Rubblization

Design and Construction Guidelines on Rubblizing and Overlaying PCC Pavements with Hot-Mix Asphalt

1. Introduction

Rehabilitation of existing pavements is one of the greatest pavement priorities facing local, state, and federal transportation agencies. The use of hot-mix asphalt (HMA) overlays presents a long-term and economical solution to the pavement rehabilitation challenge. HMA overlays increase the structural capacity of the existing pavement system and improve the long-term functional pavement performance including ride, noise reduction, splash and spray, friction, and general appearance.

In many respects, the rehabilitation of pavement systems is a more complex engineering task than the design of new pavement systems. Pavement rehabilitation requires significant engineering judgment in the evaluation process. The engineer must define the problem, develop potential problem solutions and then select the preferred solution. Rehabilitation of PCC pavements can be accomplished by concrete pavement restoration (CPR), reconstruction and by resurfacing. Due to the expense, time and traffic delay involved in CPR and reconstruction, resurfacing of PCC pavements with an HMA overlay is a very appealing option for many agencies.

However, existing, worn-out PCC pavements present a particular problem for rehabilitation due to the likelihood of reflection cracking when an HMA overlay is used. Horizontal and vertical movements occurring within the underlying PCC layer cause reflection cracking. Reflection cracking can occur at any PCC joint or crack. The reflection cracking problem must be addressed in the HMA overlay design phase if long-term performance of the overlay is to be achieved.

The best way to control reflection cracking in an HMA overlay over a PCC pavement is to fracture the slabs prior to placement of the HMA overlay. "Slab fracturing" techniques have proven to be an excellent method for preparation of the PCC pavement prior to overlay with HMA. NAPA's publication *Guidelines for Use of HMA Overlays to Rehabilitate PCC Pavements* (IS-117), provides an exhaustive review of all slab fracturing techniques. The information presented in IS-117 is based on a comprehensive national study performed by PCS/Law in 1991. Slab fracturing can be accomplished by crack/seat, break/seat, and rubblization processes.

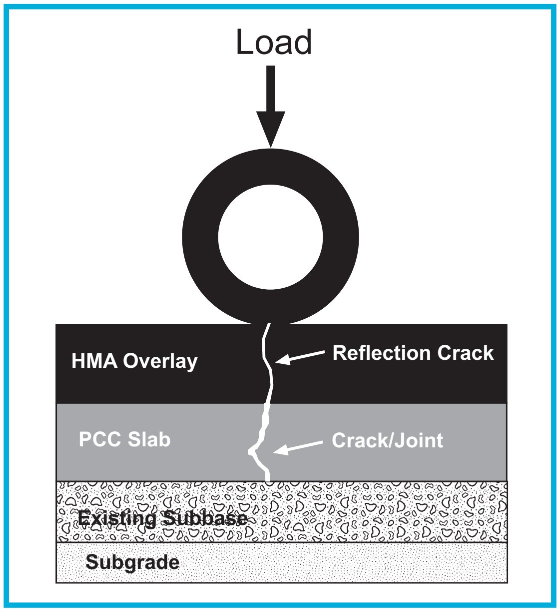
Rubblization can be used to eliminate or significantly reduce reflection cracking in HMA overlays placed on PCC. This process is normally achieved by rubblizing the slab into fragments, resulting in destruction of the existing slab action of the PCC pavement. Temperature and/or reinforcing steel, if present in the PCC pavement, is generally fully debonded from the concrete by this approach. The rubblization process is applicable to all types of PCC pavements.

This publication is intended as a companion publication to IS-117. Its objective is to provide updated design and construction guidelines specific to the PCC rubblization process. A procedure is presented for determining the required thickness of an HMA overlay placed over rubblized PCC slabs, based on the mechanistic empirical design procedures.

2. Reflection Cracking

Reflection cracking can occur in an HMA overlay over any joint or crack in the PCC pavement. The current state-of-the-technology does not provide accurate methods to predict the occurrence and growth of reflection cracks. The National Cooperative Highway Research Program (NCHRP) Project 1-41, *Selection, Calibration, and Validation of a Reflective Cracking Model for Asphalt Concrete Overlays* began in 2003 to select, calibrate, and validate a model for incorporation in the future AASHTO design guide. Figure 2-1 schematically illustrates reflection crack distress in an HMA overlay placed over a joint or crack of an existing PCC slab. Figure 2-2 illustrates the mechanism through which the crack develops and propagates in the HMA layer.

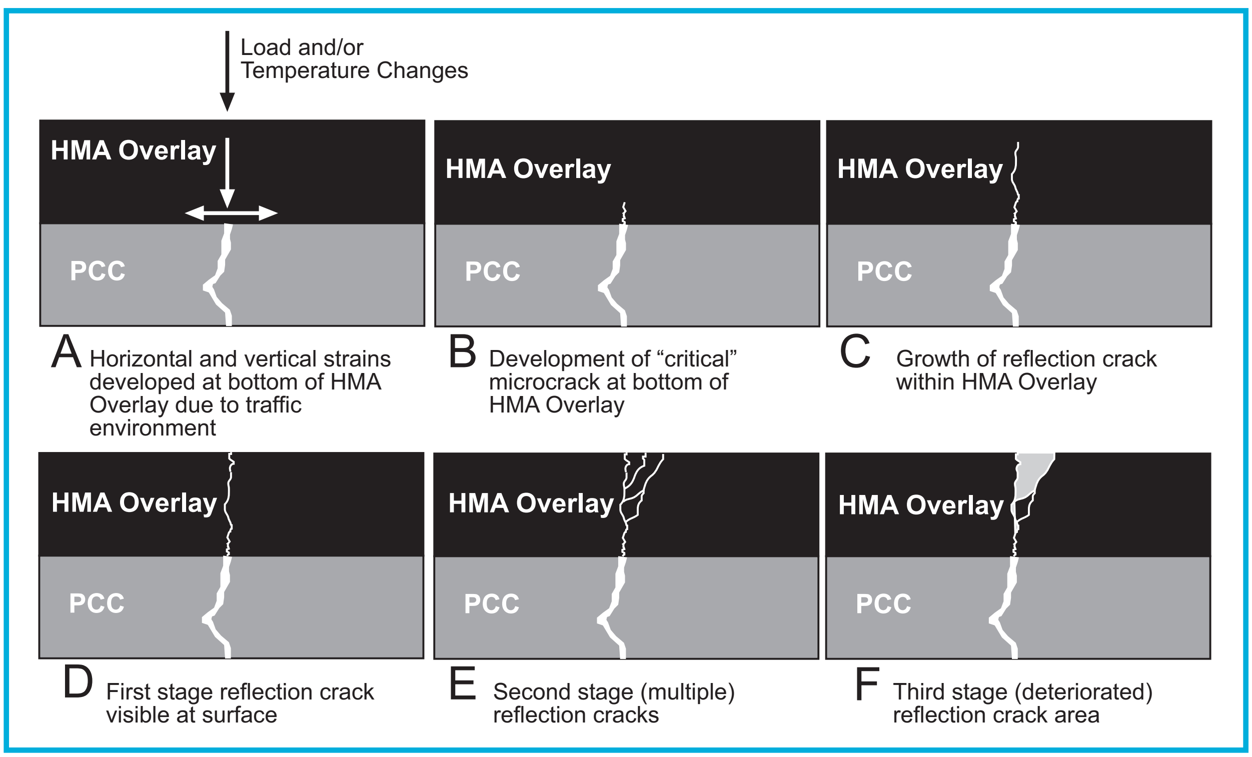
Figure 2.1
Reflection crack distress



Stresses and strains at the bottom of the HMA overlay are caused by horizontal movement of the PCC slabs due to temperature changes, moisture changes, and vertical movement caused by traffic loads. (2.2A). These stresses and strains at the bottom of the HMA overlay will eventually cause the development of a microcrack at the bottom of the HMA overlay (2.2B). With time, this microcrack will grow and eventually reflect upwards to the surface of the HMA overlay (2.2C and D). As temperature and loading cycles continue, multiple cracks will form and eventually result in significant deterioration of the HMA surface (2.2E and F). Figure 2.3 illustrates a distressed reflection crack area in an HMA overlay over an existing PCC pavement.

A variety of techniques have been used over the years in an attempt to eliminate reflection cracking in HMA overlays. These approaches include: sawing and sealing

Figure 2.2
Growth mechanism associated with reflection cracking



the HMA overlay; use of thick HMA overlays; installation of crack relief layers (including stress absorbing interlayer materials); use of modified asphalt HMA overlay materials; and slab fracturing prior to HMA overlay.

Of the slab fracturing techniques, rubblizing has proven to be one of the most economical and successful ways to eliminate reflection cracking. The underlying principle of this approach is to significantly reduce the effective slab length of the PCC pavement by fracturing the slab into small fragments and destroying the bond between reinforcing/temperature steel and concrete. The reduction of the effective slab length will result in minimal horizontal movements at joints and cracks due to temperature and moisture changes. This greatly minimizes the tensile and shear forces normally occurring at the bottom of the HMA overlay.

Slab fracturing is tempered/balanced by the need to conserve structural support. The modulus of a fractured PCC pavement(E_{PCC}) is a measure of structural support and is an important parameter in the design of HMA overlays on rehabilitated PCC systems. The greater the degree of slab fracturing and steel-concrete debonding achieved in the construction process, the lower the modulus E_{PCC}, and hence structural support. Thus, the effective modulus of a fractured slab is a function of the nominal fragment size or crack spacing actually achieved in the slab fracturing process.

