Chapter 11 – PAVEMENTS

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LIST OF EXHIBITS

CHAPTER 11

PAVEMENTS

11.1 GENERAL

This chapter identifies the pavement related policies, standards, guidance, and references approved for use in developing designs for roads and bridges in the Federal Lands Highway Programs. Refer to Section 1.1.1 for definitions of policy, standards, criteria and guidance. The intent of this chapter is to present the above information in a concise and clear manner. The chapter is not a step-by-step instructional "how-to" guide. However, where appropriate, procedures, instructional aids, AASHTO guidelines, publications, and manuals are referenced. Users of this chapter are expected to be knowledgeable in the pavement discipline and familiar with most references and concepts included. Federal Lands Highway (FLH) projects are typically developed by an interdisciplinary team (IDT) led by a project manager. This interdisciplinary team may also be referred to as a cross-functional team (CFT). It is critical that the pavement discipline representative on the IDT is fully engaged in project planning, scoping, PS&E reviews, and other project development activities. Additionally, the pavement discipline representative on the IDT should plan work and develop recommendations in close coordination with the IDT.

Compliance with all policies and standards in this chapter is essential to ensure consistency in project development for all Federal Lands Highway projects. Although policy cannot be compromised, flexibility of standards is sometimes necessary to meet project-specific objectives. (See Section 11.1.3 for exceptions and variances to standards).

As changes in policies, standards, or criteria occur, updates to this chapter will be made as described in Section 1.1.2

The information presented in this chapter is the standard practice for pavement engineering that will be applied to all projects developed and delivered for the Federal Lands Highway Programs.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

11.1.1 REFERENCES

The publications listed in this section provided much of the fundamental source information used in the development of this chapter. While this list is not all-inclusive, the publications listed will provide the designer with additional information to supplement this manual.

1. FP-XX — *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects*, FHWA, current ed.
2. Field Materials Manual — FLH *Field Materials Manual*, Publication No. FHWA-FL-91-002.

3.	Standard Drawings	Federal Lands Highway Standard Drawings, current edition.
4.	NRC-HMA Handbook	*Hot Mix Asphalt Paving Handbook*, National Asphalt Pavement Association, 2000. Available for purchase at the NAPA online store.
5.	NHI 131033	*Construction of Portland Cement Concrete Pavements Participants Manual*, National Highway Institute Course No. 131033, FHWA HI-96-027, 1996.
6.	AGDPS	*Guide for Design of Pavement Structures and 1998 Supplement*, AASHTO, 1993. Available for purchase at the AASHTO online bookstore.
7.	AGDPS Supplement	*Supplement to the AASHTO Guide for Design of Pavement Structures, Part II, Rigid Pavement Design and Rigid Pavement Joint Design*, AASHTO, 1998.
8.	NCHRP 1-37A	*Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures*, Design Guide NCHRP 1-37A, TRB, 2004.
9.	23 CFR 626	Code of Federal Regulations, Title 23, Part 626, *Pavement Policy*
10.	FAPG 23 CFR 626	Federal Aid Policy Guide (FAPG) for section 23 CFR 626, Non-regulatory supplement, 1999.
11.	AASHTO GTDP	Guidelines for Traffic Data Programs, AASHTO, 1992.
12.	FLH FWD Backcalculation and Data Collection Guide, February 2007.	
13.	DARWin-ME	DARWin-ME, Pavement Design and Analysis software, AASHTOWare
14.	Special Report 83-27	*Revised Procedures for Pavement Design Under Seasonal Frost Conditions*, US Army Corps of Engineers, September 1983
15.	LTPPBind	LTPPBind, asphalt binder selection software, FHWA
16.	FHWA-NHI-131026	*Pavement Subsurface Drainage Design*, NHI Training Course, 1999.
17.	DRIP 2.0	*DRIP 2.0 – Drainage Requirements in Pavements User's Guide*, FHWA-IF-02-053, 2002.
18.	FHWA-CFL/TD-05-004	FLH Context Sensitive Roadway Surfacing Selection Guide, 2005

19. FHWA-RD-75-48 *A Review of Engineering Experiences with Expansive Soils in Highway Subgrades*, Report No. FHWA-RD-75-48, June 1975.

20. FHWA-RD-77-94 *An Evaluation of Expedient Methodology for Identification of Potentially Expansive Soils*, Report No. FHWA-RD-77-94, 1977.

21. FAA-RD-76-66 *Design and Construction of Airport Pavements on Expansive Soils*, Federal Aviation Administration Report, January 1976,

22. EM 1110-3-138 *Pavement Criteria for Seasonal Frost Conditions - Mobilization Construction*, Army Corps of Engineers Engineering and Design Manual EM 1110-3-138, April 1984.

23. FHWA-RD-97-083 *Design Pamphlet for the Determination of Design Subgrade in Support of the 1993 AASHTO Guide for the Design of Pavement Structures*, Report No. FHWA-RD-97-083, 1997

24. ACPA American Concrete Pavement Association

25. ACPA – TB200P *Concrete Engineering of Streets and Local Roads Reference Manual*, (ACPA), 2002 or latest update.

26. FHWA-NHI-131060 *Concrete Pavement Design Details and Construction Practices*, NHI Training Course, 2001.

27. FHWA-NHI-131008 *Techniques for Pavement Rehabilitation*, Reference Manual, NHI Training Course, 1998.

28. BARM Basic Asphalt Recycling Manual (BARM), Copyright 2001, Asphalt Recycling and Reclaiming Association (ARRA).

29. Gravel Roads (LTAP) *Gravel Roads Maintenance and Design Manual*, South Dakota LTAP and FHWA, 2000.

30. Forest Service 9977 1207 SDTDC *Dust Palliative Selection and Application Guide*, USDA – Forest Service, San Dimas Technology and Development Center, 1999.

31. AASHTO TF-28 *Guidelines and Guide Specifications for Using Pozzolanic Stabilized Mixture (Base Course or Subbase) and Fly Ash for In-Place Subgrade Soil Modifications*, Task Force 28 Report, AASHTO-AGC-ARTBA Joint Committee, 1990.

32. AASHTO TF-38 *Report on Cold Recycling of Asphalt Pavements*, Task Force 38 Report, AASHTO-AGC-ARTBA Joint Committee, 1998.

33. T 5040.30 FHWA Technical Advisory T 5040 .30, *Concrete Pavement Joints*, November 30, 1990.

34.	AASHTO GVWD	*Guide for Vehicle Weights and Dimensions*, AASHTO Subcommittee on Highway Transport, 2001.
35.	AASHTO R 13	*Conducting Geotechnical Subsurface Investigations*, ASTM designation is D 420, (a more limited treatment of methodology as compared to AASHTO MSI-1 as discussed in Section 6.3).
36.	ACAA	American Coal Ash Association
37.	ACAA Fly Ash Publication	*Soil and Pavement Base Stabilization with Self-Cementing Coal Fly Ash*, American Coal Ash Association (ACAA), 1999.
38.	FHWA-IF-03-019	*Fly Ash Facts for Highway Engineers*, Report No. FHWA-IF-03-019, 2003
39.	PCA	Portland Cement Association, *Soil-Cement and Roller-Compacted Concrete Pavements*.

11.1.2 PAVEMENT PHILOSOPHY: CRADLE TO GRAVE

In order for a pavement to perform for its intended service life, it must be *designed* properly, *constructed* properly, and finally *maintained* properly. This chapter focuses primarily on the process necessary to provide a quality pavement design. The requirements to achieve quality construction are covered in the *FP-XX* and the *Field Materials Manual*. Other good sources for quality construction guidance include the *Hot-Mix Asphalt Paving Handbook* (NRC-HMA Handbook) and the NHI 131033, *Construction of Portland Cement Concrete Pavement*s, course participant's manual. See Section 11.7 for guidance on pavement preventive maintenance. FLH Standard Drawings are available for the pavement typical section details, jointing details for PCCP, and pavement transition details.

The standard design process used by FLH is the *1993 AASHTO Guide for Design of Pavement Structures (AGDPS)* and the 1998 Supplement (*AGDPS Supplement*) that pertains only to rigid pavement design. The *AGDPS* design process is an empirical design process that uses index-type values for inputs, and a design equation that is based upon observed performance. Empirical design processes are often calibrated for only a small set of varying conditions. The equation for the *AGDPS* was based upon field observations from the AASHO Road Test completed in the late 1950's. The conditions at this road test included one subgrade soil type (an A-6 silty clay), one climate condition, 18-kip [80 kN] equivalent single axle loads (ESAL) of about 1,200,000, and a flexible pavement structural section consisting of an asphalt concrete surface, crushed limestone base, and a gravel subbase. Rigid pavements were also evaluated in a similar manner at this same site. Environmental effects such as thermal cracking or frost heave were not addressed. Project conditions for FLH projects often vary from the conditions described above. It is important for the pavement engineer to understand the basis and background of the *AGDPS*.

Currently, new pavement design procedures that are more mechanistic-based are being developed and validated (such as *NCHRP 1-37A*). As these procedures mature and are standardized, it is anticipated that they will be adopted by FLH as a new standard. Pavement engineers are encouraged to become familiar with the new procedures, test methods, and inputs of mechanistic-empirical pavement design. Refer to Section 11.9 for additional information

An excellent source for state-of-the-art guidance, information, and publications is the FHWA Pavements website. Research information, workshop availability, and information about upcoming events and meetings are included on this website.

11.1.3 DESIGN EXCEPTIONS AND VARIANCES

Deviation from pavement service life standards cited within this chapter (see Section 11.2.1.1) will require justification, approval and documentation as a formal technical standard exception (See Section 9.1.3, for a description of the design and technical standard exception process). Significant deviations from other standards, criteria, and guidance cited within this chapter will be justified and documented in the project file.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

11.1.4 QUALITY CONTROL AND QUALITY ASSURANCE

Quality control and quality assurance procedures (QC/QA) will be incorporated and executed in all pavement investigations, analysis, and designs. Those responsible for pavement activities will follow their Division policy and provide signed documentation as evidence of conforming to the procedures throughout the duration of the pavement activities.

11.1.5 DOCUMENTATION AND DELIVERABLES

The type and nature of documentation and deliverables required will vary depending upon the project. **It is the policy of FLH that the pavement activities for a project be properly documented in a project file and eventually archived.** It is important that this project documentation is accurate, comprehensive, and presented in a user-friendly format. Typical project documentation will include formal reports and memos, but informal correspondence such as emails and meeting notes may also be included.

Typical projects will include the pavement discipline deliverables described in the following sections. In addition to the timely delivery of these reports, memos, and documents, it is critical that the pavement engineer is engaged in PS&E reviews and field reviews.

11.1.5.1 Pavements Project Start-Up Information

Include as much of the following information as possible:

- As-built plans including date of original construction
- Existing or archived pavement and/or geotechnical reports and other historical documentation
- Maintenance and rehabilitation history of the road
- Preliminary field investigation needs
- Unique, pavement-related project issues, if applicable
- RIP / PMS information
- Project constraints that may affect pavement recommendations
- Basic climate and geology information
- Local material availability (consult with Materials Engineer)

Also refer to Section 4.5.2 for information included in the Project Scoping Report.

11.1.5.2 Preliminary Pavements Recommendation

The recommended pavement structure is generally required by the 30% design stage. In most instances the field investigation and a pavement design analysis as required by 23 CFR 626 is completed. Coordinate the pavement recommendations with the project's cross-functional team. Briefly summarize the following data and information:

- Field investigation, including pavement, base, and subgrade conditions and quality.
- Material testing results.
- Design criteria used.
- Design alternatives considered and evaluated.
- Design alternative recommended.
- Recommended follow-up testing or additional information gathering.

Also refer to Section 4.10.1 for information included in the Preliminary Engineering Study Report.

11.1.5.3 Final Pavements Recommendation

This deliverable is needed by at least the 70% design stage, but may be required at an earlier design stage, refer to Division Supplements. This document is made available to construction contractors during the bidding phase. Comprehensively document and support design recommendations, to a level commensurate with the project scope and risk, with the following:

- General project information
- Approval sheet (i.e. QC/QA documentation)
- Procedures and results
    - ◊ Summary of the performance history of the pavement as documented in the Pavements Project Start-Up Information deliverable above.

