that stresses transmitted to the pavement foundation will not result in permanent deformation of that layer. Additionally, it facilitates the construction of the surface layer. Designed with larger aggregates, the intermediate layer is intended to provide resistance to rutting and to intercept top-down fatigue cracking. In most instances, only one intermediate mix lift will be used on a project. Intermediate mixes are given the IM-XY.Z designation in contracts, specifications and special provisions where IM stands for intermediate mix and XY.Z denote the nominal maximum aggregate size.

IM-19.0 This mix is a 'coarse' (3/4 inch (19.0 mm) nominal maximum aggregate size) mix generally placed at 2 inches (50 mm) thickness. This mix can handle public traffic during construction for an extended period of time and allows for later application of a surface mix to provide a final wearing surface. In certain cases where structure is of a prime concern or traffic loadings are extreme, this mixture may be designated as a **SM-19.0** mixture and used as a final surface course, which requires a non-polishing aggregate when used as the final surface.

(3) Base Mix

As the name implies, the base mix is the base asphalt layer for the pavement structure. Its major function is to provide the principal support of the pavement structure. The base mix uses the largest aggregate particles to provide resistance to rutting and to bottom-up fatigue cracking. Unlike surface mixes, more than one lift of base mix may be placed on a project to obtain the designed base layer thickness. Base mixes are given the BM-XY.Z designation in contracts, specifications and special provisions where BM stands for base mix and XY.Z denotes the nominal maximum aggregate size.

BM-25.0 This mix is a 1 inch (25.0 mm) nominal maximum aggregate size mix generally placed at 3 inches (75 mm) or greater thickness. Depending on the aggregate gradations and placement procedures, this base does not usually require placement of an intermediate course to provide a platform for placement of a smooth wearing surface. Public traffic should not be permitted on this material for extended periods of time without restrictions**.**

(b) Gap Graded Mixes

Gap graded mixes, are asphalt mixes with a non-uniform distribution of aggregate sizes. Stone Matrix Asphalt (SMA) is the only gap graded mix in Virginia. These mixes contain aggregates retained on the upper and lower sieves, but with little aggregate retained on the middle sieves. As with dense graded mixes, gap graded mixes (SMA) are identified based on the nominal maximum aggregate size. Two families of gap graded mixes are used in Virginia – surface and intermediate.

SMA is composed of a gap-graded aggregate that maximizes rutting resistance and durability with a stable stone-on-stone skeleton held together by a rich mixture of asphalt binder (specified PG grading), filler and stabilizing agents such as fibers. This mix is for use on heavy to extreme heavy traffic volume routes where the expected higher cost can be justified with improved performance over other mixes. SMAs are recommended for placements of a minimum of 5,000 tons and only in heavy traffic conditions due to their higher cost and special considerations in their design, production, and placement.

A description of each family and the associated asphalt mix(s) are provided in the following section. All gap graded mixes are given the designation SMA-XY.Z(binder type) in contracts, specifications and special provisions where SMA stands for stone matrix asphalt, XY.Z denotes the nominal maximum aggregate size, and (binder type) denotes the binder to be used.

(1) Surface Mixes

VDOT has two SMA surface mixes.

SMA-9.5 This mix is a ‘fine’ to ‘medium’ (3/8 inch (9.5 mm) nominal maximum aggregate size) surface mix generally placed at 1 ½ inches (40 mm) thickness. SMA 9.5 surface mix is recommended for final surface applications on high traffic volume and high truck volume routes.

SMA-12.5 This mix is a ‘medium’ (½ inch (12.5 mm) nominal maximum aggregate size) surface mix generally placed at 2 inches (50 mm) thickness. SMA 12.5 surface mix is recommended for final surface applications on high traffic volume and high truck volume routes.

(2) Intermediate Mix

In most instances, only one intermediate mix lift will be used on a project. When rigid pavement is overlaid, more than one intermediate mix lift may be used.

SMA-19.0 This mix is a 'medium' to 'coarse' (¾ inch (19.0 mm) nominal maximum aggregate size) mix generally placed at 2 inches (50 mm) thickness. SMA 19.0 mixes are recommended for intermediate applications on high traffic volume and high truck volume routes.

(3) Base Mix

VDOT does not have any SMA Base Mix designation. If a base mix is desired for use with SMA, use a dense graded Base mix.

(c) Specialty Mixes

While the vast majority of asphalt placed in Virginia is either dense graded or gap graded, VDOT does use some specialty mixes. These mixes are designed to provide specific functions in the pavement structure. Below is a description of two mixes used in Virginia.

Thin Hot Mix Asphalt Overlay (THMACO) This mix is a 'fine' to 'medium' (3/8 inch (9.5 mm) nominal maximum aggregate size) surface mix generally placed at 3/4 inch (19 mm) thickness. THMACO is a gap graded hot mix asphalt applied atop a polymer-modified emulsion membrane and it is used for final surface applications as a functional overlay on flexible and rigid pavements. THMACO is primarily used for pavement preservation.

Open Graded Drainage Layer (OGDL) is a 'medium' (¾ inch (19.0 mm) nominal maximum aggregate size) mix generally placed at 2 inches (50 mm) thickness. This mix has very little fine aggregate material to allow for the movement of water. It is used as part of a pavement drainage system. Guidelines on use of OGDL can be found in Section 604.

Sec. 605.03 VDOT Asphalt Binders

As with the asphalt mixes, VDOT typically uses letters to designate asphalt binders in contracts, specifications and special provisions. For dense graded mixes, asphalt binder designations A, D and E are used. Mix stiffness generally increases from 'A' to 'E', with 'A' being the softest. For gap graded asphalt concrete, no letter designation is used in contracts, specifications and special provisions. In the specifications and special provisions for specialty mixes, the asphalt binder is declared. The following sections defined each asphalt binder.

(a) Dense Graded Mix Binder Letter Designations

'A' - The 'A' designation corresponds with a Performance Graded (PG) asphalt binder of PG 64-22. Surface asphalt mix types using the 'A' binder designation are intended to experience 0 to 3 million cumulative equivalent single axle loads (ESALs); intermediate mix types up to 10 million ESALs; and base mix types up to 20 million cumulative ESALs over a specified service life. See Table 1 in Section 605.04 for service life per mix type and Section 604 for the procedure to determine cumulative ESALs. This designation should perform well in low to medium traffic loading situations.

'D' - The 'D' designation corresponds with a Performance Graded (PG) asphalt binder of PG 70-22. Surface asphalt mix types using the 'D' binder designation are intended to experience 3 to 10 million cumulative equivalent single axle loads (ESALs); intermediate mix types between 10 and 20 million ESALs; and base mix types exceeding 20 million cumulative ESALs over a specified service life. See Table 1 in Section 605.04 for service life per mix type and Section 604 for the procedure to determine cumulative ESALs. This designation should perform well in medium to high traffic loading situations.

'E' - The 'E' designation corresponds with a Performance Graded (PG) asphalt binder of PG 76-22 with polymer modification. Surface asphalt mix types using the 'E' binder designation are intended to experience in excess of 10 million cumulative equivalent single axle loads (ESALs) and intermediate mix types above 20 million ESALs over a specified design life. In general applications, the 'E' binder designation is not used in a base mix. See Table 1 in Section 605.04 for service life per mix type and Section 604 for the procedure to determine cumulative ESALs. Mixes with this binder designation should perform well in high to extremely high traffic loading situations. The stiffness of mixes using this binder should not be used as a substitute for deficient pavement structure (high deflections under traffic loadings will destroy any pavement structure).

(S) Stabilized - designation indicates the use of a PG 64-22 binder with an approved stabilizing additive from the Department's approved list in the Materials Division Manual of Instructions. This designation can be used in extreme traffic loading situations. This designation does not provide resistance to reflective cracking. This designation should only be combined with 'A' mixes.