Figure 2.4 illustrates the relationship of the fractured slab modulus (EPCC) to both functional distress caused by reflection cracking and structural requirements of the HMA overlay. As the fractured PCC modulus decreases (slab becomes more intensely fractured), the likelihood of having reflection cracking problems in the HMA overlay is significantly reduced. However, as the fractured PCC modulus decreases, the structural capacity of the fractured PCC slabs also decreases, requiring a thicker HMA overlay. The ultimate goal is to reduce the E_{PCC} value to a minimum or critical value such that reflection cracking will not occur, but not so low a value that the capacity of the fractured slab is reduced to a point where an excessive HMA overlay thickness is required.

Rubblizing has been used extensively by many states in the last 20 years. In general, field performance of HMA overlays on rubblized slabs has been found to be good to excellent.

The field-proven success and growing use of this rehab approach indicates that this technique no longer needs to be considered as research or experimental in nature.

Figure 2.3
Reflection cracking in HMA overlay of PCC pavement
(courtesy Antigo Construction, Inc.)

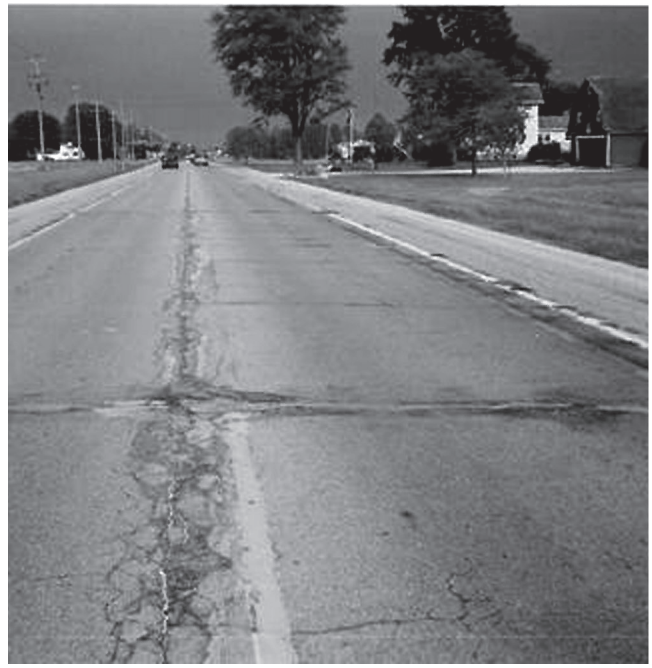
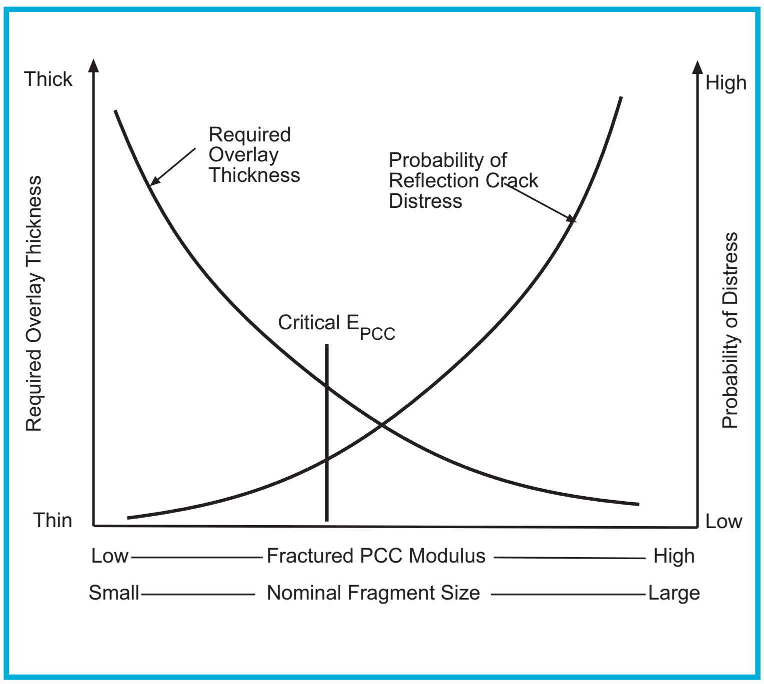


Figure 2.4
Influence of PCC fractured modulus upon structural and reflection crack failure



3. Project Evaluation

Every rough, worn-out PCC pavement may not be a candidate for rubblization with an HMA overlay. A structural evaluation of the existing pavement including considerations for traffic, subgrade, and environmental conditions must be performed. Condition surveys of the existing pavement are important to understand the types, severity, and extent of distresses and their likely causes.

It is vital to understand the soil and moisture conditions for the pavement system prior to making a decision on the rehabilitation type. These steps are imperative to determine if the specific pavement is an appropriate candidate for rubblization. However, most PCC pavements can be rubblized in an appropriate manner and overlaid with HMA.

Evaluation of the Existing Structure

As with any pavement overlay project, it is necessary to know the existing condition of the pavement. It may be that existing conditions are so poor that nothing short of removal and replacement is appropriate. These are decisions that must be made by the design engineer, given an appropriate engineering evaluation of the project.

The key elements of the evaluation are:

- Perform visual condition survey to define the type, amount and severity of distresses.
- Cracking (corner, mid-slab, fatigue, etc.)
- Amount and type of patching
- Joint deficiencies
- Surface defects
- Miscellaneous distresses
- Evaluate existing pavement structure
- Layer types (materials and strengths)
- Layer thickness
- Drainage
- Shoulder condition
- Determine soil conditions.
- Soil types
- Bearing value (modulus)
- Moisture condition

Distress Survey

In order to evaluate long-term performance of the pavement system, it is critical that the pre-construction condition be known. Using the *Distress Identification Manual for the Long-Term Pavement Performance Project* (FHWA-RD-03-031), evaluate the condition of the existing pavement. Each type of distress should be identified, along with the relative extent and severity of the distress. The LTPP document describes the following distresses for PCC pavements:

Jointed PCC distresses	CRC* distresses
Cracking	**Cracking**
Corner breaks	"D" cracking
"D" cracking	Longitudinal cracking
Longitudinal cracking	Transverse cracking
Transverse cracking	**Surface defects**
Joint deficiencies	Map cracking/scaling
Joint seal damage	Polished aggregate
Spalling of joints	Popouts
Surface defects	**Miscellaneous distresses**
Map cracking/scaling	Blowups
Polished aggregate	Transverse joint deterioration
Popouts	Lane-to-shoulder drop off
Miscellaneous distresses	Lane-to-shoulder separation
Blowups	Patch deterioration
Faulting of transverse joints	Punchouts
Lane-to-shoulder drop off	Spalling of longitudinal joints
Lane-to-shoulder separation	Water bleeding and pumping
Patch deterioration	Longitudinal joint seal damage
Water bleeding and pumping	

* continuously reinforced concrete

Existing Pavement Structure

Through a process of coring and/or trenching, evaluate the existing pavement structure. The thickness of each existing layer, the material type, and condition should be determined. These data are important for the design of the new pavement system.

A sampling plan must be developed that will provide an appropriate overview of the pavement section to be rehabilitated. As a minimum, two core samples should be taken randomly per lane mile. Core locations should be in representative cut and fill locations and staggered between lanes. Any areas of obvious structural distress should be evaluated.

The condition of the pavement shoulder must also be evaluated if traffic will be routed onto it while adjacent lanes are under construction. The shoulders will need to be able to carry the traffic loading during the construction process.

As an example of evaluation criteria, Wisconsin DOT considers the rubblization process when one or more of the following conditions are met:

- Greater than 20% of the concrete pavement joints are in need of repair
- Greater than 20% of the concrete surface has been patched
- Greater than 20% of the concrete slabs exhibit slab breakup distress
- Greater than 20% of the project length exhibits longitudinal joint distress greater than 4” wide.

Subsurface Conditions

After the coring or trenching has been completed, testing of the subsurface materials, base, subbase and soil should be performed to determine the structural adequacy of the foundation material. Field tests such as dynamic cone penetrometer (DCP) and field California Bearing Ratio (CBR) have been used to characterize the materials. Laboratory testing may be performed on undisturbed samples for fine-graded materials or recompacted materials for coarser materials to determine modulus values, CBR or R-Value. Moisture content of the in-situ materials should also be determined. From the field data, typical values for the project can be developed.

The Illinois Department of Transportation (IDOT) recommends splitting the top 12 inches of the subgrade into two equal layers, determining the DCP for each layer, and using the average of the two values to determine the type of rubblization method to be used. The selection of rubblization method will be discussed later in this publication.

The soil condition survey will provide the designer with data to make decisions regarding the rehabilitation process. If very soft subgrades are noted, it may be necessary to limit the extent of the rubblization or in some cases, change the processing to another rehabilitation technique such as Break and Seat or Crack and Seat.

Non-Destructive Testing

Falling Weight Deflectometer (FWD) testing is a non-destructive testing tool for evaluating pavement structures. Modulus values for different layers may be calculated from deflection data. Many locations may be tested with FWD equipment in a short time, giving a more complete picture of material properties along the project length.

Another non-destructive tool that may be used in evaluating pavement sections is ground penetrating radar (GPR). GPR is useful in determining variations in layer thicknesses and depths and locations of underground utilities. Fluctuations in soil moisture may also be detected with GPR.