    - ◊ Pavement distress data
    - ◊ Traffic load and growth projection evaluation with estimated percentages of vehicle classifications
    - ◊ Relevant geometric site conditions (e.g. pavement and bench width, steep grades, etc.)
    - ◊ Relevant climatic and environmental information (e.g. frost depth, annual rainfall, etc.)
    - ◊ Pavement drainage characteristics
    - ◊ Tabular summary of sampling and testing (e.g. boring / coring logs, test pit information, material source quality, FWD results, DCP results, lab test results, visual descriptions, etc.)
    - ◊ Values or inputs determined by engineering judgment.

- Analysis
    - ◊ Pavement design methodology and inputs
    - ◊ Economic evaluation (e.g. comparative cost analysis of alternatives, LCCA, etc.)
- Pavement Design and Materials Recommendations
    - ◊ Structural section including material type
    - ◊ Pavement rehabilitation method, if applicable
    - ◊ Needed subexcavation, patching, crack sealing, underdrains, or other application that will resolve problems with wet and/or weak subgrade soils.
    - ◊ Auxiliary pavement items including, as applicable, prime/tack coat, asphalt binder grade, emulsified asphalt grade, stabilizing/recycling agents, antistrip additive type, cement type, gradations for base and surfacing material, and any other information that is needed to assure that the appropriate material type and quantity is used.
    - ◊ Address special construction issues related to pavements including but not limited to material haul distance, the need for special contract revisions, lift thickness, curing time, traffic control, and steep grades
- Support Information. Include the following when applicable and appropriate (generally as attachments or appendices):
    - ◊ Site map(s) with sampling and testing locations
    - ◊ Material testing reports
    - ◊ Field notes, logs, FWD data, etc.
    - ◊ Calculations and/or design software reports
    - ◊ Photos (photographically document and represent typical and atypical project conditions, features, and materials)

11.1.6 APPLICABLE LAWS AND REGULATIONS

23 CFR 626 establishes FHWA policy affecting pavement design. **All Federal Lands projects will conform to FHWA policy.** The following is the CFR definition and policy statement:

> "Pavement design means a project level activity where detailed engineering and economic considerations are given to alternative combinations of subbase, base, and surface materials which will provide adequate load carrying capacity. Factors which are considered include: materials, traffic, climate, maintenance, drainage, and life-cycle costs."

> "Pavement shall be designed to accommodate current and predicted traffic needs in a safe, durable, and cost effective manner."

The FHWA Federal-Aid Policy Guide (*FAPG*) provides standards and guidance for the interpretation of policy. FAPG 23 CFR 626 provides the basis for many of the standards recommended in this chapter.

Other FAPG sections that contain relevant guidance include:

- FAPG 23 CFR 660A – Section 7 on Forest Highway project development
- FAPG 23 CFR 660E – Attachment 3 for Guidance for design of military Transport-Erector Routes

In addition to the FAPG's above, the Park Roads and Parkways Program Implementation Manual also contains relevant guidance.

11.2 PAVEMENT DESIGN VARIABLES

There are numerous pavement design inputs and processes that may vary from project to project. A project's context, risk, and scope will help determine the specific design inputs and processes to use. This section provides an explanation of the design variables involved and guidance on how they are applied.

11.2.1 REQUIRED DESIGN INPUTS

In order to complete a pavement design in accordance with the *AGDPS* and *AGDPS Supplement*, numerous inputs must be determined. The following subsections describe the inputs necessary for the completion of a pavement design.

11.2.1.1 Pavement Performance

The initial and terminal serviceability of the pavement are required inputs. Serviceability is a measure of the functional level of service at a given point in time of the life of a pavement. In the *AGDPS*, the serviceability of a pavement is expressed in terms of the present serviceability index (PSI). The scale for PSI ranges from 0 to 5. A rating of 0 represents a pavement that is impassable and a rating of 5 represents a pavement that is perfectly smooth. The initial serviceability value of a pavement is an estimate of what the PSI will be immediately after construction. The terminal serviceability is the lowest acceptable PSI prior to a structural rehabilitation. An increase in the delta or difference between the initial and terminal serviceability, will result in a decrease in the required thickness or structural number value. **The following serviceability standards apply for typical FLH projects:**

- Use an initial serviceability of 4.2 for flexible pavements and 4.5 for rigid pavements;
- Use a terminal serviceability of 3.0 for roadways with an ADT of 5000 or greater;
- Use a 2.5 terminal serviceability for roadways with an ADT between 500 and 5000; and
- Use a 2.0 terminal serviceability for roadways with less than 500 ADT.

In addition to serviceability, the pavement service life, or period of performance, (e.g. 25 years) for a pavement must be established. An increase in the period of performance will generally result in an increase of the required pavement thickness or structural number value. **The following pavement service life (period of performance) standards apply:**

- For reconstruction projects (4R) use a minimum 25-year period of performance for flexible pavements (HACP) and a 35-year period of performance for rigid pavements (PCCP);
- For rehabilitation projects that increase structural capacity (3R), use a minimum 20-year period of performance regardless of pavement type;
- For preventive maintenance projects (i.e. surface treatments) there is no period of performance design requirement; and

- On aggregate surfaced roads use a period of performance for both reconstruction and rehabilitation projects that corresponds with the expected frequency of future rehabilitation/resurfacing treatments, which is typically 5 to 10 years.

Deviation from the above pavement service life standards will require justification, approval and documentation as a formal design exception (see Section 9.1.3, for a description of the Design Exception process).

11.2.1.2 Traffic

Accurate cumulative load estimates expressed as 18-kip [80 kN] equivalent single axle loads (ESAL) are very important to pavement structural design. Load estimates should be based on vehicle counts and classification, truck weight data, and anticipated growth in truck volumes and weights. The concepts described in the FHWA *Traffic Monitoring Guide* and the AASHTO *Guidelines for Traffic Data Programs* (AASHTO GTDP) contain procedures for obtaining accurate traffic data.

The *AGDPS* contains procedures for converting mixed traffic (with different axle configurations and weights) into design traffic equivalent single axle loads (ESALs). Part of these procedures involves converting expected axle loads and configurations into an equivalent number of ESALs. Standard load equivalency factors are used to complete this conversion, generally by developing a truck factor for each particular truck classification. AASHTO's *Guide for Vehicle Weights and Dimensions* (AASHTO GVWD) includes schematics of truck configurations as well as weight limits, and it can be used as a resource for developing truck factors.

Attaining good estimates of the daily truck traffic and truck class distribution is essential for completing a cost effective pavement design. Poor estimates of truck traffic can lead to premature failures and unplanned repair expense. However, achieving good estimates of traffic loading is not simple and generally requires a significant investment. Traffic data may exist at some project locations. Consult with local State DOTs or use the NPS Traffic Data website. The pavement and traffic engineer must balance cost and risk when determining the level of investigation needed for gathering traffic data.

For most FLH projects, it is recommended to calculate design ESALs using estimated truck factors. It is important to use representative truck factors for each truck classification that is expected to use the roadway. Refer to Exhibit 11.2–A for the 13 FHWA vehicle classifications with common truck factor ranges.

Exhibit 11.2–A FHWA VEHICLE CLASSIFICATIONS AND TRUCK FACTORS FOR FLEXIBLE PAVEMENTS

FHWA Class	Description	Truck Factor[1]
1	*Motorcycles.* This class includes all two or three wheeled motorized vehicles.	n/a

FHWA Class	Description	Truck Factor[1]
2	*Passenger cars*. This class includes all sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers.	0.0004 to 0.0008
3	*Pickups, Vans.* This class includes all 2-axle, 4-tire single unit vehicles other than passenger cars.	0.0004 to 0.004
4	*Buses.* This class includes all vehicles manufactured as passenger-carrying buses. These vehicles will typically have a 2-axle, 6-tire configuration or 3 or more axles.	0.75 to 1.75
5	*2-Axle, 6-Tire Single Unit Trucks*. Vehicles with a single frame that have 2-axles and dual rear tires characterize this class. Typical vehicle types include recreation vehicles, motor homes, and delivery vehicles.	0.3 to 0.7
6	*3-Axle, Single Unit Trucks*. All vehicles with a single frame and 3-axles make up this class. Typical vehicle types include large recreation vehicles and motor homes, garbage trucks, and dump trucks.	0.5 to 1.5
7	*4-Axle or More, Single Unit Trucks.* This class includes all vehicles on a single frame with 4 or more axles. This is a relatively uncommon vehicle class.	1.0 to 2.0
8	*4-Axle or Less, Single Trailer Trucks.* This class includes all vehicles with 4 or less axles consisting of two units (tractor and trailer). Typical vehicle types include freight hauling trucks.	1.5 to 2.0
9	*5-Axle Single Trailer Trucks*. This class includes all 5-axle vehicles consisting of two units (tractor and trailer). This class represents a very common truck on highways. It includes freight hauling trucks and logging trucks.	2.0 to 2.3
10	*6 or More Axle Single Trailer Trucks*. This class includes all vehicles with 6 or more axles consisting of two units (tractor and trailer).	2.0 to 2.3
11	*5 or Less Axle Multi-Trailer Trucks*. This class includes all vehicles with 5 or less axles consisting of three or more units.	3.0+
12	*6-Axle Multi-Trailer Trucks*. This class includes all 6-axle vehicles consisting of three or more units.	3.0+
13	*7 or More Axle Multi-Trailer Trucks*. This class includes all vehicles with seven or more axles consisting of three or more units.	3.0+

[1]Common values or ranges of truck factors for flexible pavements. Calculate project specific factors or refer to Division Supplements for more specific guidance.

The following standards apply:

- If design traffic ESALs is calculated to be less than 50,000, use 50,000 ESALs for design purposes when designing paved roads.
- Use a directional distribution of 60 percent, unless a traffic study warrants the use of some other value.
- For aggregate surfaced roads, use a minimum of 10,000 ESALs (per AGDPS).

If traffic growth projections are not available, use 2 percent for volume and 0 percent for loads, or engineering judgment. For high volume roadways, conducting a traffic study is recommended. In regards to lane distribution, use Exhibit 11.2–B taken from the *AGDPS* as guidance if measured distributions for multi-lane highways are not available.

Exhibit 11.2–B LANE DISTRIBUTION FACTORS

Number of Lanes in Each Direction	% of 18-kip [80 kN] ESAL in Design Lane
1	100
2	80 – 100
3	60 – 80
4	50 - 75

11.2.1.3 Subgrade Soil Characterization

The stiffness or strength of the subgrade soil has a significant impact on the structural requirements of a pavement and is one of the most sensitive inputs within the flexible pavement design equation. The definitive material property used to characterize soil stiffness in the *AGDPS* is the resilient modulus for flexible pavement design. The resilient modulus value is directly input into the design equation. For rigid pavement design, the elastic k-value on the top of the subgrade is the soil property used to characterize soil stiffness. **The following standards apply for determining the soil stiffness or strength:**

1. **Flexible Pavement.** Determine the soil resilient modulus using one of the following methods:
   a. Direct measurement by AASHTO T 307
   b. Backcalculation using FWD data collected in accordance with the FLH FWD Backcalculation and Data Collection Guide
   c. Completing soil index testing, either AASHTO T 193 (CBR) or AASHTO T190 (R-Value), and applying an established correlation from a local DOT, *AGDPS*, or *NCHRP 1-37A*.
   d. Completing dynamic cone penetrometer (DCP) testing according to ASTM D 6951 and applying an established correlation from a local DOT, *AGDPS*, or *NCHRP 1-37A*.

Additional guidance on determining the design resilient modulus input (i.e. effective annual resilient modulus) is included in Section 11.3.2.1.1.

2. **Rigid Pavement.** Determine the effective modulus of subgrade reaction (k-value) according to the process outlined in subsection 3.2.1 of the *AGDPS Supplement*.

In selecting a method to determine resilient modulus, the pavement engineer should consider the size, scope, and risk of the project. Standards and guidance for field investigation, sampling, and evaluation is provided in Section 11.3.1.

In areas with exceptionally soft or expansive soils, consideration of unique design elements such as installation of positive flow subsurface drainage, chemical treatment of soil, use of geosynthetics, or overexcavation should occur. In areas with frost-susceptible soils, consideration should be given to removing all or a portion of this soil and replacing with nonsusceptible soil or granular material.

11.2.1.4 Materials

Quality pavement materials and construction are essential. All materials specified should meet the requirements of the *FP-XX* and its supplements, and the applicable Division's library of specifications (LOS), and applicable project-specific SCRs. More specific guidance for materials is provided is Sections 11.3.2.3, 11.4.2.2, and 11.5.2.4.