(b) Gap Graded and Specialty HMA Binders

PG 70-22 – Like the 'D' designation for dense graded mixes, this binder is the Performance Graded (PG) 70-22. Surface asphalt mix types using the PG 70-22 binder are intended to experience 3 to 10 million cumulative equivalent single axle loads (ESALs) and intermediate mix types between 10 and 20 million ESALs over a specified service life. See Table 1 in Section 605.04 for service life per mix type and Section 604 for the procedure to determine cumulative ESALs. This binder should perform well in medium to high traffic loading situations and over continuously reinforced concrete pavement.

PG 76-22 – Like the 'E' designation for dense graded mixes, this binder is the Performance Graded (PG) 76-22 with polymer modification. Surface asphalt mix types using the 'E' binder are intended to experience in excess of 10 million cumulative equivalent single axle loads (ESALs) and intermediate mix types above 20 million ESALs over a specified service life. In general applications, the PG 76-22 asphalt binders are not used in a base mix. See Table 1 in Section 605.04 for service life per mix type and Section 604 for the procedure to determine cumulative ESALs. These designations should perform well in high to extremely high traffic loading situations and over jointed concrete pavement. The stiffness of this mix should not be used as a substitute for deficient pavement structure (high deflections under traffic loadings will destroy any pavement structure).

PG 70-28 – This binder is a polymer modified Performance Graded (PG) 70-28. The purpose of this binder is to resist thermal cracking and minimize reflective cracking over jointed concrete pavement.

Sec. 605.04 Asphalt Binder and Mix selection – General Applications

When making a determination regarding which asphalt mix type to use, the cumulative ESALs must be calculated and the pavement type must be known (new construction, existing flexible pavement or existing rigid pavement). The expected service life of the asphalt layer is necessary to calculate cumulative ESALs for selecting the mix type to use. The service life of the layer is a function of the layer's position within the pavement's structure and the asphalt mix as described in Section 605.02. Table 1 provides the expected service life for each layer.

NOTE: Preliminary analysis and field experience indicate gap graded mixes generally outperform conventional mixes; therefore, justifying the additional cost for the gap graded mixes. Further investigation will be performed to quantify the actual service life of each mix and calibrate the pavement models.

Layer	Expected Life (yrs) New Const.	Overlay	Comments
Surface	12	12	10 yrs for 2 Lane Roads for dense graded mixes
Intermediate	20	20	
Base	30	30	Generally an 'A' mix is used for most applications

Table 5 – Expected Service Life by Asphalt Layer

(a) Asphalt Binder Selection

Once the expected service life is selected, then the cumulative equivalent single axle loads (ESALs) must be calculated for selecting the appropriate binder. (Refer to Section 604 of the Manual of Instructions for the procedure in calculating cumulative ESALs.) Tables 2 through 6 summarize the binder selection process based on pavement layer, cumulative ESALs and pavement type. Note: the suggested binder is stiffer for overlay of rigid pavements than flexible pavements for equivalent ESAL levels.

(b) Asphalt Mix Selection

During the pavement evaluation and design process, a total asphalt thickness is determined. From this thickness, a series of asphalt lifts are used to construct the pavement structure. For the base layer, one or more lifts may be required. VDOT has one base mix, BM-25.0, for use in construction, reconstruction or major rehabilitation

VDOT has two intermediate and five surface mixes for use in construction, reconstruction or rehabilitation. Tables 2 through 6 summarize the mixes available for various layers based on cumulative ESALs and pavement type.

Cumulative ESALs	Mix Designation	Rigid Pavement Overlays	
	Flexible Pavements	Jointed	Continuously Reinforced
0 – 3 million	SM-9.0A or SM-9.5A	SM-9.5D or SM-12.5D	SM-9.5D or SM-12.5D
3 to 10 million	SM-9.5D or SM-12.5D	SM-9.5E or SM-12.5E	SM-9.5D or SM-12.5D
> 10 million	SM-9.5E or SM-12.5E	SM-9.5E or SM-12.5E	SM-9.5D or SM-12.5D

Table 6 – Dense Graded Surface Selection

Cumulative ESALs	Mix Designation		
	Flexible Pavements	Rigid Pavement Overlays	
		Jointed	Continuously Reinforced
0 – 3 million	IM-19.0A	IM-19.0D	IM-19.0D
3 to 10 million	IM-19.0A	IM-19.0E	IM-19.0D
> 10 million	IM-19.0D	IM-19.0E	IM-19.0D

Table 7 – Dense Graded Intermediate Selection

Cumulative ESALs	Mix Designation		
	Flexible Pavements	Rigid Pavement Overlays	
		Jointed	Continuously Reinforced
0 to 20 million	BM-25.0A	BM-25.0A	BM-25.0A
> 20 million	BM-25.0D	BM-25.0D	BM-25.0D

Table 8 – Dense Graded Base Selection

Cumulative ESALs	Mix Designation		
	Flexible Pavements	Rigid Pavement Overlays	
		Jointed	Continuously Reinforced
0 – 3 million	NR	NR	NR
3 to 10 million	SMA-9.5(70-22) or SMA-12.5(70-22)	SMA-9.5(76-22) or SMA-12.5(76-22)	SMA-9.5(70-22) or SMA-12.5(70-22)
> 10 million	SMA-9.5(70-22)* or SMA-12.5(70-22)*	SMA-9.5(76-22) or SMA-12.5(76-22)	SMA-9.5(70-22) or SMA-12.5(70-22)

NR – Gap graded mixes are not recommended

* Consideration to use of a PG 76-22 binder should be given when the Cumulative ESALS are greater than 20 million.

Table 9 – Gap Graded (SMA) Surface Selection

Cumulative ESALs	Mix Designation		
	Flexible Pavements	Rigid Pavement Overlays	
		Jointed	Continuously Reinforced
0 – 3 million	NR	NR	NR
3 to 10 million	SMA-9.5(70-22) or SMA-12.5(70-22)	SMA-9.5(76-22) or SMA-12.5(76-22)	SMA-9.5(70-22) or SMA-12.5(70-22)
> 10 million	SMA-9.5(70-22)* or SMA-12.5(70-22)*	SMA-9.5(76-22) or SMA-12.5(76-22)	SMA-9.5(70-22) or SMA-12.5(70-22)

NR – Gap graded mixes are not recommended

Table 10 – Gap Graded (SMA) Intermediate Layer Selection

Sec. 605.05 Asphalt Binder and Mix selection – Specialized locations

There will be times when a designer needs to select binder and mix types in areas with high truck percentages and slow speeds, excessive grades (>6%) and standing traffic which result in extreme pavement loadings. Some examples of theses areas are truck climbing lanes, quarry roads, or truck parking areas. In these situations, the designer should select a binder with high stiffness to resist movement under load. To aide the designer, Table 7 lists the mixes that can be used in the extreme loading situations.

Mix Type	Surface	Intermediate	Base
Truck Climbing Lane and Roads with Excessive Grades (>6%)	SM-9.5E SM-12.5E SM-19.0D SMA-9.5 (76-22) SMA-12.5 (76-22)	IM-19.0D IM-19.0E SMA-19.0 (76-22)	BM-25.0D
Industrial Route, Quarry	SM-9.5D SM-9.5E SM-12.5D SM-12.5E	IM-19.0D IM-19.0E	BM-25.0A BM-25.0D
Truck Parking Area	SM-9.5E SM-12.5E	IM-19.0D IM-19.0E	BM-25.0D
Intersections with Heavy Truck Percentage	SM-9.5E SM-12.5E	IM-19.0D IM-19.0E	BM-25.0D
Heavy Urban Traffic with Buses	SM-9.5E SM-12.5E	IM-19.0D IM-19.0E	BM-25.0D

Table 11 – Specialized Pavement Locations

Sec. 605.06 Application Rates

The normal application rate for a single lift thickness for the various mixes is shown in Table 8. Deviations to the normal application rate should be done in accordance with Section 315.05 (c) of the Road and Bridge Specifications.