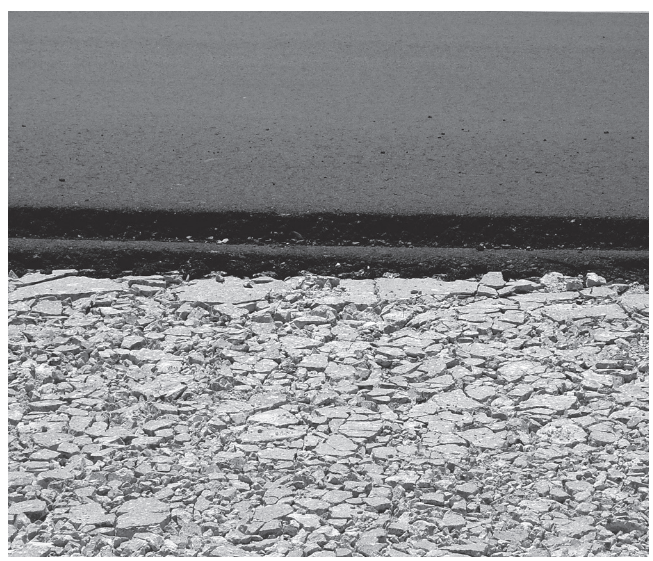
FWD and GPR should always be used in conjunction with coring and sampling of materials. This is important to gain what is often referred to as “ground truth” to calibrate the systems. However, the amount of coring and sampling can be significantly reduced while increasing the amount of useful data.

Drainage

Surface and subsurface drainage for the project should be evaluated. For surface drainage, look for areas that allow water to pond next to the roadway. Also evaluate the cross slope of the existing pavement to determine if corrections are necessary. If edge drains are present, they should be evaluated to determine they are not clogged and operating properly. If edge drains are not present, the site soil conditions should be evaluated to determine if adding edge drains would be beneficial.

Project Evaluation Report

To aid in the preparation of plans and specification, additional information should be included in a project evaluation report including comments on the material conditions at the time of sampling, clearances for overhead items for the project, location of utilities and culverts in the pavement, location of any buildings within 50 feet of the pavement to be rubblized, and the location and condition of any underdrains in the pavement.



Rubblized concrete base with HMA overlay.

4. HMA Overlay Thickness Design

The overlay thickness design process in this publication is based on mechanistic empirical design principles, whereas the procedure used in IS-117, *Guidelines for Use of HMA Overlays to Rehabilitate PCC Pavements* was based on the structural capacity deficiency approach.

The difference between these approaches are that the AASHTO guide relies on empirical correlations with past performance and models developed from experience or observations of past performance. In this procedure a structural number is determined based on traffic and soil properties. The thickness of the various pavement layers is then determined by layer coefficients and thickness for the different materials used in the pavement structure.

While this procedure has served us well for many years, it cannot accurately account for traffic loadings and material properties beyond the observed conditions used to develop the models. Mechanistic empirical designs are based on engineering properties of the materials and their calculated responses to loading. Stresses and strains may be calculated at various depths in the pavement structure. These stresses and strains can then be related to performance based on empirical relationships. The advantage to this procedure is that we can calculate pavement responses to different loading situations and material properties and relate this response to performance.

The design procedure recommended in this publication was developed using the PerRoad software which is available from the Asphalt Pavement Alliance for the design of Perpetual Pavements. The PerRoad software is a layer/elastic software that can calculate stresses and strains in different pavement layers. Of key interest to pavement designers are the horizontal tensile strain at the bottom of the asphalt layer and the vertical compressive strain at the top of the subgrade. The horizontal tensile strain at the bottom of the asphalt layer has been shown to be related to alligator or fatigue cracking in the HMA. Vertical compressive strain at the top of the subgrade is related to permanent deformation deep in the pavement structure.

NAPA's IS-117 describes three different levels of engineering evaluation, Level I, Level II, and Level III. The concept is that the level of engineering effort for the evaluation process should be consistent with the relative importance and the cost of the project. An increasing engineering evaluation effort is required from Level I to Level III. As a result, the procedure recommended in this publication uses a similar classification. For a Level I approach the designer would:

- Estimate subgrade support values (resilient modulus, M_r) based on soil classifications, other test values such as CBR and R-value, and charts
- Estimate base structural number
- Estimate traffic based on general road classifications

For the Level II approach, more precise data would be collected through field investigations and laboratory testing to determine subgrade support, base structural number, and traffic loading. For Level III design, mechanistic empirical design procedures such as the PerRoad analysis design software and would be used to determine the overlay thickness.

Level I is the most direct and simplest solution to the determination of an HMA overlay thickness. Simplifying assumptions are made to establish "typical" overlay variables. Subgrade support and traffic are expressed in subjective categories rather than requiring the selection of a specific value. This simplified Level I approach leads to a set of tables to provide a recommended overlay thickness for different combinations of design conditions. In general, a Level I analysis would be expected to generate a thicker, more conservative HMA overlay.

Level II requires an enhanced engineering effort to select appropriate input values for the variables used in the HMA overlay thickness determination. The engineer must select specific design values for:

- Subgrade support
- Resilient modulus (M_r)
- Design traffic repetitions
- Axle loadings (ESAL)
- Structural layer coefficients
- Existing subbase layers (a_{sb})

The solution for the Level II approach is accomplished through a set of graphs developed using data from the PCS Law Study and PerRoad software.

The Level III overlay thickness determination represents the most detailed solution approach. This solution requires the use of the PerRoad software to determine the required overlay thickness. The use of this software requires input of structural values, modulus values, and Poisson's ratio for each pavement layer. Other inputs include traffic as a load spectra and failure criteria. Using this software will also allow the user to design the overlay as a Perpetual Pavement

Level I Approach

The Level I overlay thickness determination involves five major steps. They are:

Step 1: Identify PCC thickness

Step 2: Select appropriate traffic category

Step 3: Select subgrade soil category

Step 4: Compute existing subbase layer structural number

Step 5: Select appropriate HMA overlay table and read overlay thickness

Step 1: Identify PCC Thickness

Information on the original PCC pavement type as well as thickness can generally be determined from historical records. It is always wise to confirm the as-built thickness of the PCC with core test results.

Step 2: Select Design Traffic Category

General estimates of the future equivalent 18,000 pound single axle load (ESAL) repetitions for the overlay life period are used for Level I. Table 4.1 indicates the four general traffic categories used and typical design traffic ranges for each category. The engineer must select one of these four traffic categories (low, medium, heavy, and very heavy) to proceed with the HMA overlay analysis.

Step 3: Select Subgrade Soil Category

The engineer is required to assess the existing subgrade support within one of four subgrade soil groups (poor, medium, good, and excellent). Figure 4.1 presents information to assist the engineer in the selection. The four subgrade support categories and typical ranges of resilient modulus, California Bearing Ratio, resistance value and soil classification groupings for both AASHTO and unified soil classifications systems are included in the figure.

Step 4: Compute Existing Subbase Layer Structural Number

For each subbase layer under the existing PCC pavement, the structural contribution of these layers must be evaluated by computing the combined SN_{sb} value. Subbase layers are generally of two major types:

Treated subbase

Cement treated

Asphalt treated

Lime treated

Unbound granular

Crushed stone

Sand/gravel

For the unbound granular subbase materials, the engineer must make an appropriate decision regarding the drainability (after the overlay has been placed) of these materials. This is accomplished by subjectively categorizing the anticipated drainage condition into one of three categories (excellent, fair, or very poor).

For the treated subbase materials, the engineer must evaluate the general condition of the stabilized layer prior to the rubblization process. The two categories are good-fair and poor-very poor. The severity of deterioration such as cracking in a cement-treated subbase and the amount of moisture damage in an asphalt-treated base are issues that will determine the condition category.

The structural number (SN) is determined for each subbase layer and added together to produce the combined SN for the subbase layers. Figures 4.2 through 4.5 allow the designer to determine a SN value for each of the material types. The user must identify each subbase layer present; determine the layer thickness (h) for each layer; determine the SN for each layer from the appropriate figure; and add the individual SN values to determine the combined SN_{sb}.

(PCS/Law, Guidelines and Methodologies for the Rehabilitation of Rigid Highway Pavements Using Asphalt Concrete Overlays, 1991.)

Table 4.1
Level I Design Traffic Categories

Traffic Category	*Low*	*Medium*	*Heavy*	*Very Heavy*
Design ESAL Value	$\leq 5 \times 10^6$	$5 \times 10^6 - 10^7$	$10^7 - 20 \times 10^7$	$\geq 20 \times 10^7$