Consider the following guidance for material property values and layer coefficients:

1. Rigid Pavement.
   a. PCC Elastic Modulus determination – use ASTM C469 or correlations included in the *AGDPS* or DARWin-ME software. Typical values will range from about 2,500,000 psi [17,000 MPa] to 6,000,000 psi [41,000 MPa]. 4,200,000 psi [29,000 MPa] was the value from the AASHO Road Test.
   b. PCC Modulus of Rupture determination – use AASHTO T 97 results as a basis, but remember to use the mean value expected during construction. 690 psi [4.8 MPa] was the average for the AASHO Road Test.
   c. Base modulus determination - use ASTM C469 or correlations included in the *AGDPS* or DARWin-ME software. 25,000 psi [172 MPa] is a typical value used for granular base and this was also the measured value at the AASHO Road Test. For a treated base, see Table 14 in the *AGDPS Supplement*.
   d. Slab/base friction coefficient – use Table 14 in the *AGDPS Supplement*
3. Flexible Pavement Layer Coefficients: Typical ranges are provided in Exhibit 11.2–C. Refer to the Division Supplements or testing data and analysis performed during project development to determine a specific input value. Site-specific material properties will often affect layer coefficient values. For additional resources, consult the *AGDPS*, which contains charts and equations that aid in determining layer coefficients.

Exhibit 11.2–C LAYER TYPES AND COEFFICIENTS

Layer Type	Layer Coefficient Range	Comments
HACP	0.40 – 0.44	Bid items 401 and 402.
HACP	0.38 – 0.40	Bid items 403 and 404.
Cold Asphalt Mix	0.25 – 0.35	Bid items 408 and 417.
Cold In-Place Recycling	0.25 – 0.30	Bid item 416.
Full-Depth Reclamation (FDR) – Pulverizing	0.10 – 0.12	Bid item 303. This range is appropriate for material with less than 25% passing the #200 [75 µm] sieve.
FDR – Cement	0.15 - 0.22	Bid item 304. Refer to Figure GG.9 of Volume 2 of the *AGDPS*. This layer coefficient is highly influenced by the in-situ material properties, compressive strength, and other factors.
FDR – Bituminous	0.20 - 0.25	Bid item 418. This layer coefficient value is highly influenced by the in-situ material properties, and other factors.
Treated Base	0.18 – 0.30	Bid item 302 and 309. Refer to Figure GG.9 and GG.10 of Volume 2 of the *AGDPS*.
Crushed Aggregate Base	0.12 – 0.14	Bid item 301. This range is appropriate for material with R-values greater than 80.
Subbase or Minor Aggregate Base	0.10	Bid items 301 and 308. This value is appropriate for material with R-values greater than 65.
Select Borrow	0.06 – 0.08	Bid item 204. This range is appropriate for material with R-values greater than 55.
Chemically Stabilized Subgrade	0.08 – 0.12	Bid item 213. To use 0.08, it is expected that the 28-day unconfined compressive strength is at least 100 psi [690 kPa].

11.2.1.5 Environment Considerations

The *AGDPS* considers two main environmental factors:

1. Temperature affects the stability of asphalt, asphalt oxidation rates, thermal-induced cracking, contraction and expansion of Portland cement concrete pavement (PCCP), and curling and warping of PCCP.
2. Rainfall will influence the properties of the subgrade soil, base, and surfacing material.

In addition, freezing and thawing of the subgrade soils and pavement layers remains a major concern for pavement engineers.

For frost-susceptible soils use the guidance provided in the AGDPS for identifying these soils, determining frost depth, and developing design solutions. An additional resource for seasonal frost conditions is Special Report 83-27.

The following standards apply:

1. **Flexible Pavement.** For the selection of appropriate asphalt cement, use the software program LTPPBind (LTPP models) with a 95% or greater reliability for both high and low temperatures. In determining the design resilient modulus for subgrade soil, consider seasonal variations in rainfall and saturation in order to calculate an annual effective subgrade resilient modulus.
2. **Rigid Pavement.** Average annual wind speed, temperature, and precipitation are required to determine the effective temperature differential (TD) for the PCC slab. Use the guidance and equations provided in the *AGDPS Supplement* to develop the TD value.

11.2.1.6 Drainage

Water and pavement layers are not good for each other. Maintaining positive drainage within the pavement structure is an important design consideration. Pavement engineers need to consider the effects of moisture on the performance of the pavement. Note that subsurface drainage needs as related to slope stability, intercepting springs, and other such items, is covered by the Geotechnical chapter in Section 6.4.9.2. .

When appropriate use drainage coefficients (m_i) for flexible pavement design as outlined in the *AGDPS*. As a basis for comparison, the m_i value for the conditions at the AASHO Road Test in northeastern Illinois was 1.0. For specific design alternatives (i.e. drainable bases with edge drains) and additional technical information use FHWA-NHI-131026 and the software program DRIP 2.0 for guidance. Note that the *AGDPS Supplement* does not incorporate the drainage coefficient, C_d, into the rigid pavement design equation.

11.2.1.7 Additional Rigid Pavement Design Inputs

The following standard applies to rigid pavement design: Use the *AGDPS Supplement* to optimize or select the following inputs associated with the particular dimensions of the slab:

- Joint spacing (L)
- Lane edge support adjustment factor (E)
- Base thickness (H_b)
- Joint Layout

11.2.2 DESIGN RELIABILITY AND RISK

Reliability is defined by the *AGDPS* as follows:

> "The reliability of a pavement design-performance process is the probability that a pavement section designed using the process will perform satisfactorily over the traffic and environmental conditions for the design period."

The pavement engineer needs to consider risk and reliability during the design process. The *AGDPS* has incorporated reliability concepts that allow the designer to vary the level of risk based on various classes of roads or other factors. As long as the standards and guidance of this chapter are followed it is recommended *that mean values be used as opposed to conservative values* for each of the design inputs. It is important to note that the design equations were developed using actual variations and mean values.

The following standards apply:

1. Use the following design reliability on FLH projects:
   a. 75 percent on roadways with less than 2500 ADT;
   b. 85 percent on roadways with 2500 to 5000 ADT; and
   c. 90 percent on roadways with ADT greater than 5000.
2. For the overall standard deviation of the design process (S_o), use 0.49 for flexible pavement design and 0.39 for rigid pavement design. These are "default" values recommended by the *AGDPS* to use when no formal study on local conditions has been completed.

11.2.3 ENGINEERING ECONOMIC EVALUATION

When multiple pavement design alternatives exist, a construction cost analysis should be completed. Pavements are long-term investments and on high volume routes additional costs that occur over the pavement life should be considered including maintenance costs and user costs. However, most FLH projects are on low-volume roads and a rigorous economic analysis of alternative strategies, materials, and user costs is typically unnecessary. If the alternatives are not structurally equivalent, minimum design standards are not met, and/or the alternatives have different maintenance requirements, completing a life cycle cost analysis (LCCA) may be appropriate. Refer to the FHWA *Final Policy Statement on LCC Analysis* published in the Federal Register September 18, 1996 for the requirements. The goal of LCCA is to identify the long-term economic efficiency of competing pavement designs.

When a LCCA evaluation is needed, the following documents and manuals provide excellent guidance:

- FHWA Memorandum *National Highway System Designation Act – Life Cycle Cost Analysis Requirements*, April 19, 1996.

- FHWA's Interim Technical Bulletin: *Life Cycle Cost Analysis in Pavement Design*, FHWA-SA-98-079, September 1998.
- FHWA's Demonstration Project 115: *Probabilistic Life Cycle Cost Analysis in Pavement Design*.
- RealCost LCCA software and User's Manual.

The FHWA policy on alternate bids for alternate pavement types is addressed in 23 CFR 635.411(b). This section requires the use of alternate bids "When…more than one…product…will fulfill the requirements…and these…products are judged…equally acceptable on the basis of engineering analysis and the anticipated prices…are estimated to be approximately the same." FLH does not encourage the use of alternate bids to determine the mainline pavement type, mix type, or rehabilitation method, primarily due to the difficulties in developing truly equivalent pavement designs.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

11.2.4 PREVENTIVE MAINTENANCE

Pavements will generally not reach their intended service life without some form of maintenance. Reactive maintenance, while necessary at times, is much less cost effective than preventive maintenance. AASHTO defines preventive maintenance "as the planned strategy of cost effective treatments to an existing roadway system and its appurtenances that preserves the system, retards future deterioration, and maintains or improves the functional condition of the system without increasing structural capacity." Examples of preventive maintenance treatments include chip seals, slurry seals, crack sealing, micro-surfacing, and friction courses.

An October 8, 2004 memorandum issued by the FHWA states, "Timely preventive maintenance and preservation activities are necessary to ensure proper performance of the transportation infrastructure." Research and experience has shown that when properly planned and applied, preventive maintenance treatments are the most cost effective way to extend the service life of pavements. An agency can improve the condition of their roadway network without an increase in funding through the implementation of a pavement preservation program. In other words, establishing a pavement preservation program offers a way of increasing the return of investment on roadway construction projects.

The FHWA memo titled Pavement Preservation Definitions discusses the components of pavement preservation and clarifies pavement preservation terminology.

11.2.5 ROADWAY SURFACING TYPE SELECTION

On projects in environmentally or historically sensitive areas or on projects where stakeholders have differing views and opinions on the purpose and need of the roadway project, the use of FHWA-CFL/TD-05-004 may be beneficial. This Guide includes a step-by-step process for selecting a surfacing type amongst a group of diverse stakeholders. This Guide also includes a catalog of all surfacing types that includes descriptions of the surfacing performance, appearance, constructability, costs, and numerous other factors. To go along with this catalog is a photo album that contains photos and design details of the surfacing types.

11.3 FLEXIBLE PAVEMENT DESIGN

11.3.1 FIELD RECONNAISANCE AND INVESTIGATION

There are two major phases in pavement design:

1. Field investigation and data gathering
2. Analysis of data through a design process

This subsection provides standards and guidance for field investigations. It is important to complete a well-planned field investigation that fits the scope, needs, and budget of the project. Coordinate the field reconnaissance, data gathering and investigation with other discipline scoping activities during the conceptual studies and preliminary design phase. Also refer to Section 4.3.2.15.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

11.3.1.1 Climate, Terrain, and Pavement History

Research and document the typical climate conditions for the project site including average annual rainfall, temperature ranges, and climatic zone of the project area. This information will help to determine drainage coefficients, timeframes for suitable construction, and the need for special measures to combat frost heave and/or thaw-weakening conditions.

Gather historical reports, scoping reports, archived files, RIP data, Visidata, and other such information to become familiar with the terrain of the project area, traffic volume, project context, areas of wetlands or springs, and general geology. Maximize the use of this information in developing the field investigation plan.

Gather information about the history of the existing surfacing including maintenance, rehabilitation, re-occurring problematic areas, original construction date, and as-built plans. The local facility managers are often excellent sources for this information. Again, maximize the use of this information in developing the field investigation plan.

11.3.1.2 Existing Pavement and Roadway Conditions

Determine typical surfacing/pavement distress and probable failure mechanisms, as appropriate. Use the Distress Identification Manual for the Long-Term Pavement Performance Program (LTPP), Publication No. FHWA-RD-03-031, to define and quantify distress.

If there is the potential that the pavement structural section may be salvaged and reused, measure pavement and bench widths at numerous locations (i.e. at every boring location) to characterize the range of widths. Also retain representative surfacing, base, and subbase samples for classification, gradation, and, if appropriate, strength testing.

Measure and record the thickness of the pavement structural layers (i.e. asphalt pavement, aggregate base, subbase) at a minimum of every 0.5 mile [0.8 km]. It may be necessary to have additional depth measurements if the structural layers will be salvaged. Record visual condition of pavement structural layers. In particular note whether there is evidence of such occurrences as asphalt stripping, excessive weathering, contamination by fines, and sulfate damage.

Record the roadway drainage conditions and determine the drainage coefficient (m_i) value. Using engineering judgment and information gathered from Section 11.3.1.1 above, estimate the quality of drainage. Exhibit 11.3–A, taken from the *AGDPS*, provides guidance.

Identify low clearance areas that may be problematic for construction equipment.

Identify existing features such as manholes, utilities, bench width, curb and gutter, and walls that may affect the pavement design or construction of the pavement.