Asphalt Concrete Mixes	Nominal Maximum Aggregate Size	Normal Application Rate Note 1
Surface Mix		
SM-9.0	3/8 inch (9.5 mm)	1 inch – 110 lb/ yd^2 (25.0 mm – 60 kg/m^2)
SM-9.5	3/8 inch (9.5 mm)	1.5 inch - 165 lb/yd^2 (40.0 mm – 90 kg/m^2)
SM-12.5	1/2 inch (12.5 mm)	1.5 inch - 165 lb/yd^2 (40.0 mm – 90 kg/m^2)
SM-19.0	3/4 inch (19.0 mm)	2 inch – 220 lb/yd^2 (50.0 mm – 125 kg/m^2)
SMA-9.5	3/8 inch (9.5 mm)	1.5 inch - 165 lb/yd^2 (40.0 mm – 90 kg/m^2)
SMA-12.5	1/2 inch (12.5 mm)	1.5 inch - 165 lb/yd^2 (40.0 mm – 90 kg/m^2)
Intermediate Mix		
SMA 19.0 (intermediate)	1/2 to 1 inch (12.5 to 19.0mm) Note 2	2 inch – 220 lb/yd^2 (50.0 mm – 125 kg/m^2)
IM-19.0	3/4 inch	2 inch – 220 lb/yd^2

Asphalt Concrete Mixes	Nominal Maximum Aggregate Size	Normal Application Rate [Note 1]
Surface Mix		
	(19.0 mm)	(50.0 mm – 125 kg/m^2)
Base Mix		
BM-25.0	1 inch (25.0 mm)	3.0 inch[Note 3] (75.0 mm)
Open Graded Drainage Layer		
OGDL	--	2.0 inch (50 mm)
Thin Hot Mix Asphalt Concrete		
THMACO	--	3/4 inch (19.0 mm)

Note 1 Application rate is based upon 110 pounds per square yard per inch (2.35 kilograms per square meter per millimeter) of thickness.

Note 2 SMA Intermediate design criterion allows the mixture to meet the definition of either nominal maximum aggregate size.

Note 3 Application rate for BM Type mixes should be determined from the actual specific gravity of the mixture as called for by the Materials Division or by region as indicated in Table 9.

Table 12 – VDOT Mix Comparison Table

<u>Sec. 605.07 Typical asphalt Base mix application rates</u>

Table 9 should be used to determine the approximate quantity of base asphalt for construction and maintenance program projects. This table contains the average weight for the base mix based on the aggregate present in the District.

VIRGINIA DEPARTMENT OF TRANSPORTATION WEIGHT OF BASE ASPHALT MIXES FOR APPROXIMATE QUANTITY CALCULATIONS

DISTRICT	AREAS	Mass kg/m^2/mm	Lbs/S.Y./In
Bristol	Abingdon-Marion-Wytheville-Galax	2.46	115
	Bluefield-Big Stone Gap-Woodway-Bristol	2.39	112
Salem	Buchanan-Roanoke-Salem-Radford-Martinsville	2.43	114
	Lynchburg	2.41	113
Lynchburg	Danville	2.35	110

VIRGINIA DEPARTMENT OF TRANSPORTATION WEIGHT OF BASE ASPHALT MIXES FOR APPROXIMATE QUANTITY CALCULATIONS

DISTRICT	AREAS	Mass $kg/m^2/mm$	Lbs/S.Y./In
	South Boston	2.37	111
Richmond		2.35	110
Hampton Roads		2.35	110
Fredericksburg		2.35	110
Culpeper	Charlottesville	2.52	118
	Culpeper - Flint Hill	2.41	113
Staunton		2.39	112
NOVA	Arlington - Fairfax	2.61	122

Table 13 – Application Rates for Asphalt Base Mix

SECTION 606 – PAVEMENT TYPE SELECTION

Sec. 606.01 Definitions

Pavement Type Selection:

The process of determining the most cost effective pavement type that is capable of supporting the anticipated traffic under the prevailing environmental conditions, and provides the safety and comfort to the traveling public of Virginia highways.

Pavement Design:

The process of selecting a practical and economical combination of materials of known strength and adequate thicknesses to support anticipated traffic under the prevailing environmental conditions. The process also provides for the determination of alternate structures using a variety of materials and construction procedures.

Design Period:

The period of time elapsed as initial pavement structure deteriorates from its initial to its terminal serviceability. This is used to determine the pavement structure (typically 30 years) for both asphalt and concrete pavements, interstate and primary roads. (See "Guidelines for 1993 AASHTO Pavement Design" (May 2000) for more details).

Analysis Period:

The period of time for which the life cycle cost analysis is conducted and used for economic analysis. During this analysis period, AASHTO recommends at least one major-rehabilitation activity. Therefore, VDOT has adopted a 50-year analysis period for all pavement types.

For asphalt pavements the following noise reducing technology should be considered, where applicable:

1. Use of gap graded asphalt concrete surface mix such as Porous Friction Course (PFC) or THMACO
2. Use of finer SMA (i.e., SMA 9.5) at the surface

For Portland Cement Concrete pavement, the following noise reducing technology should be considered, where applicable:

1. Longitudinal tinning of the finished concrete
2. Diamond grinding of the finished concrete
3. Use of a gap graded asphalt concrete surface mix or SMA at the finished surface

Sec. 606.02 Introduction

This document will briefly describe the procedures used by VDOT in selecting a pavement type for a project.

Pavement Evaluation

For projects where the existing pavement will be utilized, the structural and functional condition of the pavement must be determined. The following evaluation processes may be utilized:

Falling Weight Deflectometer Testing for Structural Capacity

Visual Condition and Patching Survey

Pavement Coring and Subgrade Boring

Laboratory Material Testing

Pavement Design

For projects requiring a functional or structural improvement, VDOT's Pavement Designer will perform pavement designs as well as specify any maintenance to be performed. The pavement designs will be based on current AASHTO procedures. The Pavement Designer will use data collected in Pavement Evaluation phase to determine the current pavement condition and future requirements based on anticipated traffic. Where possible the Pavement Designer will develop multiple alternatives for a project in order to perform life cycle cost comparisons. The Pavement Designer should consider changing maintenance approaches (more vs. less patching), changing overlay thickness, changing milling thickness, changing materials, etc. For new projects, the pavement will be designed to accommodate future traffic based on the project's location and materials.

The following sections describe the design considerations and methods used by VDOT Pavement Designers.

Design considerations:

For all projects, most of the following design considerations should be incorporated into a pavement recommendation:

Pavement performance (Structural, functional, safety)
Traffic – existing and predicted
Roadbed soil
Materials of construction
Environment
Drainage
Reliability
Life cycle costs

Design Methods:

In Virginia, two pavement design methods are normally used. For Interstate, Primary and High-Volume Secondary Routes, the AASHTO Pavement Design Approach is required. For Low-Volume Secondary and Sub-division streets, the Virginia and AASHTO methods are acceptable.

Input parameters

AASHTO Method

An empirical method based on the AASHO Road Test. The following parameters are needed to develop a pavement design for flexible pavements:

- Resilient modulus for the subgrade

- Cumulative ESAL'S for the design life of the pavement.
- Drainage coefficient for unbound materials
- Reliability level
- Overall standard deviation
- Serviceability

For concrete pavement additional parameters are used:
- Modulus of subgrade reaction
- Elastic modulus of concrete
- Modulus of rupture of concrete
- Load transfer factor

These parameters are documented in the "AASHTO Guide for Design of Pavement Structures" (Rev. 1993) and elsewhere in Chapter 6. Several programs including DARWin (Pavement Design Analysis and Rehabilitation for Windows) and WinPAS are used.

Virginia Method
- California Bearing Ratio (CBR)
- Resiliency Factor
- Traffic is terms of the Equivalent Single Axle Loads (ESAL's) also known as 18 kip (18,000 Lbs Single Axle Loading) projected to the mid design period of 30 years for primary and interstate roads.
- Thickness Equivalency Factor, which is the relative index of strength the material contributes per inch of pavement depth. It can be defined as the ratio of the strength of one inch thickness of the material to that of one inch of asphalt concrete.

