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Guide for Mechanistic-Empirical Design

OF NEW AND REHABILITATED PAVEMENT STRUCTURES

FINAL REPORT

PART 3. DESIGN ANALYSIS

CHAPTER 5. IDENTIFICATION OF FEASIBLE REHABILITATION STRATEGIES

NCHRP

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PART 3—DESIGN ANALYSIS

CHAPTER 5
IDENTIFICATION OF FEASIBLE REHABILITATION STRATEGIES

This chapter provides an introduction to procedures for identifying feasible project-level rehabilitation strategies, an overview of preventive and repair treatments used for developing rehabilitation strategies, and procedures for identifying the preferred rehabilitation strategy for flexible, composite, and rigid pavements. Figure 3.5.1 shows the flow of technology in selection of rehabilitation strategies.

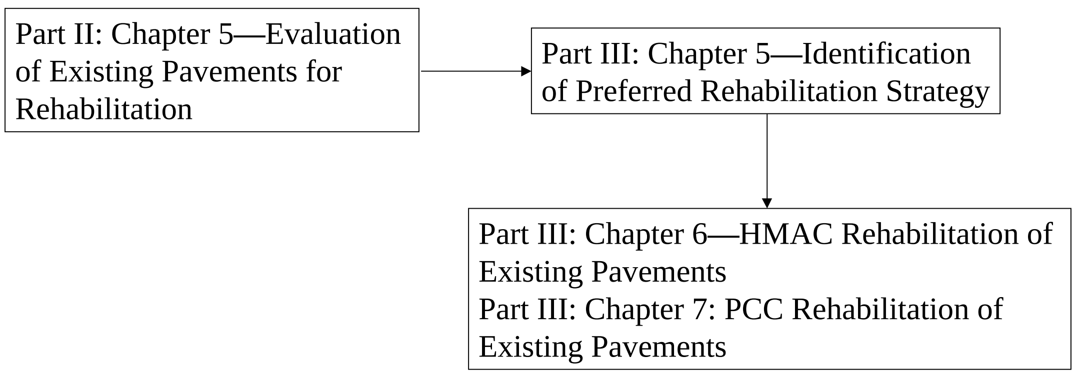

Figure 3.5.1. Summary of rehabilitation process in the Design Guide.

3.5.1 INTRODUCTION

A feasible rehabilitation strategy is one that addresses the cause of pavement distress and deterioration and is effective in both repairing it and preventing or minimizing its reoccurrence. A feasible rehabilitation strategy must meet critical constraints such as traffic control. Repair treatments are actions taken to restore the pavement's integrity (i.e., to repair the problem definitively), such as filling a pothole. Prevention treatments are actions taken to stop or delay the deterioration process, such as a structural overlay to reduce critical deflections.

This chapter provides an overview of strategies for the rehabilitation of existing flexible, rigid, and composite pavements. Flexible pavements include hot mix asphalt concrete (HMAC) over granular base material, HMAC over stabilized base, and full-depth HMAC. Rigid pavements include the various kinds of portland cement concrete (PCC) pavements such as jointed plain concrete pavements (JPCP), jointed reinforced concrete pavements (JRCP), and continuously reinforced concrete pavements (CRCP). Existing pavements also include composite pavements such as HMAC over PCC, PCC over HMAC, and PCC over PCC.

3.5.1.1 Scope

The major objectives of this chapter are to present general guidelines for identifying feasible rehabilitation strategies and then for selecting the preferred rehabilitation strategy for use on a specific project. Rehabilitation strategy is defined as a combination of repair and preventive treatments performed over a defined period to restore the ability of pavement to carry expected future traffic with adequate functional performance. The treatments discussed in this chapter encompass functional and structural rehabilitation treatments.

3.5.1.2 Organization

This chapter is organized into four major sections. Section 3.5.2 presents the general issues associated with pavement rehabilitation and major rehabilitation strategies.

Section 3.5.3 presents a detailed discussion on the selection factors and procedures used in selecting feasible strategies (e.g., multiple repair and prevention treatments implemented over time [staged construction or repair]), while section 3.5.4 presents a summary of all of the concepts discussed.