Exhibit 11.3–A QUALITY OF DRAINAGE

Quality of Drainage	Water Removed Within
Excellent	2 hours
Good	1 day
Fair	1 week
Poor	1 month
Very Poor	Water will not drain

11.3.1.3 Subgrade Soil Conditions

The strength of the subgrade soil has a significant influence on the eventual pavement design. It is critical that the strength of the subgrade soil is properly quantified. Additionally, swelling soils, springtime thaw-weakening conditions, and frost heave will impact pavement performance and these conditions should be investigated as appropriate. Complete subsurface investigations in conformance with the sample retention, safety, boring closure, and logging methods described in Section 6.3 and AASHTO R 13, Conducting Geotechnical Subsurface Investigations. Always attain the necessary utility clearances and access permits prior to any investigation.

Coordinate with the geotechnical engineer on the project cross-functional team (CFT) for sampling and testing soil from areas that will be excavated during construction and used to construct embankments below the pavement structure. Consider the properties of this excavated material in determining design soil strength values.

Complete shallow borings, generally to a depth of 5 ft [1.5 m] below top of subgrade, a minimum of every 0.5 mile [0.8 km]. Photograph, log and visually classify the material. As appropriate, retain samples for classification, in-situ moisture content (retain sample in waterproof baggy), moisture-density relation, and strength testing per Section 11.2.1.3. A DCP may be used in lieu of or to supplement soil strength testing. Although not typically used on new or reconstruction projects, the FWD may also be used in lieu of or to supplement soil strength testing.

Investigate areas that may have unsuitable material within 5 ft [1.5 m] of the top of finished subgrade. Estimate limits and quantities for subexcavation. Recommend design details for the subexcavated area using Section 11.3.2 as guidance. It is important to provide positive drainage of the area by daylighting the backfill material to a foreslope or providing underdrains.

On projects where continuous or long stretches of unsuitable material (such as weak, wet, and/or high plasticity soils) exist, subexcavation may become cost prohibitive. Retain representative soil samples for follow-up analysis of potentially cost effective alternatives such as stabilization by chemical treatment, and/or stabilization by geosynthetics.

On projects where expansive soil may exist beneath the pavement structure, retain representative samples for follow-up testing according to AASHTO T 258 and T 92 and retain samples for investigating remedial methods to control swell. For additional guidance consult FHWA-RD-75-48, FHWA-RD-77-94, and FAA-RD-76-66.

Frost heave is the raising of a surface due to the formation of ice lenses in the underlying soil. At a minimum, pavements will be designed to prevent interruption of traffic due to bumps caused by differential heave. The past history of roadway performance in the area may provide a good indication of whether or not frost heave needs to be investigated. Additionally, a ground water table within 5 ft [1.5 m] of the surface is another signal of potential frost heave action. Refer to guidance in the *AGDPS*, EM 1110-3-138, and Special Report 83-27 for testing and investigation procedures.

Thaw weakening is related to frost heave above. It occurs as the gradual melting of ice lenses leaves soil unconsolidated and saturated. Support capacity can be greatly reduced during the thaw-weakening period. If annual load restrictions are not applied by the road-owner or are not practical, the pavement will be designed to account for the effects of thaw-weakened subgrade soil. Refer to Special Report 83-27 for testing and investigation procedures. Additional sources of information include the following:

- Technical Report ERDC/CRREL TR-00-6, *Thaw Weakening and Load Restriction Practices on Low Volume Roads*, 2000
- *Using TDR and RF Devices to Monitor Seasonal Moisture Variation in Forest Road Subgrade and Base Materials*, Gordon L. Hanek, et at, USDA Forest Service, 2001, and
- *Guidelines on the Use of Thermistor and TDR Instrumentation for Spring Thaw Road Management on Low-Volume Asphalt Roads*, USDA Forest Service publication number 0177 1805 – SDTDC, 2001.

It is not FLH standard practice to include drainable bases with an edge drain system on projects. However, designing a drainable base with an edge drain system or providing some other form of positive drainage of the pavement layers may be necessary to achieve long-term pavement performance in special cases. Using the materials of FHWA-NHI-131026, NCHRP 1-37A (Part 3, Chapter 1) and the software program DRIP 2.0, as guidance, evaluate whether or not special drainage measures are necessary and cost effective.

Exhibit 11.3–B provides a summary of the general soil characteristics that are evaluated on projects for pavement design purposes. Note that additional, more specialized testing may be necessary when expansive or frost susceptible soil exists.

The following standard applies: The number and frequency of samples submitted for testing will vary from project-to-project due to differing conditions and scope. At a minimum, representative soil samples from every mile will be tested for soil characteristics.

Exhibit 11.3–B SUMMARY OF GENERAL SOIL CHARACTERISTICS TO EVALUATE FOR PAVEMENT DESIGN

Characteristic	Test(s)
Strength	R-Value – AASHTO T 190 CBR – AASHTO T 193 Resilient Modulus – AASHTO T 307 FWD – FLH FWD Backcalculation and Data Collection Guide DCP – ASTM D 6951
Classification	AASHTO M 145 (AASHTO Soil Classification) ASTM D 2487 (Unified Soil Classification System)
Moisture Content (in-situ)	AASHTO T 255 or T 265
Moisture-Density Relation	AASHTO T 99, method C AASHTO T 180, method D

11.3.1.4 Project Constraints

In addition to investigating and documenting the soil, pavement, performance, terrain, and climate conditions discussed above, there are often other issues that can affect the pavement design and/or cost of the pavement. Investigate and/or document the project constraints as appropriate. A list of potential project constraints to consider is included below. This list may not be all encompassing.

- Can the road be closed to traffic or must traffic be maintained through the construction zone?
- What types of pavement materials are available locally? Will there be a substantial haul distance for materials?
- Are there project-funding constraints?
- Is there a lack of local contractors or certain construction equipment to perform the work?
- Will there be construction restrictions due to environmental issues?
- Limitations on grade raise?

11.3.2 DESIGN STANDARDS AND GUIDANCE

Use the methodology of the *AGDPS* for pavement design. Sections 11.2.1 and 11.2.2 contain standards and guidance for all the required design inputs. Additional guidance is provided below for designing layer thickness, specifying material types, and designing for problematic subgrade soils.

11.3.2.1 Subgrade Soil

Proper characterization and preparation of the subgrade are two of the most critical items in achieving a long-lasting pavement. Without an adequate foundation, pavement performance will suffer. Technical guidance is provided below to help determine the design soil strength as well as identify problem soils and minimize their effects.

11.3.2.1.1 Design Strength

For determining the design resilient modulus of the subgrade soil, it is important that an *annual average* resilient modulus or what is referred to as the effective soil resilient modulus is estimated as opposed to using a worst-case resilient modulus value. Inherent variability of soil conditions within a project is addressed by using the reliability and standard deviation values discussed in Section 11.2.2, and thus any value above an average value could result in an overly conservative design. Guidance for determining the effective soil resilient modulus is provided in the *AGDPS* and FHWA-RD-97-083. Equations for correlating index soil tests to resilient modulus are provided in the *AGDPS*, *NCHRP 1-37A*, and *AGDPS Vol. II*. Correlations equations developed by individual State DOTs may also be considered and used as appropriate.

11.3.2.1.2 Unsuitable (weak) Soil

There are projects where small areas of weak or compressible soils may exist amongst much stronger, more predominant soil. If these areas are small and localized, they will not significantly affect the pavement design. However, to avoid localized failures in these areas, it is recommended that a minimum of 2 ft [0.6 meters] of the unsuitable soil be removed (subexcavated) and replaced with select borrow or aggregate base. It is also recommended to place a geosynthetic fabric at the bottom of the subexcavation to provide separation and additional strength. De-watering the subexcavated area by daylighting the backfill material to a foreslope or providing some other form of positive drainage (i.e. underdrain) is important, especially in wet areas.

11.3.2.1.3 Swelling Soils and/or Soils with High PI (> 15)

Swelling or expansive soils can be very damaging to pavements. At a minimum, pavements should be designed to remain serviceable and safe under swelling and expansive soil conditions for the required performance period. Deformations or bumps caused by heaving or shrinking of the soil can be a safety issue and damaging to vehicles. These soils can also cause constructability problems such as difficulty in achieving compaction due to the pumping action of the soils. Construction equipment can also get bogged down in these soils especially in wet conditions. Even if swelling is not expected to occur due to the particular project conditions, these soils are weak and generally require a substantial pavement structural section. For additional guidance consult FHWA-RD-75-48 and FAA-RD-76-66.

The following is a list of potential treatments of expansive and/or high plasticity soils beneath the pavement structure (not intended to be all inclusive):

- When the expansive soil layer is just a few feet thick, remove the layer and replace with a select borrow material.
- Subexcavate the expansive soil to a suitable depth (see Exhibit 11.3–C) and backfill with an impermeable soil that is not expansive. A variation of this treatment is to include a waterproof membrane such as a plastic sheet, geosynthetic, or asphalt cement that completely lines the subgrade from backslope to backslope. When a waterproof membrane is used, it may not be necessary to backfill with impermeable material.
- Chemically stabilize the soil with lime or Portland cement. When an adequate quantity of lime is added and mixed with expansive soil, it can reduce the PI, and create a nearly impermeable, stable, and non-expansive layer. Chemical stabilization is a widely used method for controlling expansive soils. Refer to Exhibit 11.3–D on Soil Stabilization for additional guidance.

In general, the rational of the treatments is to keep the moisture content of the swelling soils constant. Swelling can be prevented if the moisture level of the expansive soils stays relatively constant. The pavement engineer must be judicious in the treatment selection. Not all of the treatments will be appropriate for every project. Cost /benefit analysis, project scope, and risk should all be considered.

Exhibit 11.3–C GUIDANCE ON SUBEXCAVATION DEPTH OF EXPANSIVE SOILS

Plasticity Index (PI)	Liquid Limit (LL)	Depth of Subexcavation
15 – 25	< 50	2 ft [0.6 m] *
25 – 35	50 – 60	2 – 4 ft [0.6 m – 1.2 m] *
> 35	> 60	4 – 6 ft [1.2 m – 1.8 m] *

*Traffic volume, project significance, and results of AASHTO T 258 and T 92 should influence subexcavation depth.

11.3.2.1.4 Frost-Susceptible Soils

For frost-related pavement problems to occur, three conditions must be present:

1. Frost-susceptible soils
2. Freezing temperatures that penetrate into the soil, and
3. A source of water.

Frost susceptible soils can lead to two pavement performance problems:

1. Heaving or deformation of the pavement due to the formation of ice lenses in the underlying soil, and
3. Pavement fatigue damage due to thaw-weakened subgrade of the springtime or any freeze-thaw cycle period.

Because thawing of the frozen subgrade occurs top-down, free water becomes trapped in the upper subgrade resulting in reduced bearing capacity of the soil (sometimes as low as 20% of the normal modulus during the summer). Pavements should be designed to remain safe and serviceable under frozen subgrade conditions for the required performance period. Usually the "complete protection" design approach of removing and replacing all frost-susceptible soil for the entire depth of frost is cost prohibitive. A more limited approach of permitting some frost penetration into the natural subgrade will generally keep surface roughness to an acceptable level.

The following resources can be used to determine frost design soil classification, frost depths, and design of treatments:

- EM 1110-3-138
- National Climatic Data Center (NCDC)
- *NCHRP 1-37A*
- PCase Software (Pavement-Transportation Computer Assisted Structural Engineering), use the MODBERG module for frost depth estimation, US Corps of Engineers
- USDA's County Soils Reports.

Design of treatments for frost susceptible soils generally involve two steps:

1. Assuring there is adequate pavement layer structure to account for the loss of bearing capacity during the spring thaw, and
2. Removing and replacing highly frost susceptible soil for a portion of the expected frost penetration.

Highly frost-susceptible soils include silts and some clays.

11.3.2.1.5 Soil Stabilization or Improvement

For long-term pavement performance and good constructability, an adequate foundation is very important. As stated in *NCHRP 1-37A*, stabilization of soils is usually performed for two reasons:

1. For construction expediency, to dry wet soils, and facilitate the compaction of the upper layers. In this case the improved or marginally stabilized soil is not considered as a structural layer

2. To strengthen a weak soil or combat swelling soils. In this case the significantly strengthened and stabilized soil is given some structural value in the pavement design process.

It is the responsibility of the pavement engineer to provide a pavement structural design that meets the performance criteria of the project at the lowest cost. On some projects soil stabilization may be an economical solution where fair to poor soils exist or where the combination of climate and soil conditions dictate the need for construction aids or expediency. Exhibit 11.3–D provides guidance on when and how to incorporate soil stabilization into the overall pavement structure. It is important to note that "bridging over" the problematic soil by providing a thick layer of select borrow or aggregate is a feasible option in most cases. However, when acceptable and inexpensive local aggregates are not available, this option can be cost prohibitive. In these cases, soil stabilization can be an economical alternative.