Figure 4.1
Typical subgrade soil categories

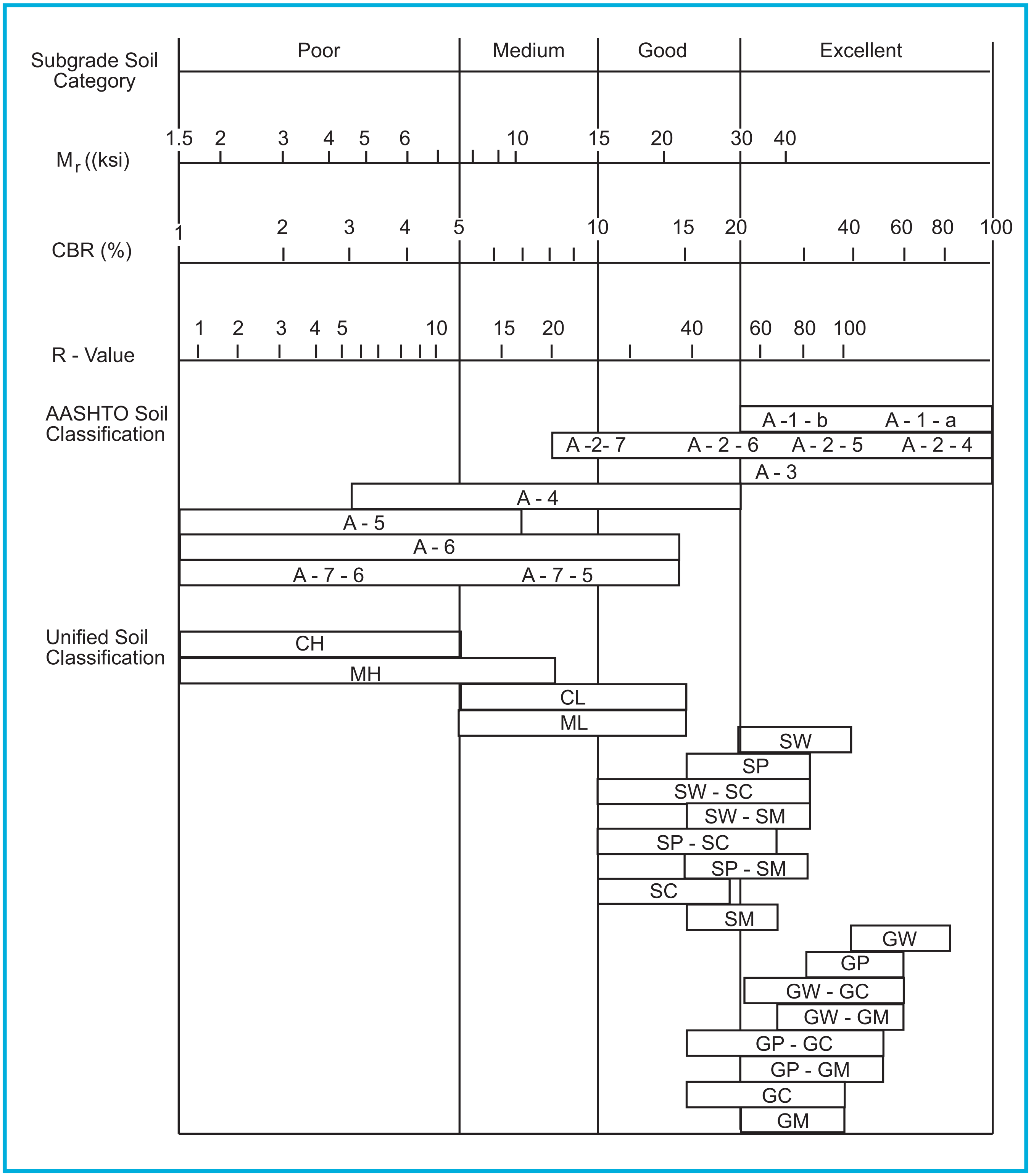


Figure 4.2
Asphalt treated base

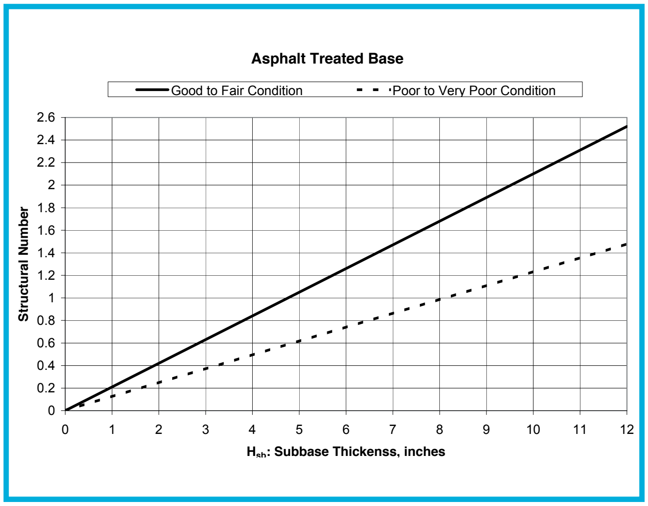


Figure 4.3
Cement treated base

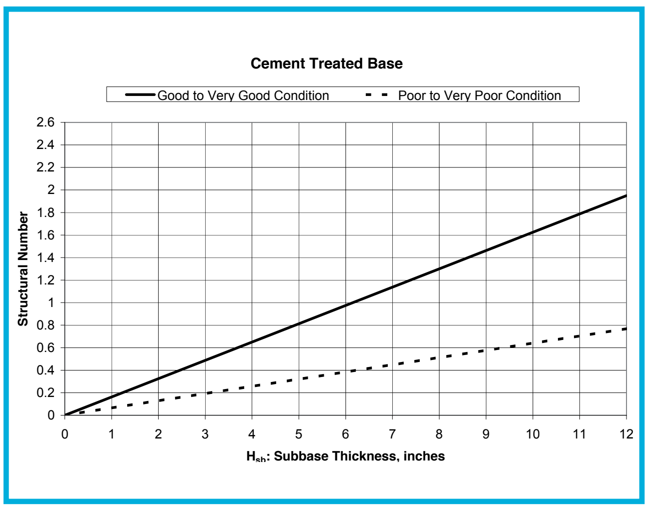


Figure 4.4
Crushed stone base

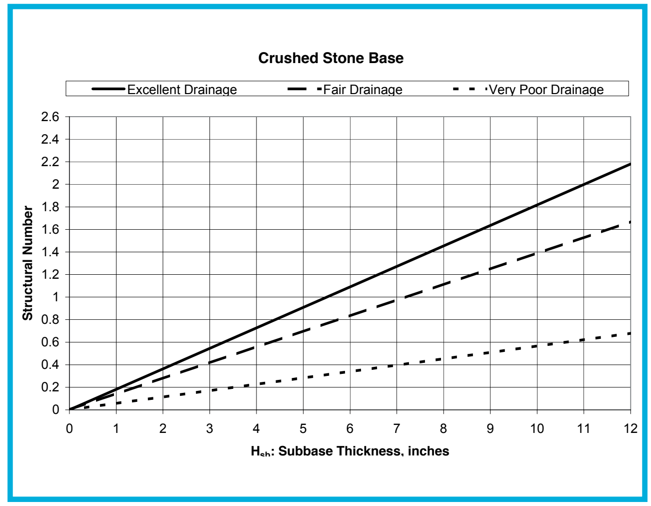
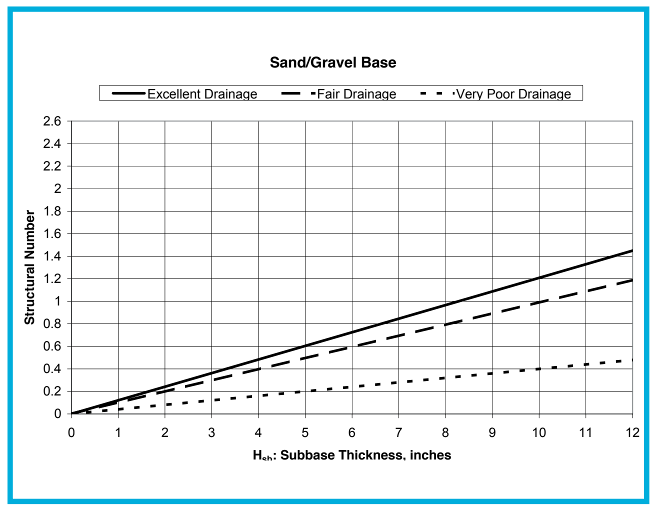


Figure 4.5
Sand/gravel base



Step 5: Select Appropriate HMA Overlay Thickness Table and Read Overlay Thickness.

From steps 1 through 4, the design engineer has identified the PCC type and thickness, the design traffic category, the subgrade soil classification, and the total subbase SN. The next and final step is to determine the overlay thickness required. For the Level I analysis, the overlay thickness is obtained from a series of tables for different pavement types and conditions.

Figure 4.6 illustrates the use of the thickness tables. The example shown is for the following conditions:

PCC Type: JPCP (Jointed Plain Concrete Pavement)
Fracture Mode: Rubblization
PCC Thickness: 8.0 inches
Design Traffic Category: Heavy Traffic
Subgrade Soil Category: Medium Subgrade Support
Total Subbase SN: SN_{sb} = 1.2
HMA Overlay Thickness = 7.0 inches

Figure 4.6
HMA overlay thickness example

Required HMA Overlay Thickness (inches)

Existing PCC slab thickness	Structural number subbase	Medium Traffic				Heavy Traffic			
H(pcc)	Total	Subgrade Soil Category				Subgrade Soil Category			
(in.)	SN_{sb}	Poor	Med	Good	Exc	Poor	Med	Good	Exc
7	0	10.00	7.50	6.00	6.00	12.00	9.00	7.00	7.00
7	0.4	10.00	7.50	6.00	6.00	12.00	9.00	7.00	7.00
7	0.8	9.50	6.50	6.00	6.00	11.00	8.00	7.00	7.00
7	1.2	9.00	6.00	6.00	6.00	10.50	7.00	7.00	7.00
7	1.6	8.50	6.00	6.00	6.00	9.50	7.00	7.00	7.00
7						9.00	7.00	7.00	7.00
8	0	9.00	6.50	6.00	6.00	10.50	8.00	7.00	7.00
8	0.4	9.00	6.50	6.00	6.00	10.50	8.00	7.00	7.00
8	0.8	9.00	6.00	6.00	6.00	10.50	7.00	7.00	7.00
8	**1.2**	8.00	6.00	6.00	6.00	9.50	**7.00**	7.00	7.00
8	1.6	7.00	6.00	6.00	6.00	9.00	7.00	7.00	7.00
8	2.0	6.00	6.00	6.00	6.00	8.00	7.00	7.00	7.00
9	0	7.50	6.00	6.00	6.00	9.50	7.00	7.00	7.00
9	0.4	7.50	6.00	6.00	6.00	9.50	7.00	7.00	7.00

HMA Overlay Thickness = 7 inches

Table 4.2 (see page 15) provides overlay thickness design information for all concrete pavements including jointed plain concrete pavements (JPCP), jointed reinforced concrete pavements (JRCP), and continuously reinforced concrete pavements (CRCP). The values in the tables already incorporate recommended minimum HMA overlay thickness as a function of traffic. The minimum values shown in these tables are different than the values given in IS-117. Ten years of experience since the publication of IS-117 have shown that, in spite of the fact that the minimum values may have satisfied theoretical structural requirements, some of the minimum values in IS-117 were too thin. General industry opinion today is that the minimum overlay thickness should be 5 inches with some exceptions for low-volume roads.