These parameters yield a structural number or total thickness of pavement. The determination of the individual layer thicknesses is achieved using the thickness equivalency factors and the most practical layer thickness for constructability.

The computer program Flex-pd 2000 allows the designer to input the cost of each material and to choose from a list of different materials.

The above procedure is documented in the "Flexible Pavement Design Guide for Primary and Interstate Roads in Virginia" (Rev. Jan 1995) also documented in the "Pavement Design Guide for Subdivision and Secondary Roads in Virginia" (Rev. August 2000).

Output parameters:

Output for Flexible Pavement, whether from the Virginia Method or AASHTO, yields a structural number for the total pavement and the individual layer thicknesses. For rigid pavement design, AASHTO yields a slab thickness for concrete pavement.

Initial Cost Estimates

Cost estimates for paving materials can be obtained from the Information Systems Division using their computerized Engineering Estimate System. This system derives unit costs from a historical database of bid tabulations. For an updated cost estimate on unique projects that do not match the information in the data base, Programming and Scheduling Division is contacted and estimates are verified.

Life Cycle Cost Analysis: (LCCA)

For projects that meet the criteria in SECTION 607.02 for conducting a life cycle cost analysis (LCCA), it is used to examine the economic worth of each pavement type. It consists of the initial cost estimate of the paving materials and the future maintenance activities necessary to maintain the road at an acceptable serviceability level to the traveling public. These activities cover maintaining the pavement quality, namely smoothness and safety in terms of non-skidding, and the structural capacity, namely the elimination of cracks, faulting, potholes, and rutting. Present worth approach is used to represent the translation of specified amounts of costs or benefits occurring in different time periods into a single amount at a single instant (usually the present).

Since pavement type selection is not an exact science but one which the highway engineer must make an engineering judgment a difference up to 10% in Life Cycle Cost Analysis (LCCA), net present worth, shall not be considered as the sole reason for selecting pavement type. In this case engineering judgment shall be used to select pavement type.

For more information on LCCA, please see Section 607.

Justifications:

A combination of LCCA and engineering judgment are documented to finalize the pavement type selection. When the net present worth for both types of pavements is within 10% other factors are examined. These factors are:

Traffic,
Soils characteristics,
Weather,
Construction consideration,
Recycling,
Cost comparison,
Performance of similar pavements in the area,
Adjacent existing pavement,
Conservation of materials and energy,
Availability of local materials or contractor capabilities,
Traffic safety,
Incorporation of experimental features,
Stimulation of competition,
Municipal preference,
Participating local government preference, and
Recognition of local industry.

SECTION 607 – LIFE CYCLE COST ANALYSIS

Sec. 607.01 Executive Summary

With increasing customer expectations and limited funding, VDOT must ensure that the most cost-effective, smooth, and long-lasting pavements are constructed on Virginia's highways. With the volume of traffic using Virginia's highways, the public will no longer tolerate excessive work-zone disruptions because of emergency or unplanned maintenance on a roadway. Additionally, VDOT cannot afford to rehabilitate these pavements prematurely. Both the public and VDOT want VDOT to "Get In, Get Out, and Stay Out." To fulfill this expectation, VDOT is designing pavements using new approaches and enhanced state-of-the-art materials such as SUPERPAVE® asphalt, high performance concrete and analytical tools like HYPERPAVE.

In addition to new pavement design methods and materials, VDOT is incorporating a revised life cycle cost analysis (LCCA) procedure into the process of selecting pavement type. This analysis incorporates proven national methodologies (ACPA, FHWA Demo 115, Asphalt Institute) customized to Virginia's unique circumstances. With this new approach, VDOT looks beyond initial construction costs by considering the future maintenance and rehabilitation needs associated with a particular type of pavement. This approach, then, improves the decision-making process by enabling the selection of the most cost-effective type of pavement based on an estimation of *costs incurred* throughout a suitable analysis period, or "life cycle." For the LCCA procedure, a 50-year analysis period is considered sufficiently long to capture the maintenance and rehabilitation costs that span at least one full series of treatment activities. A review of the age and condition of many of Virginia's high-volume roadways, particularly interstate facilities, reveals that pavements constructed 25 to 40 years ago are now in need of major rehabilitation.

This section provides the framework for future enhancements to the LCCA process as we refine real maintenance cost and performance data based on actual experience. Anticipated future improvements to VDOT's LCCA approach include 1) the application of probabilistic concepts to account for the variability of input factors (unit costs, activity timing, etc.); and 2) the integration of user costs associated with work zone delays. The procedure herein was derived largely from the Federal Highway Administration Technical Bulletin, *Life Cycle Cost Analysis in Pavement Design*[1]. Geared toward state highway agency personnel responsible for designing highway pavements, the bulletin provides technical guidance and recommendations on "good practice" in conducting LCCA in pavement design. It was authored by representatives of various state transportation departments, the Federal Highway Administration (FHWA), the National Asphalt Pavement Association, and the American Concrete Pavement Association. References to applicable sections of the Technical Bulletin are made throughout this LCCA document. On subjects not specifically covered by the FHWA Technical Bulletin, VDOT's LCCA Guidelines draw upon the experience and expertise of its own workforce, particularly in areas related to pavement performance prediction and maintenance effectiveness. Where records are available, historic performance data were used to support planned maintenance/rehabilitation intervals for certain activities.

LCCA will enhance VDOT's ability to make sound engineering and cost-effective economic decisions pertaining to the construction/reconstruction of Virginia's major highways. However, it is important to remember that the LCCA process is based on the premise that the pavements are properly designed and will be reasonably maintained, that the quality of the construction and materials is consistently good, and that the pavement is not subject to adverse or unforeseen site conditions.

Sec. 607.02 Introduction

A major factor in selecting the type of pavement for use on new construction and major rehabilitation projects is cost. In many cases, the initial construction cost is the main consideration. Although a particular pavement type may have a low initial cost, the future maintenance and rehabilitation costs may be exorbitant and, therefore, must be considered in a fair and objective decision-making process. In order to account for the initial and future costs associated with the construction and maintenance of roadway infrastructure, a life cycle cost analysis (LCCA) should be performed.

Purpose

The purpose of this document is to provide technical guidance to VDOT engineers involved in selecting a pavement type for major construction and rehabilitation projects. This document describes LCCA, the history of LCCA in VDOT, and projects requiring LCCA.

What Is LCCA?

LCCA is an economic method to compare alternatives that satisfy a need in order to determine the lowest cost alternative. According to Chapter 3 of the *AASHTO Guide for Design of Pavement Structures*[2], life cycle costs "refer to all costs which are involved in the provision of a pavement during its complete life cycle." These costs borne by the agency include the costs associated with initial construction and future maintenance and rehabilitation. Additionally, costs are borne by the traveling public and overall economy in terms of user delay. The life cycle starts when the project is initiated and opened to traffic and ends when the initial pavement structure is no longer serviceable and reconstruction is necessary.

History of LCCA in VDOT

VDOT has used LCCA to evaluate and select pavement types on new Interstate and Primary Route projects for many years. Past LCCAs for pavements considered a 24-foot surface width and dealt with the cost for a lane mile. A 30-year analysis period was used, and only continuously reinforced concrete, jointed concrete, and flexible pavements were considered.

LCCA Projects

LCCA may not be necessary on all projects largely because of the nature and location of a particular project. For most widening projects, for example, LCCA may not be necessary. In this case, because of visual and construction considerations, the new pavement is selected and designed to be similar to the adjacent pavements. This approach is consistent with design recommendations found in Appendix B of the *AASHTO Pavement Design Guide*[2]. For intersection improvement projects, the new pavement may be selected and designed based on local experience and construction issues. For most short projects (less than one mile), the new pavement will be similar to the adjacent pavements. In urban areas where numerous utilities are located under the pavement or cross under the pavement, a flexible pavement is typically selected. Flexible pavement can be removed and patched easier if utilities must be repaired, replaced, or installed. If utilities are not a concern, then either pavement may be feasible and the engineer should consider performing LCCA to assist in selecting the final structure.