Exhibit 11.3–D TYPES OF SOIL STABILIZATION

Stabilization Type	Common Uses	Evaluation and Comments	Resources
Lime	♦ Increase strength of cohesive, clayey soils (application rates of 3 to 8 percent). ♦ Reduce or eliminate PI. (Use of lime is only recommended when PI of soil is > 10 and has > 25% passing #200 [75 µm] sieve.) ♦ Reduce swell potential of expansive soils. ♦ Drying wet subgrade (application rates of 1 to 3 percent). ♦ Improve constructability and workability of soil.	♦ Complete preliminary analysis using AASHTO M 216, ASTM C 977, and ASTM D 5102 to determine feasibility. ♦ Unconfined compression strengths of 100 psi [690 kPa] after a 28-day cure are desired (to be considered a structural layer). ♦ Sulfates in soil can have a detrimental impact when mixed with lime. Refer to the Technical Memorandum - Guidelines for Stabilization of Soils Containing Sulfates	National Lime Association Lime-Treated Soil Construction Manual NCHRP 1-37A Evaluation of Structural Properties of Lime Stabilized Soils and Aggregates Consideration of Lime-Stabilized Layers in M-E Pavement Design

Stabilization Type	Common Uses	Evaluation and Comments	Resources
Lime-Fly Ash (Class C and F)	♦ Increase strength of plastic and non-plastic soils (application rates 8 to 20 percent fly ash and 2 to 6 percent lime). ♦ Versatility for use on a broader range of soils (i.e. silts and sands). ♦ Improve constructability and workability of soil.	♦ Complete preliminary analysis using ASTM C 593 and ASTM D 5239 to determine feasibility. ♦ Different sources of fly ash will have different properties and may react differently with the soil. ♦ Unconfined compression strength results should be similar to what you would expect when using cement (> 200 psi [1.4 MPa]).	American Coal Ash Association (ACAA) Fly Ash Facts for Highway Engineers, FHWA-IF-03-019 ACAA Fly Ash Publication AASHTO TF-28
Fly Ash (Class C, self-cementing	♦ Increase strength of plastic and non-plastic soils (application rates of 10 to 20 percent). ♦ Drying wet subgrade. ♦ Improve constructability and workability of soil.	♦ If stabilization (increased strength) is desired, complete preliminary analysis using ASTM C 593 and ASTM D 5239 to determine feasibility. ♦ Different sources of fly ash will have different properties and may react differently with the soil. ♦ Unconfined compression strengths of 100 psi [690 kPa] after a 28-day cure or 50 psi [345 kPa] after a 7-day cure are desired (to be considered a structural layer).	American Coal Ash Association (ACAA) Fly Ash Facts for Highway Engineers, FHWA-IF-03-019 ACAA Fly Ash Publication AASHTO TF-28

Stabilization Type	Common Uses	Evaluation and Comments	Resources
Cement	♦ Increase strength of plastic and non-plastic soils (application rates of 3 to 12 percent). ♦ Used to treat clayey soils with a PI less than 20. ♦ Improve constructability and workability of soil.	♦ If stabilization (increased strength) is desired, complete preliminary analysis using ASTM D 1633, AASHTO T134, T 135, and T 136. ♦ Unconfined compression strengths of 200 psi [1.4 MPa] after a 7-day cure are desired (to be considered a structural layer).	Soil-Cement Laboratory Handbook (PCA publication) Properties and Uses of Cement-Modified Soil (PCA publication IS 411.02) Soil-Cement Construction Handbook (PCA Publication)
Asphalt	♦ Increase strength of granular, cohesionless soils (i.e. sand) ♦ Waterproofing subgrade.	♦ Not a common treatment. ♦ Similar to a prime coat, with more thickness.	
Geosynthetics /Geogrids	♦ Reinforcement of weak soils ♦ Provide construction expediency in saturated soil conditions.	♦ Some guidelines are included in AASHTO PP-46, AASHTO M 288, and ASTM D 4439.	NCHRP 1-37A (Part 2, Chapter 1)

11.3.2.1.6 Borrow Material

The better soil (i.e. more granular, lower PI material) obtained from excavated or other areas along the project should be used in the upper part of embankment or fill areas. Soil that has strengths below the design strength should not be used in the upper 2 ft [0.6 m] of embankments and fills.

11.3.2.2 Required Structural Number (SN) and Designing Layer Thickness

After all of the design inputs have been estimated or determined, calculate the required structural number (SN) by using the flexible pavement design equation or flexible design nomagraph included in the *AGDPS*. The AASHTO DARWin-ME software can also be used to calculate the SN.

Once the SN is determined, it is necessary as stated in the *AGDPS* "to identify a set of pavement layer thicknesses which, when combined, will provide the load-carrying capacity corresponding to the design SN." It is important to note that there is not a single unique solution for the pavement layering system that will meet the design SN. The pavement engineer will need to consider several factors when trying to optimize the layering system. These factors include material costs, traffic, construction constraints, subgrade soil characteristics, historical performance, and maintenance constraints. A typical pavement structural section for FLH includes a HACP top layer over a crushed aggregate base and/or subbase over a prepared subgrade. However, layers consisting of treated aggregate bases, chemically treated subgrade, and select borrow may be advantageous to use under certain project conditions.

In general, historical performance has shown when a granular layer such as an aggregate base or subbase course contributes to at least 35 percent of the design SN the pavement performs satisfactorily. This is especially true over fine-graded subgrade soil. The benefits of a granular layer include improved drainage, improved frost protection, and more uniform foundation for the placement of asphalt pavement.

The following standards apply:

- Recommend design layer thickness in ½ in [13 mm] increments, rounding up.
- Regardless of the SN required it is impractical and sometimes uneconomical to place base and asphalt courses of less than some minimum thickness, the following are minimum pavement layer thicknesses for reconstruction (4R) projects:
    - ◊ HACP, 2 in [50 mm]
    - ◊ Aggregate Base or Subbase, 4 in [100 mm] (a stabilized subgrade may be used in lieu of this requirement)

11.3.2.3 Selecting Material Types

The use of quality materials that meet the strength, durability, and consistency criteria used to develop the pavement design is important to achieve a durable and long-lasting pavement. The following, which references specifications from the *FP-XX*, provides guidance for specifying material types of the various pavement layers. Refer to the Division Supplements for design application rates and unit weights to use for estimating purposes:

11.3.2.3.1 Asphalt Mix (HACP)

Either Section 401 (Superpave) or 402 (Hveem or Marshall) are specified on most projects. Selection of 401 or 402 is usually based on the mix design commonly used by the local State DOT or what is the most practical within the region of the project. Typically either a ½ in or ¾ in [13 mm or 19 mm] nominal maximum aggregate size is specified, but refer to Division Supplements for specific guidance on gradation and mix type.

Section 403, allows for a Hveem, Marshall, Superpave, or other State DOT asphalt concrete mixture to be used. Section 403 is commonly specified on small projects when it is impractical to accept material statistically (i.e. < 4000 tons [tons] HACP)

Section 404 is generally only used for sidewalks, paved waterways, and other areas that don't receive significant traffic loading.

Section 405, open graded friction course (OGFC), is specified as a riding surface only when splash and spray, tire-pavement noise, and/or wet pavement skid resistance is identified as a significant project issue. In areas where freezing temperatures occur, caution should be employed when specifying an OGFC because durability can be an issue with these mixes in cold climates.

11.3.2.3.2 Asphalt Binder

When specifying Section 401 or 402 asphalt concrete mixes, use the software program LTPPBind (LTPP models) and select an asphalt binder grade with a 95% or greater reliability. Verify that the selected asphalt cement grade is locally available. An asphalt binder grade is typically not specified when using 403 or 404 asphalt mixes. For pavements with multiple asphalt layers, a different grade may be specified for layers below the surface course as long as 95% reliability is met for the layer depth. However, the practicality and economic considerations of specifying multiple grades should be evaluated. Generally, at least 10,000 tons [tons] of mix in the lower layer is needed to have a significant cost impact.

11.3.2.3.3 Additives for HACP mixes

Refer to Division Supplements for specific guidance on usage, types, and application rates for additives such as lime.

11.3.2.3.4 Untreated Aggregate Base and Subbase

Section 301 (Untreated Aggregate Base) is specified on most projects when base and/or subbase is part of the pavement structure. Refer to Division Supplements, for specific guidance on gradation designation.

Section 308 (Minor Aggregate) is typically specified on projects when small quantities (i.e. < 4000 tons [tons]) make it impractical to accept material statistically.

FLH does not have a standard specification for permeable base. If permeable base is necessary on a project, it is recommended that a bound permeable base be used as opposed to an unbound permeable base. Unbound permeable bases can be difficult to compact and will often not provide a stable construction platform to complete paving operations. Refer to FHWA-NHI-131026 for guidance.

On some projects it may be economical to use a select borrow material as a lower subbase layer, especially when there is a readily available material source near the project location. Typically Section 204 is used to pay for this material.

11.3.2.3.5 Treated Base

Section 302 (Treated Aggregate Courses) or 309 (Emulsified Asphalt-Treated Base Course) can be specified when advantageous or cost effective for the project conditions. Some conditions that may warrant the use of a treated base include very high traffic loading, necessity to improve properties of lower quality aggregates, and bridging over poor subgrade.

11.3.2.3.6 Stabilized or Reinforced Subgrade

Section 213 (Subgrade Stabilization) or 207 (Earthwork Geotextiles) can be specified when advantageous or cost effective for the project conditions. Refer to Section 11.3.2 for additional guidance on usage, stabilizer type, and application rate.

11.3.2.3.7 Prime Coat, Tack Coat, and Fog Seal

Section 412 (Tack Coat) is specified on all projects with multiple lifts of HACP. Typically, the contractor is given the option to choose from the following emulsified asphalt grades: CSS-1, CSS-1h, SS-1, and SS-1h.

Section 411, Prime Coat, is typically specified on all projects with an aggregate base course beneath the HACP. Refer to Division Supplements and *Guidelines for Using Prime and Tack Coats* for additional information and guidance. If a specific prime material is specified in the contract, verify that the material is readily available, allowed by the local county or jurisdiction, and formulated to penetrate.

Refer to Division Supplements, to determine whether or not Section 409 (Fog Seal) is required on the project.

11.4 STRUCTURAL DESIGN OF AGGREGATE SURFACING

Most pavement and materials practitioners will agree that it is acceptable and practical to have an aggregate surfaced road when the ADT is less than 50. However, it is much more difficult getting agreement among practitioners on where the upper ADT threshold should lie for an aggregate surfaced road. Factors such as the type of traffic and function of the road are also important to consider when determining the suitability of aggregate surfacing.

11.4.1 FIELD RECONNAISANCE AND INVESTIGATION

There are two major phases in structural design of aggregate surfacing:

1. Field investigation and data gathering, and
2. Analysis of data through a design process.

This subsection provides standards and guidance for field investigations. It is important to complete a well-planned field investigation that fits the scope, needs, and budget of the project.

The following standard applies: Complete the field reconnaissance and investigation procedures as discussed in Section 11.3.1.1, 11.3.1.2, 11.3.1.3, and 11.3.1.4, albeit with an intensity and scope suitable and efficient for the project needs.

Generally structural performance issues related to frost heave, expansive soils, and subsurface drainage are not mitigated on aggregate surfaced roads. Coordinate these issues with the project cross-functional team.

11.4.2 DESIGN STANDARDS AND GUIDANCE

It is FLH standard practice to use the aggregate thickness design procedure included in the *AGDPS* and Gravel Roads (LTAP) manual. It is also acceptable to use the procedure in the Forest Services' *Aggregate Surfacing Design Guide* (Report number J669, February 1990) or *Earth and Aggregate Surfacing Design Guide for Low Volume Roads* (Report number EM-7170-16 or FHWA-FLP-96-001, October 1995). Both of these guides were developed for the Forest Service and specific inputs or process is not discussed in this chapter.