Table 4.2
All concrete pavements – fracture mode: rubblization
Required HMA Overlay Thickness (inches)

Existing PCC slab thickness	Structural number subbase	Low Traffic				Medium Traffic				Heavy Traffic				VERY HEAVY TRAFFIC			
H(pcc)	Total	Subgrade Soil Category				Subgrade Soil Category				Subgrade Soil Category				Subgrade Soil Category			
(in.)	SN_{sb}	Poor	Med	Good	Exc	Poor	Med	Good	Exc	Poor	Med	Good	Exc	Poor	Med	Good	Exc
7	0	8.50	6.00	5.00	5.00	10.00	7.50	6.00	6.00	12.00	9.00	7.00	7.00	15.50	12.50	9.50	8.00
7	0.4	8.50	6.00	5.00	5.00	10.00	7.50	6.00	6.00	12.00	9.00	7.00	7.00	15.50	12.50	8.50	8.00
7	0.8	8.00	5.00	5.00	5.00	9.50	6.50	6.00	6.00	11.00	8.00	7.00	7.00	14.50	11.50	8.00	8.00
7	1.2	7.00	5.00	5.00	5.00	9.00	6.00	6.00	6.00	10.50	7.00	7.00	7.00	14.50	10.50	8.00	8.00
7	1.6	6.50	5.00	5.00	5.00	8.50	6.00	6.00	6.00	9.50	7.00	7.00	7.00	13.5	9.50	8.00	8.00
7	2.0	5.50	5.00	5.00	5.00	7.50	6.00	6.00	6.00	9.00	7.00	7.00	7.00	13.5	8.00	8.00	8.00
8	0	7.00	5.00	5.00	5.00	9.00	6.50	6.00	6.00	10.50	8.00	7.00	7.00	14.00	11.50	8.50	8.00
8	0.4	7.00	5.00	5.00	5.00	9.00	6.50	6.00	6.00	10.50	8.00	7.00	7.00	14.00	11.00	8.00	8.00
8	0.8	7.00	5.00	5.00	5.00	9.00	6.00	6.00	6.00	10.50	7.00	7.00	7.00	14.00	10.50	8.00	8.00
8	1.2	6.50	5.00	5.00	5.00	8.00	6.00	6.00	6.00	9.50	7.00	7.00	7.00	13.50	9.50	8.00	8.00
8	1.6	5.50	5.00	5.00	5.00	7.00	6.00	6.00	6.00	9.00	7.00	7.00	7.00	13.00	9.00	8.00	8.00
8	2.0	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	8.00	7.00	7.00	7.00	12.00	8.00	8.00	8.00
9	0	6.00	5.00	5.00	5.00	7.50	6.00	6.00	6.00	9.50	7.00	7.00	7.00	13.00	10.5	8.00	8.00
9	0.4	6.00	5.00	5.00	5.00	7.50	6.00	6.00	6.00	9.50	7.00	7.00	7.00	13.00	10.00	8.00	8.00
9	0.8	6.00	5.00	5.00	5.00	7.50	6.00	6.00	6.00	9.50	7.00	7.00	7.00	13.00	9.50	8.00	8.00
9	1.2	5.00	5.00	5.00	5.00	6.50	6.00	6.00	6.00	8.50	7.00	7.00	7.00	12.50	8.50	8.00	8.00
9	1.6	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	8.00	7.00	7.00	7.00	12.00	8.00	8.00	8.00
9	2.0	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	11.00	8.00	8.00	8.00
10	0	5.00	5.00	5.00	5.00	6.50	6.00	6.00	6.00	8.50	7.00	7.00	7.00	12.00	9.50	8.00	8.00
10	0.4	5.00	5.00	5.00	5.00	6.50	6.00	6.00	6.00	8.50	7.00	7.00	7.00	12.00	9.50	8.00	8.00
10	0.8	5.00	5.00	5.00	5.00	6.50	6.00	6.00	6.00	8.50	7.00	7.00	7.00	12.00	8.50	8.00	8.00
10	1.2	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.50	7.00	7.00	7.00	11.5	8.00	8.00	8.00
10	1.6	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	11.00	8.00	8.00	8.00
10	2.0	5.00	5.00	5.00	5.00	6.00	6.00	6.00	5.00	7.00	7.00	7.00	7.00	10.00	8.00	8.00	8.00
11	0	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.50	7.00	7.00	7.00	11.00	8.50	8.00	8.00
11	0.4	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.50	7.00	7.00	7.00	11.00	8.50	8.00	8.00
11	0.8	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	10.00	8.00	8.00	8.00
11	1.2	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	10.00	8.00	8.00	8.00
11	1.6	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	9.00	8.00	8.00	8.00
11	2.0	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	8.50	8.00	8.00	8.00
12	0	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	10.00	8.00	9.50	8.00
12	0.4	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	10.00	8.00	8.50	8.00
12	0.8	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	10.00	8.00	8.00	8.00
12	1.2	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	10.00	8.00	8.00	8.00
12	1.6	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	9.00	8.00	8.00	8.00
12	2.0	5.00	5.00	5.00	5.00	6.00	6.00	6.00	6.00	7.00	7.00	7.00	7.00	8.00	8.00	8.00	8.00

Level II Approach

The solution to the HMA overlay thickness determination used in the Level II approach is an enhanced engineering analysis of the Level 1 tabular solution procedure. In the Level II approach, the engineer is required to determine or select specific design input values for the following variables:

ESAL: Design traffic value
h_{PCC} = PCC slab thickness (inches)
M_r: Design subgrade modulus
SN_{sb}: Subbase layers structural numbers

ESAL: Design Traffic Value

The design traffic for Level II analysis is based upon the expected equivalent single axle loads (ESAL) anticipated during the design period for the overlay. ESAL is a widely used and accepted industry standard for quantifying traffic loads. The values used in the graphs are million equivalent single axle loads (MESAL).

M_r: Design Subgrade Modulus

The subgrade support is characterized by the resilient modulus parameter, M_r. It is difficult to use lab results of resilient modulus tests directly into the solution procedure. Correlations between conventional subgrade design parameters such as CBR and R-value to the resilient modulus value of subgrade soils have been established. Figure 4.3 illustrates these correlations. However, some agencies are developing experience and confidence in performing resilient modulus testing. If lab or field (FWD) estimated resilient modulus data are available that represent a cross section of materials for the project, they may be used in lieu of the correlation to other properties. It is recommended that the correlation be used to verify the lab test properties.

SN_{sb}: Subbase Layer Structural Number

The structural number of the subbase (SN_{sb}) is the sum of the structural number for each layer of subbase. This structural number is determined by multiplying the structural layer coefficient of the material (a_{sb}) by the layer thickness in inches. Detailed guidance for the selection of these values is contained in the AASHTO Guide for the Design of Pavement Structures. For unbound granular layers, it is important to adjust the a_{sb} by the AASHTO drainage coefficients, m_{sb}.

For treated subbase layers, difficulties arise in the selection of an appropriate design a_{sb} value. The engineer must evaluate the probable loss of structural capacity in the original (as-built) pavement layer due to subsequent damage incurred during the previous performance life of the pavement. It is likely that some additional damage will occur to the stabilized layer during the rubblization process. As a result, typical values of a_{sb} for cement and asphalt treated materials used in new construction must be reduced accordingly to compensate for possible loss of strength. If specific information is not available, the engineer can use the procedure discussed for Level I to determine the Structural Number of the subbase layers.

Level II Graphical Solution for Thickness Design

The graphical solution to overlay thickness design provides a simple method with minimal input requirements. To determine the overlay thickness:

- Select the appropriate chart based on the thickness of the rubblized concrete and structural number of the subbase (SN_{sb}).
- Draw a vertical line upward from the subgrade modulus value until it intersects the traffic value.
- Draw a horizontal line from this intersection to the y-axis, and read the overlay thickness required.

Figure 4.7 illustrates the use of the graphical solution.