LCCA should be used on large-scale construction and rehabilitation projects. Many of these projects are located on interstates and high-volume primary or secondary routes. For projects on routes like these, LCCA should be part of a large corridor improvement plan where practical.

Components of This Document

To aid the engineer in performing LCCA, this document has six major sections in addition to the Introduction. Section II describes the basic economic analysis components; Section III describes the cost factors included in LCCA; Section IV outlines the overview of LCCA pavement options; Sections V through XI provide information on each pavement option; Section XII provides unit costs and measures for each pavement-related activity; and Section XIII discusses the interpretation of results.

Sec. 607.03 Economic Analysis Components

Analysis Period

To maintain consistency with the FHWA Technical Bulletin, *Life Cycle Cost Analysis in Pavement Design*[1], LCCA periods should be sufficiently long to reflect long-term differences associated with reasonable maintenance strategies. The analysis period should generally be longer than the pavement design period. As a rule of thumb, the analysis period should be long enough to incorporate at least one complete cycle of rehabilitation activity. The FHWA's September 1996 Final LCCA Policy Statement[3] recommends an analysis period of at least 35 years for all pavement projects, including new or total reconstruction projects and rehabilitation, restoration, and resurfacing projects (*Life Cycle Cost Analysis in Pavement Design*, FHWA, March 1998, p. 11). For VDOT's revised LCCA procedure, a 50-year analysis period was selected. This period is sufficiently long to reflect the service lives of several rehabilitation activities.

Discount Rate

In order to account for the cost related to future activities, the time value of money must be considered. In LCCA, the discount rate is used. The *discount rate* is defined as the difference between interest and inflation rates. Historically, this value has ranged from 2% to 5%; for LCCA purposes, a value of 4% will be used. This value is consistent with the values recommended in the FHWA Interim Technical Bulletin[1] and other economic research performed by VDOT[4]. The discount rate accounts not only for the increased cost associated with performing an activity in the future but also for the economic benefit the agency would receive if those funds were instead invested in an interest-bearing account.

Evaluation Methods

Numerous economic analysis methods can be used to evaluate pavement alternatives. The two most common are the present worth (PW) method and the equivalent uniform annual cost (EUAC) method.

The EUAC method describes the average cost an agency will pay per year over the analysis period. All costs including initial construction and future maintenance are distributed evenly. Although this dollar value may not seem realistic in years when little pavement action is required, it can be used to evaluate and compare alternatives.

The PW method reports initial and future pavement costs as a lump sum amount in today's dollar value. For activities that occur in the initial year of the analysis period, the PW cost is the same as the actual cost, i.e., no adjustment for inflation and interest. For future maintenance and rehabilitation activities, the PW cost is less than the actual cost (based on today's unit prices) since total costs are discounted. Please note that for two identical actions that occur 30 years apart, the later action will cost much less. This is because of the number of years that are discounted. The PW method is the more widely used approach for pavement LCCA. It gives an indication of how much a pavement alternative will cost over the analysis period and can be used to clearly compare alternatives for lowest cost.

Sensitivity Analysis

As with any analysis, it is important to understand what variables make the largest difference in the final results. For pavement design, the pavement subgrade strength and traffic loading have the largest impact on the design outcome. For LCCA, multiple variables can affect the final PW or EUAC for a pavement alternative. For example, the unit cost of a material alone can be significant enough to cause a particular alternative go from the lowest PW to the highest. Therefore, the engineer must ensure that the unit costs used are reasonable; likewise, it is important to understand how sensitive the cost of an alternative is to the input assumptions. This is accomplished by performing a limited sensitivity analysis whereby various combinations of inputs are selected to qualify their effect on the analysis results. Other factors that can greatly influence the LCCA results are discount rate, analysis period, and timing of activities.

Sec. 607.04 Cost Factors

Numerous costs are included in LCCA for pavements, ranging from initial costs associated with new construction to future maintenance costs associated with patching, sealing, and other activities.

Initial Costs

To conduct an LCCA for comparing pavement alternatives, the initial cost is a major percentage of the PW or EUAC over the analysis period. The initial cost is determined at Year 0 of the analysis period.

Although numerous activities are performed during the construction, reconstruction, or major rehabilitation of a pavement, only those activities that are specific to a pavement alternative should be included in the initial costs. By focusing on those activities, the engineer can concentrate on estimating the quantities and costs related to those activities. Actions dependent on pavement type include, but are not limited to the following:

- milling
- pavement removal
- asphalt concrete paving
- portland cement concrete paving

- fracturing portland cement concrete slabs.

Rehabilitation Costs

For all pavement options, the initial pavement life is designed to support traffic for 30 years. At the end of the 30-year period, the pavement must be rehabilitated. For flexible pavements, this rehabilitation includes removing AC surface and intermediate materials and replacing with new AC material. For rigid pavements, concrete pavement restoration (CPR) is conducted and an AC overlay may be placed. Rehabilitation activities may include the following:

- milling
- AC paving
- PCC and AC patching
- joint cleaning.

Structural/Functional Improvement Costs

Structural/functional improvement activities are performed during the life of a pavement in order to maintain a smooth, safe, durable pavement surface. Structural/functional improvements are designed to last 10 years. Typical improvement activities include the following:

- milling
- AC and PCC patching
- AC paving
- PCC grinding
- joint cleaning and sealing

Maintenance Costs

All pavement types require preventive and corrective maintenance during their service life. The timing and extent of these activities vary from year to year. Routine reactive type maintenance cost data are normally not available except on a very general, area wide type cost per lane mile. Fortunately, routine reactive type maintenance costs are generally not very high due to the relatively high performance levels maintained on major highway facilities. Further, state highway agencies that do report routine reactive maintenance costs note little difference between most alternative pavement strategies. When discounted to the present, small reactive maintenance cost differences have negligible effect on PW and can generally be ignored.[1] Therefore, they are not included in this LCCA procedure.

Salvage Value

At the end of the LCCA period, the pavement structure may be defined as having some remaining value to the managing agency, known as the salvage value. In many cases, a structural/functional improvement performed near the end of the analysis period retains some value in the form of useful life that extends beyond the end of the analysis period. The FHWA Interim Technical Bulletin[1] recognizes that a pavement's serviceable life represents a more significant component of salvage value than does its residual value as recycled material. In fact, the Bulletin states that the differential residual value between pavement design strategies is generally not very large, and when discounted over 35 years or more, tends to have little impact on LCCA results. For this reason, the VDOT LCCA procedure follows the recommendation of the Bulletin for Serviceable Life. This is defined as the remaining service life in a pavement alternative at the end of the analysis period. The following equation is used to define salvage value:

*Salvage value = Structural/functional improvement cost at Year X * Percentage of remaining life at year 50*

This approach is consistent with other state highway agencies such as the Utah DOT[5]. Even with this approach, the salvage value is negligible when discounted back 50 years.