Additional design inputs not addressed in the guidance and standards in Section 11.2 include the following:

- Allowable Rutting: Typical values fall between 1.0 and 2.0 in [25 and 50 mm].
- Aggregate Loss of Surface Layer: This value is highly dependent upon the climate, traffic level, and frequency of maintenance / grading performed. The loss of ½ in [13 mm] of gravel per year can be used if specific information is not available.
- Length of Season: Estimate this variable using the table and figures in the *AGDPS* or from trusted climatic data from other sources.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

11.4.2.1 Designing Layer Thickness

The structural layers of an aggregate surfaced road will generally consist of an aggregate surfacing layer (with a gradation and plasticity that will provide binding and stability) over a prepared subgrade. If the existing subgrade soil is weak and/or traffic loading is relatively large, it may be economical to use additional structural layers such as geotextile reinforcement, soil stabilization, or select borrow.

Aggregate surfaced roads are inherently dusty. The use of dust palliatives should always be considered. In addition to reduced dusting, dust palliatives can provide stabilization and reduce the frequency of blade maintenance. Dust palliatives reduce the loss of fines, which leads to reductions in the loss of larger aggregates and reductions of distresses such as washboarding. The Gravel Roads (LTAP) and Forest Service 9977 1207 SDTDC contain additional guidance.

The following standards apply:

- Recommend design layer thickness in ½ in [13 mm] increments, rounding up.
- Regardless of the calculated thickness design results, it is impractical and sometimes uneconomical to place aggregate surfacing less than some minimum thickness. The minimum aggregate surfacing layer thickness for reconstruction (4R) projects is 6 in [150 mm].

11.4.2.2 Selecting Material Types

The use of quality materials that meet the strength, durability, and consistency criteria used to develop the aggregate surfacing structural design is important to achieve a durable and long-lasting pavement. The following, which references specifications from the *FP-XX*, provides guidance for specifying material types of the various pavement layers. Refer to Division Supplements, for design application rates and unit weights to use for estimating purposes.

11.4.2.2.1 Aggregate Surfacing and Subbase

Section 301 (Untreated Aggregate Base) is specified on most projects when aggregate surfacing is part of the structural section. Typically, at least the top 6 in [150 mm] of the structural section will meet the requirements of Section 703.05 (c) to provide binding and stability. Refer to Division Supplements, for specific guidance on gradation designation.

Section 308 (Minor Aggregate) is typically specified on projects when small quantities (i.e. < 4000 tons [tons]) make it impractical to accept material statistically.

On some projects it may be economical to use a select borrow material as a lower subbase layer, especially when there is a readily available material source near the project location. Typically Section 204 is used to pay for this material.

11.4.2.2.2 Stabilized or Reinforced Subgrade

Section 213 (Subgrade Stabilization) or 207 (Earthwork Geotextiles) can be specified when advantageous or cost effective for the project conditions. Refer to Section 11.3.2 for additional guidance on usage, stabilizer type, and application rate.

11.4.2.2.3 Dust Palliatives

Section 306 is specified on projects requiring a dust palliative. It contains specifications for the more traditional dust palliatives such as salts, lignin sulfides, and emulsified asphalts.

11.5 RIGID PAVEMENT DESIGN

FLH designs and builds few mainline Portland cement concrete pavements (PCCP) due to the predominant low-volume traffic conditions on most FLMA routes. However, it is common for FLH to design and build PCCP at spot locations such as low-water crossings, bus parking/turnarounds, entrance station kiosks, and boat ramps. The thickness design in these spot locations is usually governed by minimum thickness requirements as opposed to traffic loading. Regardless, a design methodology and required design inputs for PCCP are presented in this chapter.

11.5.1 FIELD RECONNAISSANCE AND INVESTIGATION

There are two major phases in pavement design:

1. Field investigation and data gathering, and
2. Analysis of data through a design process.

This subsection provides standards and guidance for field investigations. It is important to complete a well-planned field investigation that fits the scope, needs, and budget of the project.

Generally, the field reconnaissance and investigation procedures included in Section 11.3.1 are to be used. However, if existing PCCP is going to be removed or salvaged, and replaced with new PCCP, note the following exceptions:

- Existing Pavement and Roadway Conditions
  - ◊ If good quality as-built information exists, coring of the PCCP for determining layer thickness can be eliminated. However, coring of the PCCP and base should still occur, as needed, for forensic analysis and/or for determining salvage value.
  - ◊ Determine whether steel reinforcement and/or steel dowels exist within the PCCP.
- Subgrade Soil Conditions
  - ◊ Characterization of soil subgrade for determining k-value should be evaluated by FWD analysis (or historical reports). This will reduce the amount of time-consuming and relatively expensive coring operations.

11.5.2 DESIGN STANDARDS AND GUIDANCE

When traffic loading dictates, use the methodology of the *AGDPS Supplement* for jointed plain concrete pavement (JPCP) design. Otherwise use the minimum thickness requirements listed in Exhibit 11.5–A below.

Sections 11.2.1 and 11.2.2 contain standards and guidance for all the required design inputs of the AGDPS process. Additional guidance is provided in the following subsections for design checks, slab and base minimum thickness values, joint design, use of reinforcement/dowels, material types, and subsurface drainage.

Refer to [EFLHD – CFLHD – WFLHD] Division Supplements for more information.

11.5.2.1 Designing Slab and Base Thickness

Review the guidance provided in Exhibit 11.5–A to evaluate whether or not it is necessary to complete a thickness design using the *AGDPS Supplement*.

Exhibit 11.5–A MINIMUM THICKNESS FOR PCCP AND BASE

Traffic Level, 18 kip [80 kN] ESALs (or function of PCCP)	PCCP in [mm]	Base in [mm]	Comments
Greater than 1,000,000	8.0 [200]	4.0 [100]	Evaluate acceptability of minimum thickness using *AGDPS Supplement*
500,000 to 1,000,000 (or Low-Water Crossings, and Boat Ramps)	8.0 [200]	4.0 [100] (untreated)	No design necessary. Evaluate need for treated base/subgrade and increased thickness when building over A-7 soils (fat clays)
Less than 500,000	6.0 [150]	4.0 [100] (untreated)	No design necessary. Evaluate need for treated base/subgrade and increased thickness when building over A-7 soils (fat clays)

11.5.2.2 Design Checks

When it is necessary to use the *AGDPS Supplement* for thickness design and dowels are not being used at the transverse joints, it is good practice to check that the stresses created at the top of the slab when an axle load is at the joint are not excessive. Complete the "joint load position cracking" check as described in the *AGDPS Supplement*.

When it is necessary to use the *AGDPS Supplement* for thickness design, complete a "joint faulting" check as described in the *AGDPS Supplement* after the required slab thickness is determined. As stated in the *AGDPS Supplement*, "Slab thickness should not be increased in an effort to improve the joint load transfer design, because slab thickness has only a minimal effect on joint faulting." The *AGDPS Supplement* suggests other potential adjustments to reduce faulting including using or increasing the diameter of dowels, and/or selecting a different base type.

11.5.2.3 Joint Design, Use of Dowels, Use of Reinforcement, and Other Details

The guidance and details provided below is meant for use on typical FLH projects such as rural roads or city streets. It may or may not be appropriate for high volume highways. The guidance was developed using the *AGDPS* and the ACPA's *Concrete Engineering of Streets and Local Roads Reference Manual* (ACPA – TB200P). For guidance on higher volume roads refer to FHWA Technical Advisory T 5040.30, Concrete Pavement Joints and FHWA-NHI-131060.

11.5.2.3.1 Joint Design

Use a maximum transverse joint spacing of 15 ft [4.6 m] for 8 in [200 mm] slab thickness or greater, and a maximum joint spacing of 12 ft [3.7 m] for 6 in [150 mm] slab thickness.

Use a slab width to length ratio that does not exceed 1.25. Avoid joint intersection angles less than 60°.

The use of expansion joints is generally not necessary with the above transverse joint spacing. However, the use of isolation joints is critical at intersecting roads, drainage structures, or other fixed objects.

Longitudinal joints should be placed at the centerline to aid in delineation of traffic lanes.

Additional guidance for joint layout along roadways, intersections, and parking areas is provided in the ACPA *Design and Construction of Joints for Concrete Streets* and *Intersection Joint Layout* publications included in ACPA – TB200P.

11.5.2.3.2 Use of Dowels

Consider using dowel bars to minimize faulting when Class 9 semi-tractor trailer traffic exceeds 50 per day or when the 18 kip [80 kN] ESALs exceed 1 million.

If dowel bars are required, use a 14 in [350 mm] long, ¾ in [19 mm] diameter dowel for a 6 in [150 mm] slab, and a 17 in [430 mm] long, 1¼ in [32 mm] diameter dowel for an 8 in [200 mm] slab.

Place dowels at 12 in [300 mm] centers along the joint.

11.5.2.3.3 Use of Reinforcement

It has been well established that distributed steel or wire mesh can serve to hold cracks tightly together, but the steel in the amount needed for holding cracks together does not add to the structural strength of the pavement. As a result, if proper joint layout and geometry is accomplished, no intermediate cracking should occur and distributed steel can be omitted.

When long and narrow slabs, irregular shaped slabs, or unsupported/untied edges are necessary, it is good practice to place small diameter reinforcement (i.e. #3 [#10] bars spaced on 12 in [300 mm] centers both longitudinally and transversely) 2 in [50 mm] below the surface.

Using reinforcement may be advantageous when the slab functions as a low-water crossing, boat ramp, or any riding surface where highly erodible or saturated conditions exist.

Use deformed tie bars to tie longitudinal joints when there is no curb or other firm lateral restraint. Curbing that is tied to the mainline slab will also keep the longitudinal construction joint tight. Never place tie bars within 15 in [380 mm] of transverse joints or they may interfere with joint movement.

11.5.2.3.4 Other Details

For information and details on joint sealant, deformed bar length and sizes, typical sections, joint types, etc., refer to the 501 series of standard drawings and specials. For guidance on surface texture, refer to FHWA Technical Advisory T 5040.36, Surface Texture for Asphalt and Concrete Pavements.

11.5.2.4 Selection Material Types

The use of quality materials that meet the strength, durability, and consistency criteria used to develop the pavement design is important to achieve a durable and long-lasting pavement. The following provides guidance for specifying material types of the various pavement layers:

- Rigid Pavement (PCCP) – From the *FP-XX*, Section 501 is typically used to specify concrete pavement.
- Untreated and Treated Base; Stabilized and Reinforced Subgrade – Specify as indicated under Section 11.3.2.3.

Refer to Division Supplements, for design application rates and unit weights to use for estimating purposes.

11.6 PAVEMENT REHABILITATION

The *AGDPS* defines pavement rehabilitation as "any work that is undertaken to significantly extend the service life of an existing pavement through the principles of resurfacing, restoration, and/or reconstruction." The AASHTO Highway Subcommittee on Maintenance defines major rehabilitation as "…structural enhancements that both extend the service life of an existing pavement and/or improve its load-carrying capability." This second definition better fits the focus of this section.

11.6.1 REHABILITATION METHODS: FLEXIBLE PAVEMENTS

In addition to institutional knowledge, three primary resources were used to develop the standards and guidance included in this subsection:

- FHWA-NHI-131008
- ARRA's Basic Asphalt Recycling Manual (BARM)
- *AGDPS*

11.6.1.1 General Field Reconnaissance and Investigation

Generally, the field reconnaissance and investigation procedures included in Section 11.3.1 are to be used. Additions and variances to those procedures are included below. With a reconstruction project (4R), the pavement engineer is primarily concerned with properly characterizing the subgrade soil conditions. With a pavement rehabilitation project (3R), the pavement engineer is still concerned about the subgrade strength but also has to consider how best to rehabilitate the existing pavement structure. Due to the additional variables, the pavement investigation for rehabilitation projects is generally more time-consuming and intense.

Identify and document whether or not steep grades exist (> 8 percent). Identify and document if the road has a curvy alignment and the number of sharp curves (radius < 40 ft [12 m]). These factors can affect cost and feasibility of some rehabilitation methods.

Identify stonewalls, low clearances, utilities, and other obstacles that may affect the selection of a rehabilitation method.

When as-built, rehabilitation, and maintenance information is not available, measure and record the thickness of the pavement structural layers at least every ¼ mile [400 m]. It is good practice to vary coring/boring locations transversely across the pavement. If the pavement thickness has significant variability, additional measurements or use of ground penetrating radar (GPR) may be necessary. Typical areas where variation in pavement depths may occur include patched/repaired areas, over culverts, shoulders vs. mainline, and wetland areas.