The example shown is for the following conditions:

PCC type: JPCP (jointed plain concrete pavement)
Fracture mode: Rubblization
PCC thickness: 8.0 inches
Design traffic: 50 MESAL
Subgrade modulus: 7 ksi
Total subbase SN: SN_{sb} = 1.2
HMA Overlay Thickness = 8.5 inches

Figure 4.7
Example Level II design

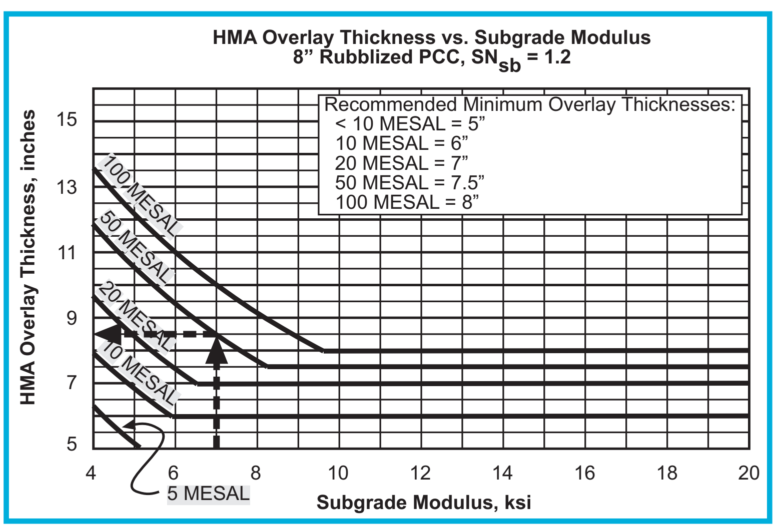


Figure 4.8
Level II overlay design charts 7” rubblized PCC

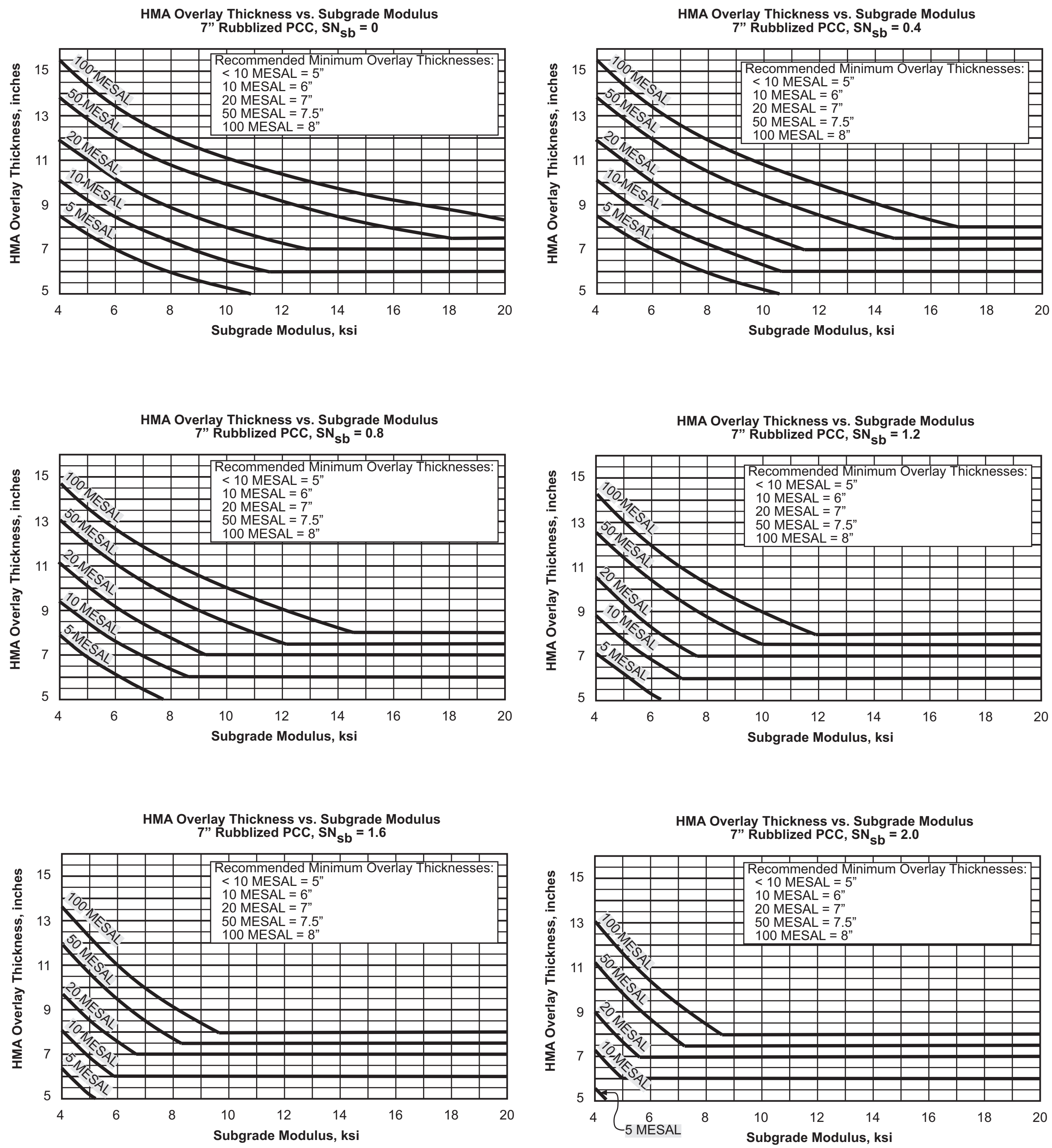


Figure 4.9
Level II overlay design charts 8” rubblized PCC

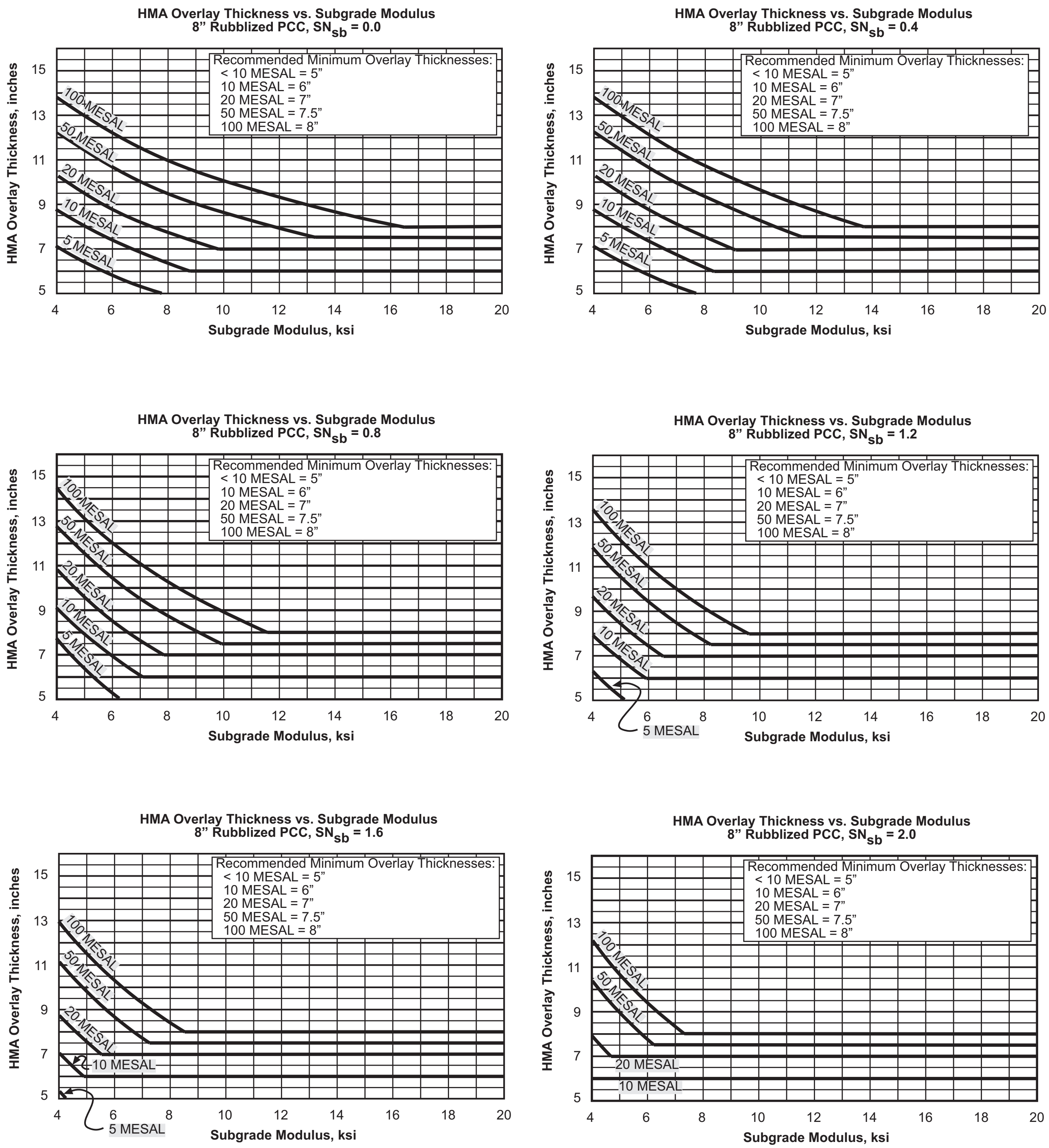


Figure 4.10
Level II overlay design charts 9” rubblized PCC

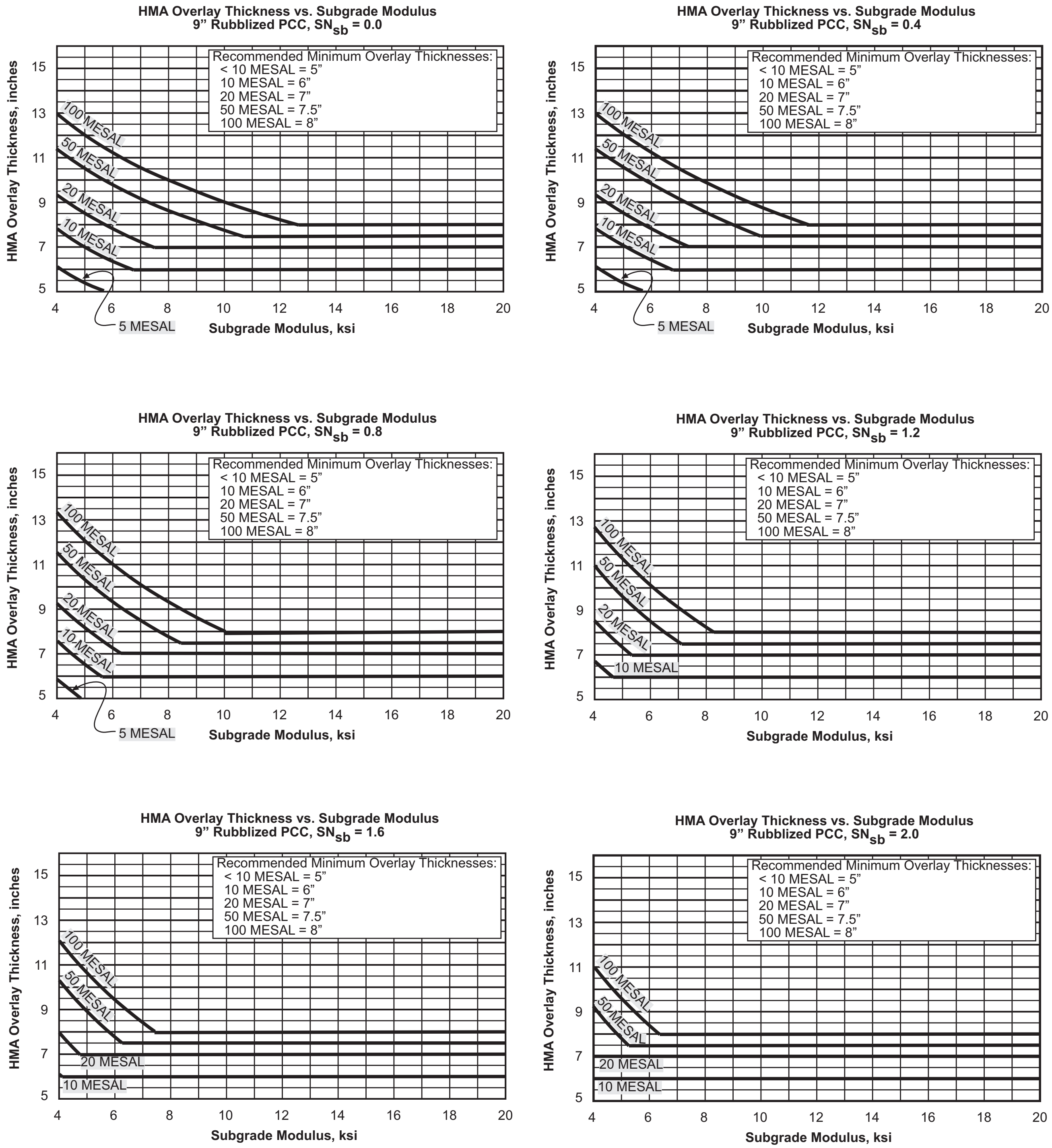


Figure 4.11
Level II overlay design charts 10” rubblized PCC

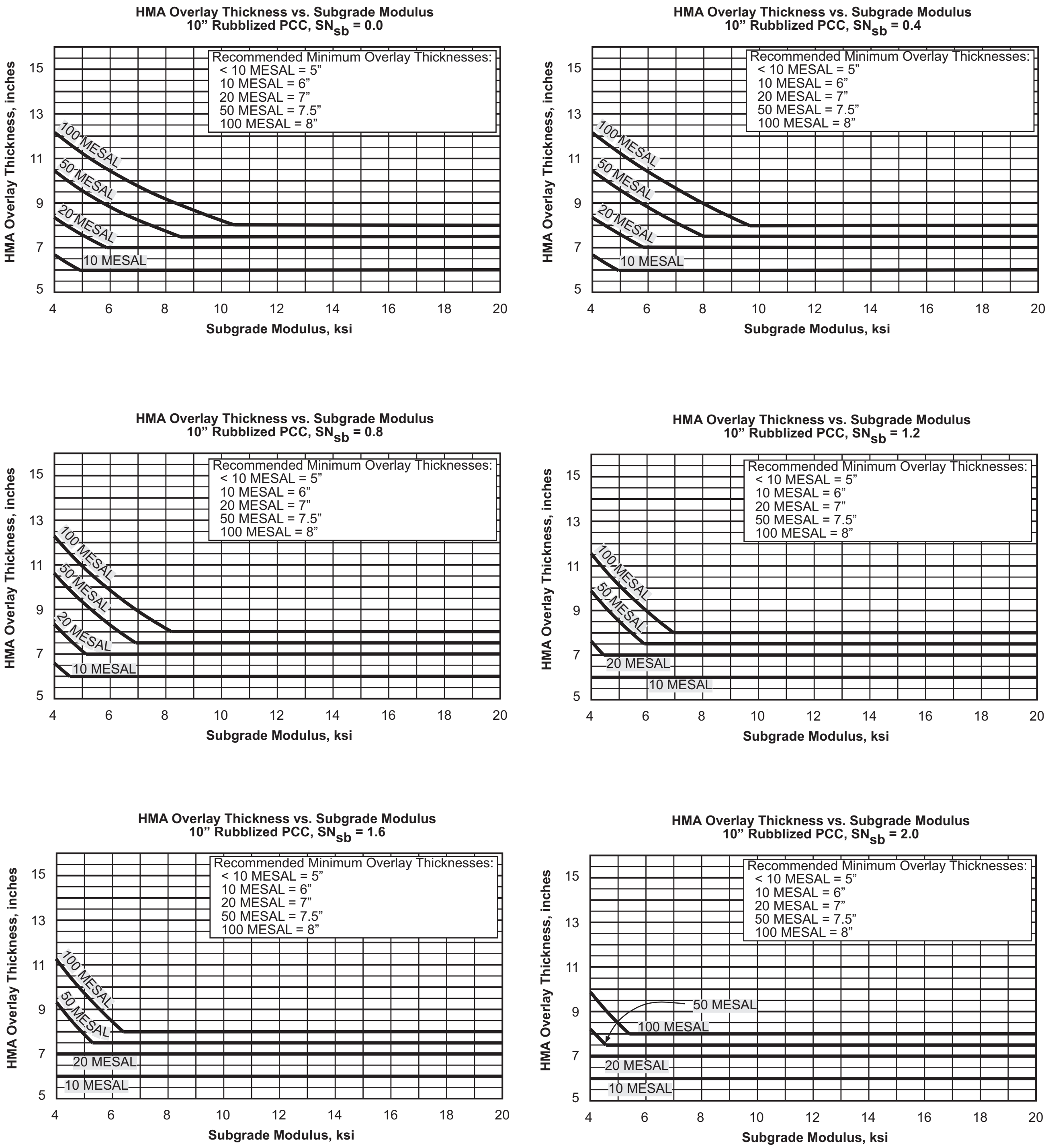


Figure 4.12
Level II 0verlay design charts 11” rubblized PCC

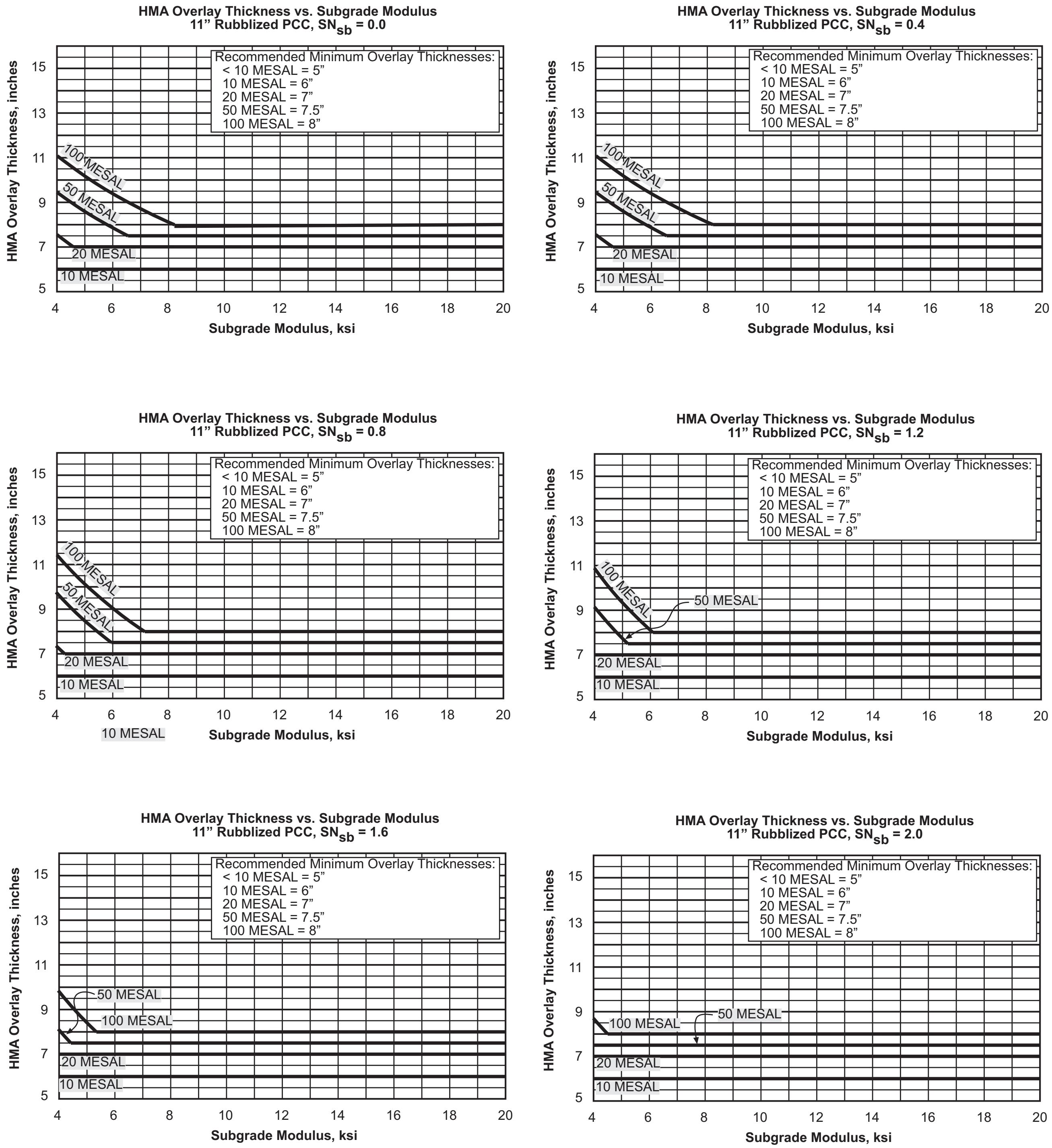
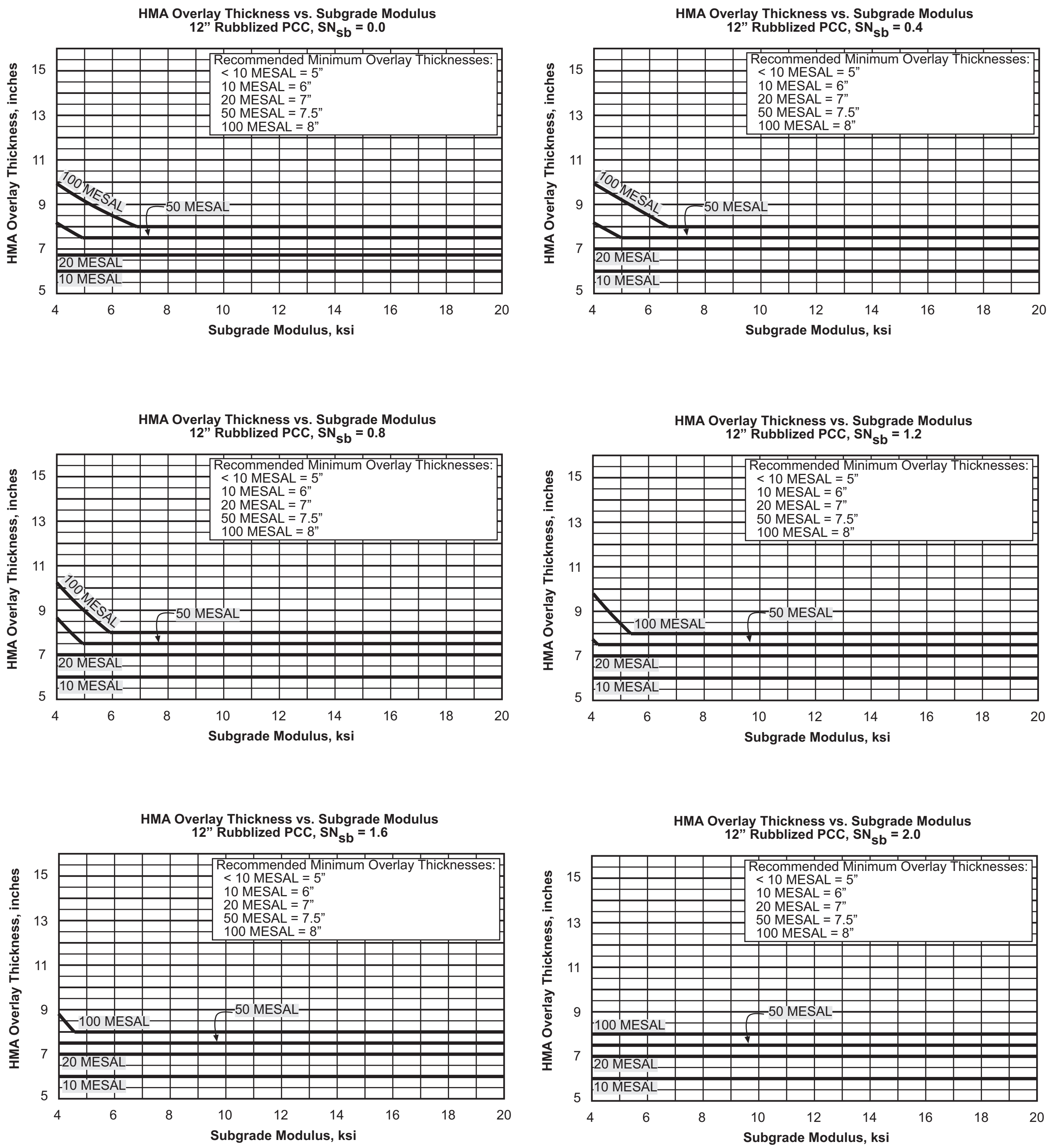


Figure 4.13
Level II overlay design charts 12” rubblized PCC



Level III PerRoad Layer Elastic Analysis

The Level III design requires the use of PerRoad software which is available for download from the Asphalt Pavement Alliance at www.asphaltalliance.com. PerRoad is a mechanistic-based procedure for the design of flexible long-life or Perpetual Pavement structures. The procedure was developed at the National Center for Asphalt Technology (NCAT) at Auburn University in conjunction with the Asphalt Pavement Alliance (APA).

The design software utilizes layered elastic theory to compute critical pavement responses under axle load spectra. Monte Carlo simulation is used to model the uncertainty corresponding to material, loading, and construction variability. The program can be used as a design and analysis tool to assess the likelihood that critical pavement responses will exceed a threshold set by the analyst. Additionally, transfer functions may be used to determine a damage accumulation rate for pavement responses exceeding the threshold.