Sec. 607.05 Overview of LCCA Pavement Options

In order to conduct a LCCA, different pavement options must be identified and compared for a project. The number and type of viable pavement options depend on the project's characteristics. After an examination of the pavement structures (flexible, rigid, and composite) that exist on Virginia's interstates and high-volume primary routes, seven pavement options were created. The following table identifies these pavement options:

Construction/Major Rehabilitation Pavement Options
Asphalt Concrete Construction/Reconstruction
Rehab of Rigid Pavement with AC Overlay
Rehab of Rigid Pavement with Unbonded Jointed Concrete Overlay
Jointed Plain Concrete Construction/Reconstruction with Tied PCC Shoulders
Jointed Plain Concrete Construction/Reconstruction with Wide Lane and AC Shoulders
Continuously Reinforced Concrete Pavement Construction/ Reconstruction with Tied PCC Shoulders
Continuously Reinforced Concrete Pavement Construction/ Reconstruction with Wide Lane and AC Shoulders

The pavement options, criteria and suppositions in the table were made to accommodate the consistent application of LCCA across the state. Without these guidelines, an infinite number of pavement options could be developed. For some pavement options, specific criteria and suppositions were made. The general criteria and suppositions made were:

- No reconstruction is planned during the analysis period beyond the original rehabilitation/reconstruction.
- Flexible pavements remain flexible throughout the analysis period, i.e., no white-topping.
- Rigid pavements are overlaid with AC during the analysis period. No unbonded or bonded concrete overlays are programmed.
- Subsurface drainage systems are independent of pavement type. If a site needs drainage, then all options call for drainage. Therefore, this cost is treated as fixed regardless of pavement type.
- Full-depth shoulders are designed to carry potential future traffic.
- The timing of functional improvements and major rehabilitation is fixed.
- The activities associated with new construction, reconstruction, major rehabilitation, and functional improvements are a function of the project. The activities included in LCCA must be determined by the engineer and supported by documentation.

Sec. 607.06 Asphalt Pavement Construction/Reconstruction

For most projects, asphalt pavement construction or reconstruction is a viable option. Asphalt pavement can be constructed on a new alignment or an existing alignment. For existing alignments, the in-situ pavement is removed completely.

As with all pavement options, several criteria were established and assumptions made:

6. The initial pavement design life is 30 years. Because of functional mill and replace at Year 12 and structural mill and replace at Year 22, major rehabilitation is not scheduled until Year 32.
7. For the structural rehabilitation at Year 32, the pavement surface life is 12 years. The pavement is considered "new" and to have a performance similar to new construction.
8. Structural/functional mill and replace is a fixed activity at Years 12, 22, and 44 in order to provide 10 additional years of life to the pavement surface and structure. The 10-year period is the average life for an AC surface based on data in VDOT's pavement management database.
9. For structural adequacy, the pavement overlay design life at Year 32 is 20 years. Pavement activities and required structures must be determined by the engineer (e.g., thickness of AC base, intermediate and surface layers,).
10. Patching of AC pavements is based on area of pavement surface.
11. Milling to a depth of 2 inches is performed to remove the 1.5-inch wearing course and a portion of the underlying layer to minimize scabbing.
12. Preventive maintenance activities considered in the analysis include surface treatments (e.g., BSTs, thin overlays, slurrys, microsurfacing), crack sealing, and patching. Preventative maintenance is only specified in the analysis for the shoulders if a functional or structural improvement is performed on the mainline pavement. No preventative maintenance is programmed for the mainline pavement as part of the LCCA.

Pavement Activities Table

Year 0 – New Construction/Reconstruction	Year 12 – Functional Mill and Replace
Mainline AC Surface Material AC Intermediate Material AC Base Material Stabilized Drainage Layer CTA or DGA Subbase Shoulders AC Surface Material AC Intermediate Material AC Base Material Stabilized Drainage Layer CTA or DGA Subbase	Mainline Pre-overlay repair - Patch – 1% Mill - 2 Inches Replace with AC Wearing Course - 2 Inches Shoulders Surface Treatment

Year 22 – Structural Mill and Replace	Year 32 – Major Rehabilitation
Mainline Pre-overlay Repair - Patch – 1% Mill - 2 Inches	Mainline Pre-overlay Repair - Patch – 5% Deep Mill (All Surface and Intermediate

Replace with AC Intermediate Materials – 2 Inches Overlay with AC Wearing Course – 1.5 Inches Shoulders Overlay with AC Wearing Course – 1.5 Inches	Layers) Replace with AC Base Material AC Intermediate Material AC Wearing Course Shoulders Overlay with AC Wearing Course

Year 44 – Functional Mill and Replace	Year 50 – Salvage Value
Mainline Pre-overlay repair - Patch – 1% Mill - 2 Inches Replace with AC Wearing Course - 2 Inches Shoulders Surface Treatment	Salvage Value = [AC Overlay Cost at Year 44] – [AC Overlay Cost at Year 44 * (4-yr Remaining Service Life/10-yr Design Life)]

Sec. 607.07 Rehab of rigid pavement with ac overlay

One pavement option for rehabilitating existing rigid pavement is fracturing and overlaying with AC. Fracturing techniques includes break and seat, crack and seat, and rubblization. The type of fracturing performed is based on the existing rigid pavement type, e.g., jointed plain, jointed reinforced, or continuously reinforced concrete. Once the pavement has been fractured and overlaid, it is considered a flexible pavement structure

As with all pavement options, several criteria were established and assumptions made:

13. The initial pavement design life is 30 years for fractured pavement areas and areas of pavement reconstruction. Because of the anticipated service lives resulting from the structural mill and replace at Year 12 and functional mill and replace at Year 22, major rehabilitation is not scheduled until Year 32.
14. For the structural rehabilitation at Year 32, the pavement surface life is 12 years. The pavement is considered "new" and to have a performance similar to major rehabilitation at Year 0.
15. Structural/functional mill and replace is a fixed activity at Years 12, 22, and 44 in order to provide 10 additional years of life to the pavement surface and structure. The 10-year period was determined to be the average life for an AC surface based on historic performance data in VDOT's pavement management database.
16. For pavement structural adequacy, the pavement overlay design life at Year 32 is 20 years. Pavement activities and required structures must be determined by the engineer (e.g., thickness of AC base, intermediate and surface layers).
17. The full-depth patching percentage for AC pavements is based on pavement surface area.
18. Milling to a depth of 2 inches is performed to remove the 1.5-inch wearing course and a portion of underlying layer to minimize scabbing.
19. Preventive maintenance activities considered in the analysis include surface treatments (e.g., BSTs, thin overlays, slurrys, microsurfacing), crack sealing, and patching. Preventative maintenance is only specified in the analysis for the shoulders if a functional or structural

improvement is performed on the mainline pavement. No preventative maintenance is programmed for the mainline pavement as part of the LCCA.

Pavement Activities Table

Year 0 – PCC Overlaid with AC	Year 12 – Functional Mill and Replace
Mainline Fracture Existing PCC AC Surface Material AC Intermediate Material AC Base Material Stabilized Drainage Layer Shoulders (If Requires Reconstruction) Shoulder Removal AC Surface Material AC Intermediate Material AC Base Material Stabilized Drainage Layer CTA or DGA Subbase Soil Stabilization Shoulders (If Existing PCC) Fracture Existing PCC AC Surface Material AC Intermediate Material AC Base Material Stabilized Drainage Layer	Mainline Pre-overlay repair - Patch – 1% Mill - 2 Inches Replace with AC Wearing Course - 2 Inches Shoulders Surface Treatment

Year 22 – Structural Mill and Replace	Year 32 – Major Rehabilitation
Mainline Pre-overlay Repair - Patch – 1% Mill - 2 Inches Replace with AC Intermediate Materials – 2 Inches Overlay with AC Wearing Course – 1.5 Inches Shoulders Overlay with AC Wearing Course – 1.5 Inches	Mainline Pre-overlay Repair - Patch – 5% Deep Mill (All Surface and Intermediate Layers) Replace with AC Base Material AC Intermediate Material AC Wearing Course Shoulders Overlay with AC Wearing Course to match new profile

Year 44 – Functional Mill and Replace	Year 50 – Salvage Value
Mainline Pre-overlay repair - Patch – 5% Mill - 2 Inches Replace with AC Wearing Course - 2 Inches Shoulders Surface Treatment	Salvage Value = [AC Overlay Cost at Year 44] – [AC Overlay Cost at Year 44 * (4-yr Remaining Service Life/10-yr Design Life)]

Sec. 607.08 Rehab of rigid pavement with Unbonded Jointed Concrete Overlay

A rehabilitation option for existing rigid pavement is to place an unbonded jointed plain concrete pavement overlay. For this rehabilitation option, minimal repair is made to the existing rigid pavement, a thin AC bond-breaking layer is placed, and then a concrete pavement is placed. This pavement structure is considered rigid.