Record the visual condition of the pavement structural layers. In particular record the type of material/mix, whether there is evidence of stripping or raveling, approximate maximum aggregate size, and contamination by fines. It may be prudent to retain samples for follow up evaluation of properties such as moisture susceptibility.

When the rehabilitation scope includes recycling and/or reclamation, retain bulk samples of the asphalt pavement, base, and subgrade from test pits or large diameter coring. Multiple test pits will often be necessary as it is important that the full range of material types and conditions be sampled. Use this material for completing preliminary mix designs, gradations, and/or classifications. The results of this laboratory testing will help determine the feasibility and selection of the rehabilitation method.

When the rehabilitation scope includes recycling and/or reclamation, it is very important to quantify and characterize all of the materials and structures that will be encountered within the depth of recycling. If a contractor encounters unexpected buried manholes, paving fabric, shallow utilities, cobbles, and/or boulders, not only will FLH be culpable, but the project construction may also be delayed.

Follow Section 11.3.1.3 for subgrade soil condition investigation except when the scope of the rehabilitation includes just an overlay or a mill and overlay. In this case use a FWD to estimate the modulus values of the pavement layers and subgrade soil. Follow the testing and analysis guidance provided in the FLH FWD Backcalculation and Data Collection Guide. Using correlations equations from the *AGDPS*, the structural coefficient of the individual layers and/or overall SN can be estimated.

11.6.1.2 Design Standards and Guidance

Unless otherwise indicated, use the methodology of the *AGDPS* for pavement design. Additionally, Module 3-11, Identification of Feasible Alternatives in FHWA-NHI-131008 provides specific criteria and guidance for selecting rehabilitation methods.

For HACP overlays or mill and overlays the preferred practice is to use FWD deflection data and the backcalculation software program MODTAG to estimate layer moduli values and correlate these values to structural coefficients for the completion of a component design. The inputs and process discussed in Section 11.2 and 11.3 would apply. A secondary option is to use FWD deflection data and the backcalculation analysis included with the DARWin-ME software program. In this case, the overlay design program included with the DARWin-ME software would also be used.

When providing a rehabilitation recommendation, it is important that the pavement engineer considers the type of pavement deterioration, physical project constraints, costs of several alternatives, disruption of traffic, constructability, climate, and other pertinent issues. On most projects there is more than one feasible rehabilitation alternative, it is incumbent upon the pavement engineer to complete a comprehensive analysis of these factors before putting forth a recommendation. The following subsections and links present standards, guidance, and criteria to use for determining a cost effective and appropriate pavement rehabilitation method.

The following standard applies: For an HACP layer to be assigned a structural value (or coefficient), it must be at least 1½ in [38 mm] thick.

11.6.1.3 HACP Overlays

As indicated in FHWA-NHI-131008 the general purpose of an HACP overlay is to improve the functional or structural performance of an existing pavement. So it is important that the need for an overlay be accurately identified and the condition of the existing pavement properly characterized.

This subsection primarily covers the use of structural overlays, but it is important to recognize that thin and ultra-thin overlays are commonly used to correct functional deficiencies such as roughness, hydroplaning, and surface friction. Refer to Section 11.7 for use of thin overlays as a preventive maintenance treatment or to correct functional deficiencies.

Do not use overlays on pavements that have high severity fatigue, block, transverse and/or longitudinal cracking throughout the project area. Pavements nearing the end of their service life are better candidates for reclamation and recycling alternatives. Do not use overlays on pavements that are stripping and are moisture sensitive.

Closely evaluate the cost effectiveness and service life of an overlay on a pavement that exhibits moderate severity fatigue, block, transverse, and/or longitudinal cracking throughout the project area. If an extensive amount of pre-overlay repair is needed to achieve the required service life, recycling and reclamation alternatives may be more cost effective.

Pavements that are rutted (and not moisture sensitive), with low severity cracking distress, and relatively infrequent locations of higher severity distress, are good candidates for an overlay. Appropriate pre-overlay repairs should be completed prior to the overlay. According to both the *AGDPS* and FHWA-NHI-131008, the amount of pre-overlay repairs is one of the most significant factors affecting the future service life of the overlay. Exhibit 11.6–A contains a list of common pre-overlay repairs.

Advantages of overlays include:

- Very common treatment with a large availability of contractors that can complete the work
- Construction is relatively simple and can be completed with minimal disruption to traffic.
- When used appropriately, life-cycle costs are competitive

Limitations of overlays include:

- The greater the deterioration of the existing pavement, the lower the cost effectiveness.
- Increased risk of premature cracking or other failures, due to pre-existing conditions.

For material type selection, refer to Section 11.3.2.3.

Exhibit 11.6–A TYPICAL PRE-OVERLAY REPAIRS

Distress Type	Suggested Repair
Fatigue cracking and/or potholes	Saw cut and remove all distressed pavement. Replace with a suitable bituminous mixture. Depending upon whether the distress is related to the asphalt mix or the subgrade, subexcavation according to Section 11.3.2.1 may also be necessary.
Thermal and longitudinal cracks	Seal cracks < 0.75 in [19 mm] in width with a suitable material. Wider cracks may have to be filled with a sand-asphalt mix or other suitable material and may require reflection cracking control measures.
Rutting	Place a leveling course of HACP or remove ruts by milling.
Heaving, depressions, bumps	Investigate cause and treat the *cause*, not just the symptom.
Distress related to poor drainage conditions	Improve or correct drainage conditions.

11.6.1.4 Asphalt Pavement Milling

Asphalt pavement milling uses a self-propelled milling machine with drum-mounted carbide steel cutting teeth to chip off the surface of a pavement. With a milling operation, the depth of removal, longitudinal profile, and cross-slope can be controlled. The resulting grooved or textured asphalt surface is suitable for an overlay, once it is cleaned, broomed, and tack coated.

Generally, all milling operations precede an overlay or recycling process. Rarely is the milled surface used as the permanent riding surface. The most common use of milling for FLH is to eliminate grade raise or restore pavement elevation to the curb reveal. Other common uses of milling include removal of rutting, restoration of cross-slope geometry, and improve smoothness.

Single pass milling depths can be very shallow (i.e. ½ in [13 mm]) using micro-milling or relatively thick (> 4 in [100 mm]) using high capacity milling machines.

Milling should not be used to mitigate full-depth cracks, unless the full-depth of asphalt pavement is milled.

Constructability issues to consider include determining overhead clearances for the milling machine and identifying buried utilities such as abandoned manholes or other castings within the pavement layers to be milled.

When an HACP overlay is to follow the milling operation, it is necessary to have enough remaining pavement structure to support the paving equipment and operations. Generally, on a low-volume road, no less than 2 in [50 mm] of asphalt pavement should remain in-place. If the stability and durability of this lower depth asphalt pavement is questionable, a mill and overlay rehabilitation should not be recommended.

Advantages of milling include:

- Efficient way to restore required geometry, smoothness, and eliminate grade raises.
- Minimal traffic disruption.
- Millings can be recycled.

Limitations of milling include:

- Production levels may be reduced on steep grades or on sharp curves.
- If millings are not recycled locally, they may have to be hauled a long distance for storage/disposal.

Use Section 413 of the *FP-XX* to specify the cold milling operation. Refer to the *ARRA Basic Asphalt Recycling Manual* (*BARM*) for additional guidance and information on milling.

11.6.1.5 Full Depth Reclamation (FDR)

The *ARRA Basic Asphalt Recycling Manual* (*BARM*) describes FDR as a "…rehabilitation technique in which the full thickness of the asphalt pavement and a predetermined portion of the underlying materials (base, subbase, and/or subgrade) is uniformly pulverized and blended to provide an upgraded, homogeneous base material." There are three general categories of FDR:

1. Mechanical stabilization which includes just pulverizing, grading, and compacting,
2. Chemical stabilization which includes pulverizing, adding cement to stabilize, grading, and compacting, and
3. Bituminous stabilization which includes pulverizing, adding foamed asphalt or emulsified asphalt as a stabilizing agent followed by grading and compacting.

FDR is a versatile and cost effect rehabilitation option. The FDR process can accommodate some widening (~ 2 ft [0.6 m]), grade or geometry corrections, high traffic volumes, variable materials, curb and gutter, and pulverization depths up to 12 in [300 mm]. There are numerous good references and resources to use when evaluating the suitability of using of FDR. The following are recommended:

- *ARRA Basic Asphalt Recycling Manual* (*BARM*)
- *Soil-Cement Laboratory Handbook*, PCA
- *Wirtgen Cold Recycling Manual*, Wirtgen Group
- *Guide to Full-Depth Reclamation with Cement*, PCA (item code EB234, date 2005)

Use FDR to treat pavements with significant distress and to increase structural capacity of pavements nearing the end of their service life. FDR requires a wearing surface such as HACP.

FDR does not address localized subgrade or drainage problems. These areas should be identified during the pavement investigation with solutions developed to address the cause.

Constructability issues include:

- Determining overhead clearances for reclaimer/pulverizer,
- Identifying buried utilities such as abandoned manholes or other castings within the pavement layers to be pulverized,
- Assure no boulders or oversize rocks are within the depth to be pulverized,
- Determining feasibility of lowering manholes or other utilities within the roadway to accommodate pulverizing operation.

Collect bulk samples of the pavement layers per Section 11.6.1.1 to evaluate material properties and complete a preliminary mix design if necessary. Use the results to determine suitability, estimate application rates, and estimate structural coefficient values to use. Exhibit 11.6–B provides additional guidance.

Exhibit 11.6–B FDR EVALUATION GUIDANCE

FDR Method	Typical Application Rate of Stabilizer	Target Strength	Test Method	Comments
Mechanical (Pulverization)	N/A	R-Value > 70 CBR > 40	AASHTO T 190 AASHTO T 193	--
Chemical (Cement)	3% – 9%	400 psi [2.8 MPa] (but always less than 800 psi [5.5 MPa])	AASHTO T 134 ASTM D 1633	♦ > 45% passing #4 [4.75 mm] sieve desired for formation of aggregate matrix. ♦ Consider evaluating durability according to AASHTO T 135 and T 136.
Bituminous (foamed asphalt or emulsified asphalt)	2% - 5%	> 50%, TSR > 45 psi [300 kPa], Wet Tensile Strength	AASHTO T 245 AASHTO T 283	♦ 5% < passing #200 [75 μm] < 25% ♦ Non-plastic or low plasticity soils ♦ Typically 1% cement is added for improved strength ♦ For foamed asphalt evaluate half-life and foaming ability of asphalt binder.

Advantages of FDR include:

- Recycles materials and conserves resources.
- Versatile.
- Eliminates reflective cracking and other distresses.
- Substantial structural improvement with the introduction of stabilizers
- Cost effective when used appropriately.

Limitations of FDR include:

- Requires a riding surface.
- Stabilization processes require specialized equipment and experienced contractors.
- Some FDR methods require a cure time.

From the *FP-XX*, use Section 304 to specify FDR with cement, Section 303 to specify FDR with just pulverization, Section 408 to specify FDR with emulsified asphalt, and the 418 SCR to specify FDR with foamed asphalt. Refer to Division Supplements, for additional guidance on material selection and application rates.

11.6.1.6 Cold In-place Recycling (CIPR)

The *ARRA Basic Asphalt Recycling Manual* (*BARM*) describes CIPR as an asphalt pavement recycling process without the application of heat. CIPR uses a number of pieces of equipment that form a recycling "train". The equipment in this train includes tanker trucks, milling machines, crushing and screening units, mixers, pavers, and rollers. With this train, all material processing is completed on grade including the mixing operation. For FLH the typical recycling depth is 3 or 4 in [75 or 100 mm]. However, recycling depths of 5 or 6 in [125 or 150 mm] may be possible with the addition of cementitious additives such as Portland cement to provide early strength gain. A 2 in [50 mm] depth is considered the minimum depth for recycling.

Just like FDR, CIPR can be a very cost effective rehabilitation alternative when appropriately used. FLH has had good long-term performance on CIPR projects. Generally, CIPR is best suited for higher-class rural roads with few curves, adequate geometry, and pavement thickness exceeding 5 in [125 mm]. However, CIPR has been used effectively on roads with many curves, where widening was necessary, and where thin asphalt pavement was present (the complete asphalt pavement thickness was recycled). There are numerous good references and resources to use when evaluating the suitability of using of FDR. The following are recommended:

- *ARRA Basic Asphalt Recycling Manual (BARM*).
- *Report on Cold Recycling of Asphalt Pavement*, AASHTO TF-38.
- *Techniques for Pavement Rehabilitation, Reference Manual*, FHWA-NHI-131008.