The following is a description of some of the inputs required for the software. A detailed description of the required inputs and how to run the software is available from the Asphalt Pavement Alliance web site.

Traffic

Traffic loading is input by load spectra, which breaks down the traffic loads by axle types and axle weights. Load spectra may be obtained from FHWA W4 tables or from default values provided with the software.

Structure

Material properties for two to five layers (including the subgrade) can be analyzed with this software. Material property inputs include resilient modulus (M_r), Poisson's ratio, and variability. Material properties for each layer can also be changed for up to five seasons to account for variations due to temperature and moisture throughout the year. Typical values of resilient modulus and Poisson's ratio for a variety of materials, including rubblized concrete, may be found in the PerRoad Guide.

A key element of this software is that performance criteria are used to calculate accumulated damage from the traffic. While the user can select any performance criteria desired, typically horizontal tensile strain at the bottom of the asphalt and vertical compressive strain at the top of the subgrade are generally used for flexible pavements. For Perpetual Pavements another key element of the performance criteria is limiting strains. A limiting strain is a strain value which if not exceeded is assumed to result in no damage to the pavement structure. For HMA pavements the recommended limiting strain criteria are:

Fatigue:
Horizontal tensile strain at bottom of asphalt
$= 70 \times 10^{-6}$

Rutting:
Vertical compressive strain at top of subgrade
$= 200 \times 10^{-6}$

Transfer functions are used to equate strain levels to damage. A number of transfer functions have been proposed by researchers. Transfer functions used in the software are:

$$\text{Fatigue: } N_f = k_1 \left[\frac{1}{\epsilon_t}\right]^{k_2}$$

$$\text{Rutting:: } N_f = k_1 \left[\frac{1}{\epsilon_v}\right]^{k_2}$$