As with all pavement options, several criteria were established and assumptions made;

20. Unbonded concrete overlays are applied to deteriorated PCC pavements at Year 0.
21. The patching percentage for concrete pavements is based on the number of joints (jointed plain concrete).
22. For structural adequacy, the pavement overlay design life at Year 30 is 20 years. Pavement activities and structures must be determined by the engineer (e.g., thickness of AC base, intermediate and surface layers).
23. Functional mill and replace is a fixed activity at Year 40 in order to provide 10 additional years of life to the pavement surface and structure.
24. The full-depth patching percentage for composite pavements (after Year 30) is based on the number of underlying PCC joints (jointed plain concrete).
25. Milling to a depth of 2 inches is performed to remove the 1.5-inch wearing course and a portion of underlying layer to minimize scabbing.
26. Grinding of PCC surfaces is for improving ride quality.
27. PCC slab costs include the costs of tie bars, dowels, cut joints, and/or seal joints.

Pavement Activities Table

Year 0 – Rehabilitation (CPR and Unbonded Overlay)	Year 10 – Concrete Pavement Maintenance
Mainline (Pre-overlay Activities) Patching AC Bond Breaker/Separator Layer AC Shoulders (if existing) Mill Existing AC if Deteriorated Patch Localized Failures AC Base Material PCC Shoulders (if existing, pre-overlay activities) Patching AC Bond Breaker/Separator Layer PCC Slab – Mainline and Shoulders	Mainline Patching – 3% Clean and Seal Joint – 100%

Year 20 – CPR	Year 30 – AC Overlay
Mainline (Concrete Pavement Repair) Patching – 10% Clean and Seal Joints – 100% Grinding – 100%	Mainline Pre-overlay Repair: Patch – 10% AC Overlay (Minimum 4 Inches) with: AC Surface Material AC Intermediate Material AC Base Material Shoulders

	AC Overlay (Minimum 4 Inches) with: AC Wearing Course AC Intermediate Material AC Base Material

Year 40 – Structural Mill and Replace	Year 50 – Salvage Value
Mainline Pre-overlay Repair Patching (AC Overlay) Based on 5% of Underlying PCC Joints Patching (PCC Base) – 5% Mill - 2 Inches Replace with AC Intermediate Material – 2 Inches Overlay with AC Wearing Course – 1.5 Inches Shoulders Overlay with AC Wearing Course – 1.5 Inches	None

Sec. 607.09 Jointed Concrete Pavement Construction/Reconstruction with Tied Portland Cement Concrete Shoulders

For most projects, a jointed concrete pavement with tied PCC shoulders is a viable construction or reconstruction option. Jointed concrete pavement can be constructed on a new alignment or on an existing alignment. If the existing pavement on an alignment is flexible, then the jointed concrete pavement can be constructed on top of it (if geometrically feasible).

As with all pavement options, several criteria were established and assumptions made:

28. Initial pavement design life is 30 years.
29. Structural mill and replace is a fixed activity at Year 40 in order to provide 10 additional years of life to the pavement surface and structure. The 10-year period is the average life for an AC surface based on data in VDOT's pavement management database.
30. For structural adequacy, the pavement overlay design life at Year 30 is 20 years. Pavement activities and structures must be determined by the engineer (e.g., thickness of AC base, intermediate and surface layers).
31. The full-depth patching percentage for composite pavement is based on the number of underlying PCC joints.
32. The full-depth patching percentage for jointed concrete pavement is based on the number of transverse joints.
33. Milling to a depth of 2 Inches is performed to remove the 1.5-Inch wearing course and a portion of underlying layer to minimize scabbing.
34. PCC slab costs include the costs of tie bars, dowels, cut joints, and seal joints.

Pavement Activities Table

Year 0 - New Construction/Reconstruction	Year 10 – Concrete Pavement Maintenance
Mainline Pavement Removal (Reconstruction) PCC Slab Stabilized Drainage Layer CTA or DGA Subbase Shoulders Shoulder Removal (Reconstruction) PCC Slab Stabilized Drainage Layer CTA or DGA Subbase Soil Stabilization	Mainline Patching – 3% Clean and Seal Joint – 100%

Year 20 – Concrete Pavement Restoration	Year 30 – AC Overlay
Mainline (Concrete Pavement Repair) Patching – 10% Clean and Seal Joints – 100% Grinding – 100%	Mainline Pre-overlay Repair: Patch – 10% AC Overlay (Minimum 4 Inches) with: AC Surface Material AC Intermediate Material AC Base Material Shoulders AC Overlay (Minimum 4 Inches) with: AC Wearing Course AC Intermediate Material AC Base Material

Year 40 – Structural Mill and Replace	Year 50 – Salvage Value
Mainline Pre-overlay Repair Patching (AC Overlay) Based on 5% of Underlying PCC Joints Patching (PCC Base) – 5% Mill - 2 Inches Replace with AC Intermediate Material – 2 Inches Overlay with AC Wearing Course – 1.5 Inches Shoulders Overlay with AC Wearing Course – 1.5 Inches	None

Sec. 607.10 Jointed Plain Concrete Pavement construction/reconstruction with Wide Lane and asphalt concrete Shoulders

For most projects, a jointed concrete pavement with wide lanes and AC shoulders is a viable construction or reconstruction option. Jointed concrete pavement can be constructed on a new alignment or an existing alignment. If the existing pavement on an alignment is flexible, then the jointed concrete pavement can be constructed on top of it (if geometrically feasible).

As with all pavement options, several criteria were established and assumptions made:

35. The initial pavement design life is 30 years for the mainline. For the AC shoulders, the total thickness of the AC layers will be equal to the thickness of the mainline PCC slab.
36. Structural mill and replace is a fixed activity at Year 40 in order to provide 10 additional years of life to the pavement surface and structure. The 10-year period is the average life for an AC surface based on data in VDOT's pavement management database.
37. For structural adequacy, the pavement overlay design life at Year 30 is 20 years. Pavement activities and structures must be determined by the engineer (e.g., thickness of AC base, intermediate and surface layers).
38. The full-depth patching percentage for composite pavement is based on the number of underlying PCC joints.
39. The full-depth patching percentage for jointed concrete pavement is based on the number of transverse joints.
40. Milling to a depth of 2 inches is performed to remove the 1.5-inch wearing course and a portion of underlying layer to minimize scabbing.
41. Grinding of PCC surfaces is for improving ride quality.
42. PCC slab costs include the costs of tie bars, dowels, cut joints, and seal joints.

<u>Pavement Activities Table</u>

Year 0 - New Construction/Reconstruction	Year 10 – Concrete Pavement Maintenance
Mainline with 14-Foot Lanes – Inside and Outside Mainline Removal (Reconstruction) PCC Slab Stabilized Drainage Layer CTA or DGA Subbase Shoulders Shoulder Removal (Reconstruction) AC Surface Material AC Intermediate Material AC Base Material CTA or DGA Subbase Soil Stabilization	Mainline Patching – 3% Clean and Seal Joint – 100% Shoulders Surface Treatment

Year 20 – Concrete Pavement Restoration and Shoulder Improvement	Year 30 – AC Overlay
Mainline (Concrete Pavement Repair) Patching – 10% Clean and Seal Joints – 100% Grinding – 100% Shoulders Surface Treatment	Mainline Pre-overlay Repair: Patch – 10% AC Overlay (Minimum 4 Inches) with: AC Surface Material AC Intermediate Material AC Base Material Shoulders

	AC Overlay (Minimum 4 Inches) with: AC Wearing Course AC Intermediate Material AC Base Material

Year 40 – Functional Mill and Replace	Year 50 – Salvage Value
Mainline Pre-overlay Repair Patching (AC Overlay) Based on 5% of Underlying PCC Joints Patching (PCC Base) – 5% Mill - 2 Inches Replace with AC Intermediate Material – 2 Inches Overlay with AC Wearing Course – 1.5 Inches Shoulders Overlay with AC Wearing Course – 1.5 Inches	None

Sec. 607.11 Continuously Reinforced Concrete Pavement construction/reconstruction with Tied portland cement concrete Shoulders

Continuously reinforced concrete pavement with tied PCC shoulders is a viable construction or reconstruction option. Continuously reinforced concrete pavement can be constructed on a new alignment or an existing alignment. If the existing pavement on an alignment is flexible, then the continuously reinforced concrete pavement can be constructed on top of it (if geometrically feasible).