Use CIPR to treat most types of pavement distress. Ideal pavement candidates are old, cracked, and have at least fair base and subgrade support. CIPR requires a wearing surface such as HACP.

Localized failures caused by wet, unstable subgrade or heaving/swelling of the subgrade should be identified during the pavement investigation and addressed separately from the CIPR operation.

If the existing pavement exhibits asphalt stripping, CIPR is not recommended without the use of cement, lime, and/or fly ash.

Do not use CIPR on projects where the recycling train cannot be supported, such as a thin pavement structure over a weak, clayey soil.

Constructability issues include:

- Determining overhead clearances for the recycling train
- Identifying utilities such as manholes or other castings within the pavement layers to be recycled,
- Long steep grades (>8%) will reduce production,
- Many sharp curves may make CIPR impractical
- Heavily shaded areas will require longer curing times. Curing time will vary from 3 days to 2 weeks depending upon weather conditions and materials used.

If there is a concern about being able to achieve a quality mix, retain representative core samples to evaluate gradation, asphalt content, stripping, penetration, and viscosity. Also, if necessary, complete a preliminary mix design to determine the suitability and emulsified asphalt type and quantity required.

Emulsified asphalt application rates typically range from 1 to 2 percent.

Advantages of CIPR include:

- Wide variety of distress types can be treated with CIPR.
- Reflective cracking can be significantly reduced.
- Recycles materials and conserves resources.
- Cost effective when used appropriately.

Limitations of CIPR include:

- Cure time
- The several constraints discussed above.
- CIPR requires specialized equipment and experienced contractors

From the *FP-XX*, use Section 416 to specify CIPR. Refer to Division Supplements, for additional guidance on material selection and application rates.

11.6.1.7 Hot In-place Recycling (HIPR)

HIPR consists of:

1. Heating and softening the existing asphalt pavement so it can be scarified or hot rotary milled to a specified depth,
2. Mixing the loosened asphalt concrete with a recycling agent and possibly virgin asphalt and
3. Placing and compacting the mixture with conventional asphalt paving equipment.

FLH does not have a specification for HIPR and has not completed a HIPR project. Refer to the *ARRA Basic Asphalt Recycling Manual* (*BARM*) and FHWA-NHI-131008 for guidance and criteria.

HIPR can be a cost effective alternative when completed on pavements with appropriate conditions.

11.6.1.8 Whitetopping

Whitetopping is a pavement rehabilitation technique that involves construction of a portland cement concrete overlay on top of HACP.

FLH does not have a specification for whitetopping and has not completed a whitetopping project. Refer to the following references for guidance and criteria:

- FHWA's Technical Brief, *Conventional Whitetopping Overlays* (Publication No. FHWA-IF-03-008)
- ACPA's *Whitetopping – State of the Practice* (Engineering Bulletin EB210P)
- NCHRP Synthesis 338 *Thin and Ultra-Thin Whitetopping*
- *Synthesis of Current Minnesota Practices of Thin and Ultra-Thin Whitetopping*

11.6.2 REHABILITATION METHODS: AGGREGATE SURFACED ROADS

FLH primarily performs three types of rehabilitation methods on aggregate surfaced roads:

1. Mechanical stabilization which includes reshaping and reconditioning the existing gravel material and/or adding additional surfacing aggregate,
2. Chemical stabilization using dust palliatives or other materials, and
3. Upgrading the aggregate surfacing to a bituminous surfacing.

Sometimes combinations of above alternatives are used.

Aggregate surfaced roads are inherently very low volume roads with construction budgets commensurate with their significance. It is critical for the pavement engineer to optimize the use of local materials without sacrificing service life.

11.6.2.1 Mechanical Stabilization

With mechanical stabilization an additional layer of aggregate surfacing can be applied to increase structural capacity, restore geometry, improve drainage, and correct surface distress such as rutting. Mechanical stabilization also includes reshaping and reconditioning the existing aggregate material with a rotary mixer/reclaimer and/or motor grader. On many projects these two processes are combined. The use of geocells, geogrids, and other geosynthetics are also forms of mechanical stabilization that may be cost effective under the right conditions.

Complete field investigations according to Section 11.4 and 11.6.1.1, as needed. Complete structural surfacing design according to the methodology of Section 11.4.

It is impractical and sometimes uneconomical to place surfacing aggregate with a thickness less than 3 in [75 mm].

Identify localized subgrade or drainage problems and develop appropriate solutions.

Advantages of mechanical stabilization:

- Relatively simple construction using readily available equipment.
- Provides the opportunity to restore or rejuvenate existing surface aggregate.
- Low initial cost

Limitations of mechanical stabilization:

- Frequent maintenance required.
- Loose particles can cause vehicle damage

Refer to Section 11.4.2.2 for selecting material types. Additionally, the Gravel Roads (LTAP) provides guidance on construction methods and material selection.

11.6.2.2 Chemical Stabilization (using dust palliatives)

Recent research by FLH and other agencies has indicated that with a slightly higher application rate and a more aggressive method of incorporation, the use of dust palliatives can increase the strength and durability of an aggregate surfacing. It has been well established that the use of dust palliatives will reduce the loss of fines, which in turn reduces the frequency of maintenance operations.

Chemical stabilization can occur as a single activity using the *in situ* aggregate surfacing or it can be used in conjunction with the addition of new aggregate.

Complete field investigations according to Section 11.4 and 11.6.1.1, as needed. Complete structural surfacing design according to the methodology of Section 11.4. Note that the compatibility of stabilizing agents with the existing soil and aggregate is critical. Additional references to consult are Forest Service 9977 1207 SDTDC and FHWA-CFL/TD-05-004.

Chemical stabilization will not address localized subgrade or drainage problems. Identify these areas during the field investigation and develop appropriate solutions.

Advantages of chemical stabilization:

- Reduced dusting and surface erosion.
- Reduced frequency of maintenance intervals.
- A reduction of the loss of aggregate.
- Increased structural capacity

Limitations of chemical stabilization:

- Many products are proprietary
- Lack of objective performance data with many products
- Certain products can impact water and plant quality

The *FP-XX* Section 306 is typically specified on projects requiring a dust palliative. However, if stabilization is desired this specification may have to be modified on a project-by-project basis to fit the needs of the stabilization/dust palliative product. Refer to Division Supplements, for additional guidance.

11.6.2.3 Upgrading to Paved Surface

When ADT values approach 150 to 200 on an aggregate surfaced road, many practitioners and agencies promote upgrading the road to a paved surface such as HACP. There is no consensus or standardized guidance on when it is appropriate to upgrade a road to a paved surface. There are other factors besides ADT that will influence the decision on upgrading, including:

- Amount and type of truck traffic,
- Function of the road,
- Harshness of climate, and
- Subgrade soil conditions.

It is the responsibility of the pavement engineer to provide technical assistance to the project team on the above factors.

Complete field investigations according to Section 11.3 and 11.6.1.1, as needed. Complete structural surfacing design according to the methodology of Section 11.3. The scope of this rehabilitation method is similar to reconstruction.

Advantages of upgrading to a paved surface:

- Higher level of functionality and service,
- Reduced frequency of maintenance,
- All-weather accessibility, and
- Elimination of dusting.

Limitations of upgrading to a paved surface include:

- Higher construction costs,
- Repairing damaged sections is generally more expensive, and
- Potential safety issues with increased speeds.

Refer to Section 11.3.2.3 for selecting material types. Additionally, Gravel Roads (LTAP) provides guidance on "When to Pave a Gravel Road".

11.6.3 REHABILITATION METHODS: RIGID PAVEMENTS

As was indicated in Section 11.5, FLH designs and builds few mainline Portland cement concrete pavements (PCCP) due to the predominant low-volume traffic conditions on most FLMA routes. Accordingly, FLH also completes few PCCP rehabilitation projects. As a result this subsection does not provide specific standards or guidance, but rather contains a list of the more common rehabilitation methods with suggested references to use for guidance.

The following are general references that cover most rehabilitation techniques:

- *Techniques for Pavement Rehabilitation Reference Manual*, FHWA-NHI-131008.
- NCHRP Web Document 35, Appendix B, *Pavement Rehabilitation Techniques*.
- FHWA and CPTP Tech Brief: Concrete Pavement Rehabilitation and Preservation Treatments, FHWA-IF-06-005, November 2005.
- *The Concrete Pavement Restoration Guide,* Technical Bulletin TB020P, ACPA 1997.

The following are more specific references for individual rehabilitation methods that can be used in conjunction with the general references listed above:

- **HACP overlays**
  - ◊ *Rubblization of Portland Cement Concrete Pavements* (TRB Circular E-C087)
  - ◊ *Ohio DOT's Long Term Monitoring of Broken and Seated Pavements* (FHWA/OH-2002/024 or State No. 14670(0))
- **Partial Depth Repairs**
  - ◊ Partial Depth Repair of Concrete Pavements (FHWA Checklist Series #9)
  - ◊ FHWA web page on Partial Depth Repairs
  - ◊ FHWA Tech Brief: *Portland Cement Concrete (PCC) Partial-Depth Spall Repair* (FHWA-RD-99-177)
  - ◊ *Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavement* (FHWA-RD-99-152)
- **Full-Depth Repairs**
  - ◊ FHWA web page on Full-Depth Repairs
  - ◊ Full-Depth Repairs of Portland Cement Concrete Pavement (FHWA Checklist Series #10)

- **Load Transfer Restoration / Dowel Bar Retrofit**
  - ◊ *Concrete Pavement Rehabilitation: Guide for Load Transfer Restoration* (FHWA-SA-97-103 or ACPA JPOOIP)
  - ◊ Washington DOT's *Ten-Year Performance of Dowel Bar Retrofit – Application, Performance, and Lessons Learned* (2003 TRB Annual Meeting Paper)
  - ◊ Dowel-Bar Retrofit for Portland Cement Concrete Pavements (FHWA Checklist Series #8)
- **Slab Stabilization and Slab Jacking** – use general references above.
- **PCC Overlays**
  - ◊ *Portland Cement Concrete Overlays – State of the Technology Synthesis* (FHWA-IF-02-045)
- **Grinding and Grooving**
  - ◊ FHWA's Concrete Pavement Rehabilitation Guide for Diamond Grinding

11.7 PAVEMENT PRESERVATION

At the time of this initial edition of the PDDM, FLH was in the early stages of developing planning, pavement management, and project development processes for pavement preservation programs for Federal Land Management Agencies (FLMAs). This is an emerging area of importance and some FLMA's are already using pavement preservation principles.

This section will be developed in the future. In the interim, use the information available on the following websites for guidance on field reconnaissance, treatment type selection, timing, and materials:

- FHWA Pavement Preservation webpage.
- The National Center for Pavement Preservation (NCPP) website.
- CalTran's Maintenance Technical Advisory Guide (MTAG)

11.7.1 PREVENTIVE MAINTENANCE TREATMENTS

(RESERVED)

11.7.2 FIELD RECONNAISSANCE AND INVESTIGATION

(RESERVED)

11.7.3 SELECTION OF TREATMENTS AND MATERIALS

(RESERVED)

11.8 PAVEMENT MANAGEMENT AND ROAD INVENTORY DATA

(RESERVED)

11.9 MECHANISTIC-EMPIRICAL PAVEMENT DESIGN

The *NCHRP 1-37A* project was funded to develop a substantially new process for designing pavements. This Mechanistic-Empirical Pavement Design Guide (MEPDG), as it has become known, was developed in 2004. To date, this process has not been adopted by AASHTO as a standard or a provisional standard. However, it is expected that in the future this design methodology will sooner or later be adopted by AASHTO.

Pavement engineers are not required but are encouraged to become familiar with the new methodology and complete "side-by-side" comparative designs using the MEPDG and *AGDPS* processes.

The FHWA has formed a Design Guide Implementation Team (DGIT) and this team conducts numerous workshops, videoconferences, and sponsors other activities. Refer to the DGIT webpage for a complete list and calendar of events.

A formal review of the products of *NCHRP 1-37A*, such as the MEPDG, was completed under *NCHRP 1-40D*. The review resulted in numerous improvements to the MEPDG and the development of Version 1.0 of the MEPDG software. It is anticipated that the MEPDG will offer FLH a better method for predicting pavement performance, developing pavement structural designs, and evaluating trade-offs in pavement thickness and materials types. FLH is formulating a long-term strategic plan for the use and/or implementation of the MEPDG.