N_f = Number of load cycles to failure
k_1, k_2 = Constants
ϵ_t = Tensile strain at the bottom of the asphalt layer
ϵ_v = Vertical strain at the top of the subgrade layer

Constants used in the transfer functions to develop the Level II design graphs were:

Fatigue: $k_1 = 2.83 \times 10^{-6}$
$k_2 = 3.15$

Rutting: $k_1 = 6.03 \times 10^{-8}$
$k_2 = 3.87$

These values were determined for pavements at the Minnesota Road Research Project that showed fatigue and deep rutting distresses, and they may vary according to soil, climate, materials and traffic.

Analysis

After all the data have been entered for traffic loads and structure, the analysis may be performed. Either a deterministic or probabilistic analysis may be run.

If the deterministic analysis is selected, the program will run through the seasons and loads that have been input. If the limiting strain values have been exceeded, the program will indicate that the structure does not meet the criteria and what the worst case pavement response is. This only indicates that the limiting strain criteria have been exceeded by one or more loads for the seasonal material strength value(s). It does not necessarily mean that it should not be considered a Perpetual Pavement. However, it may be used as a quick check before running a probabilistic analysis to see if the limiting strain criteria are greatly exceeded.

A probabilistic analysis needs to be run to truly evaluate the pavement structure. For the probabilistic analysis the program randomly selects values within the moduli and thickness variability inputs to develop a range of outputs. This type of analysis presents a risk assessment of the probability that a given threshold value will not be exceeded as well as an indication of the rate of damage from loads causing the criteria to be exceeded. For information on criteria for evaluating pavement performance using this program, refer to the PerRoad Guide.

Contractors, engineers, and agency personnel examine a test pit at a rubblization project.