As with all pavement options, several criteria were established and assumptions made:

43. The initial pavement design life is 30 years with a functional AC overlay at Year 20.
44. The pavement mill and replacement at Year 30 is fixed to provide 10 years of functional life. The 10-year period is the average life for an AC surface based on data in VDOT's pavement management database.
45. The complete removal and replacement of the AC overlay at Year 40 is a fixed activity in order to provide 10 additional years of life to the AC surface and pavement structure.
46. The full-depth patching percentage for composite pavement is based on pavement surface area.
47. The full-depth patching percentage for continuously reinforced concrete pavement is based on surface area.
48. Milling to a depth of 2 inches is performed to remove the 1.5-inch wearing course and a portion of underlying layer to minimize scabbing.

Pavement Activities Table

Year 0 - New Construction/Reconstruction	Year 10 – Concrete Pavement Maintenance
Mainline Mainline Removal (Reconstruction) PCC Slab	Mainline Patching – 2% Clean and Seal Joint – 100%

Year 0 - New Construction/Reconstruction	Year 10 – Concrete Pavement Maintenance
Stabilized Drainage Layer CTA or DGA Subbase Shoulders Shoulder Removal (Reconstruction) PCC Slab Stabilized Drainage Layer CTA or DGA Subbase Soil Stabilization	

Year 20 – Concrete Pavement Restoration and AC Overlay	Year 30 – Functional Mill and Replace
Mainline Concrete Pavement Restoration: Patching – 5% AC Overlay with: AC Wearing Course – 1.5 Inches AC Intermediate or Base Material – 2 Inches Shoulders AC Overlay with: AC Wearing Course – 1.5 Inches AC Intermediate or Base Material – 2 Inches	Mainline Patching (AC Overlay) - 5% Patching (PCC Base) – 5% Mill - 2 Inches Replace with AC Wearing Course – 2.0 Inches Shoulders Surface Treatment

Year 40 – Concrete Pavement Restoration and AC Overlay	Year 50 – Salvage Value
Mainline Concrete Pavement Restoration: Patch – 10% Mill - 3.5 Inches Replace with: AC Intermediate Material – 2.0 Inches AC Surface Material – 1.5 Inches Shoulders Surface Treatment	None

Sec. 607.12 Continuously Reinforced Concrete Pavement construction/reconstruction with Wide Lanes (14 FEET) and AC Shoulders

Continuously reinforced concrete pavement with wide lanes and AC shoulders is a viable construction or reconstruction option. Continuously reinforced concrete pavement can be constructed on a new alignment or an existing alignment regardless of the existing pavement type. If the existing pavement on an alignment is flexible, then the continuously reinforced concrete pavement can be constructed on top of it (if geometrically feasible).

As with all pavement options, several criteria were established and assumptions made:

49. The initial pavement design life is 30 years with a functional AC overlay at Year 20. For the AC shoulders, the total thickness of the AC layers will be equal to the thickness of the mainline PCC slab.
50. The pavement mill and replacement at Year 30 is fixed to provide 10 years of functional life. The 10-year period is the average life for an AC surface based on data in VDOT's pavement management database.
51. The complete removal and replacement of the AC overlay at Year 40 is a fixed activity in order to provide 10 additional years of life to the AC surface and pavement structure.
52. The full-depth patching percentage for composite pavement is based on pavement surface area.
53. The full-depth patching percentage for continuously reinforced concrete pavement is based on surface area.
54. Milling to a depth of 2 inches is performed to remove the 1.5-inch wearing course and a portion of underlying layer to minimize scabbing.

Pavement Activities Table

Year 0 – New Construction/Reconstruction	Year 10 – Concrete Pavement Maintenance
Mainline with 14-Foot Lanes – Outside and Inside Pavement Removal (Reconstruction) PCC Slab Stabilized Drainage Layer CTA or DGA Base Shoulders Shoulder Removal (Reconstruction) AC Surface Material AC Intermediate Material AC Base Material CTA or DGA Subbase Soil Stabilization	Mainline Patching – 2% Clean and Seal Joint – 100% Shoulders Surface Treatment

Year 20 – Concrete Pavement Restoration and AC Overlay	Year 30 – Functional Mill and Replace
Mainline Concrete Pavement Restoration: Patching – 5% AC Overlay with: AC Wearing Course – 1.5 Inches AC Intermediate or Base Material – 2 Inches Shoulders AC Overlay with: AC Wearing Course – 1.5 Inches AC Intermediate or Base Material – 2 Inches	Mainline Patching (AC Overlay) – 5% Patching (PCC Base) – 5% Mill – 2 Inches Replace with AC Wearing Course – 2.0 Inches Shoulders Surface Treatment

Year 40 – Concrete Pavement Restoration and AC Overlay	Year 50 – Salvage Value
Mainline Concrete Pavement Restoration: Patch – 10% Mill – 3.5 Inches Replace with: AC Intermediate Material – 2.0 Inches AC Wearing Course – 1.5 Inches Shoulders Surface Treatment	None

<u>Sec. 607.13 Unit Costs and Measures</u>

The life cycle cost for a pavement option is dependent on the corresponding activities required to construct and maintain the pavement. The cost for each activity is a function of unit cost and quantity measure. The following table provides units of measure. The measure is based on the Measurement and Payment Section in VDOT's *Road and Bridge Specifications* for each activity. The unit cost is based on historical and current costs to VDOT for similar or equivalent measures (i.e., quantities).

Activity	Measure
Milling/Planing	Square Yard – Inch
Fracturing PCC	Square Yard
AC Surface Material/Wearing Course	Tons
AC Intermediate Material	Tons
AC Base Material	Tons
Stabilized Drainage Layer	Tons
Pavement Demolition and Removal – Existing AC	Square Yard
Pavement Demolition and Removal – Existing PCC	Square Yard
Aggregate Subbase	Cubic Yard or Ton
Cement Treated Aggregate	Tons
Patching – CRCP	Square Yard
Patching – JPCP	Square Yard
Patching – AC	Tons
PCC Grinding	Square Yard
Joint Cleaning and Sealing	Linear Foot
CRCP	Square Yard
JPCP	Square Yard
Surface Treatment	Depends on Material Selected

Sec. 607.14 Interpretation of Results

Once the LCCA is completed for a project, the PW cost results must be interpreted. In general, the pavement option with the lowest PW cost should be strongly considered for the project. However, the PW cost for any pavement option is not exact; therefore, the engineer should consider all pavement options with a PW cost within 10% of the lowest PW cost as economically feasible. If more than one pavement option is determined to be economically feasible, then factors such as the following must be considered:

- initial constructability
- constructability of future improvements
- volume of traffic
- availability of materials
- availability of qualified contractors
- initial construction costs
- location of project.

Once the PW cost and other project factors are considered, then a pavement recommendation can be made.

Sec. 607.15 References

"Life-Cycle Cost Analysis in Pavement Design – In Search of Better Investment Designs;" *Pavement Division Interim Technical Bulletin* (September 1998); Federal Highway Administration.

AASHTO Guide for Design of Pavement Structures (1993); American Association of State Highway Transportation Officials.

LCCA Policy Statement; *FHWA Technical Memorandum* (September 1996); Federal Highway Administration.

VDOT Research for GASB 34 Compliance

Life Cycle Cost Analysis Instructional Manual (1994); Engineering Services Division Utah Department of Transportation.