3.5.2 MAJOR REHABILITATION STRATEGIES

A pavement rehabilitation strategy usually includes a combination of individual rehabilitation treatments that are required to repair existing deterioration and minimize future deterioration. A rehabilitation strategy by definition is explicit—spelling out both the types and quantities of treatments to be applied and when it should be applied. Rehabilitation strategies should be detailed enough to allow for both a detailed evaluation and comparison with other strategies in terms of expected performance and costs. Finally, a rehabilitation strategy should be capable of repairing and preventing deficiencies in the following pavement conditions defined and characterized in PART 2, Chapter 5 of this Guide:

- Structural condition.
- Functional condition including foundation movement.
- Subsurface drainage condition.
- Material durability condition.
- Shoulder condition.

Feasible strategies should also consider variations in the pavement conditions along the project and must be effective within all possible sets of constraints (e.g., cost, traffic) expected for the project.

The following is a list of the common major rehabilitation strategies that may be applied singly or in combination to obtain an effective rehabilitation strategy (1, 2, 3, 4):

- Reconstruction without lane additions.
- Reconstruction with lane additions.
- Structural overlay (may include removal and replacement of selected pavement layers).
- Non-structural overlay.
- Restoration without overlays.

Engineers should also take advantage of recent advances in research into the properties of recovered paving materials and industrial byproducts that has made it possible to apply these materials—recycling—in pavement reconstruction and overlay construction.

Overall rehabilitation strategy usually consists of various combinations treatments commonly applied during rehabilitation. Each major strategy is briefly described in the next few sections.

3.5.2.1 Reconstruction with/without Lane Additions

Reconstruction is the most invasive rehabilitation option; however, it may be the most cost-effective if life cycle costs are considered. Reconstruction may be applied to existing flexible, rigid, and composite pavements. It is most suitable for flexible pavements with high-severity load-related distress such as fatigue cracking or rutting or material durability problems such as stripping. For rigid pavements, reconstruction is most appropriate for pavements with a high percentage of cracked slabs, a high percentage of deteriorated joints, inadequate subgrade or foundation support, or material-related distresses such as D-cracking. Reconstruction is also feasible for both flexible and rigid pavements exhibiting major foundation movements and frost heave where the upper subgrade material must be replaced (3, 4).

Reconstruction usually involves the removal and replacement of parts of the pavement, (e.g., removal and replacement of a single lane), the complete removal of the entire pavement (including support layers), removal and replacement of shorter areas, or the addition of extra lanes to an existing pavement with or without reconstruction of the existing pavement. When only one or two lanes are removed from an existing multi-lane pavement for reconstruction, the replacement pavement is called an inlay. Recycled materials from the existing pavement may be used in reconstruction (3, 4, 5).

One other form of rehabilitation is widening of old narrow pavement cross-sections. This is a very challenging design because it requires the matching of an already existing pavement with an entirely new structure with the new structure performing a closely to the existing pavement as possible so that there is uniform performance across the widened traffic lane. Designing is even more difficult when constraints forces the new outer wheel path to fall directly on the widened longitudinal joint. In most situations, failure along the joint is inevitable unless a good structural design is performed.

3.5.2.2 Rehabilitation with Structural Overlay

Structural overlays represent a wide variety of treatments to rehabilitate a pavement. They are used when the pavement has medium to high levels of load-related distress, which would make the use of preventive maintenance/repair treatments too expensive or ineffective. Structural overlays for flexible, rigid, and composite pavements are placed for the purpose of substantially increasing existing pavement structural capacity.

Structural overlays fall into four basic categories:

- HMAC overlay over an existing flexible pavement.
- HMAC overlay over an existing rigid pavement.
- HMAC overlay over an existing composite pavement.
- Bonded or unbonded JPCP and CRCP over existing rigid or composite pavement.
- PCC overlay over an existing flexible pavement.

The PCC overlays fall into two subcategories, bonded and unbonded. Brief descriptions of the various structural overlay types are presented in the following sections (1, 3, 4). Note that recycling of one or more pavement layers should be considered for any type of rehabilitation.

HMAC Overlays. Typically, an HMAC overlay of a flexible pavement (HMAC/HMAC), an AC overlay of a rigid pavement (AC/PCC), or an AC overlay of a composite pavement (HMAC/ HMAC /PCC) is placed to improve the ride quality, surface friction, or to substantially increase the structural capacity of the existing pavement. A variety of alternative HMAC mixtures exist as described in PART 2, Chapter 2. The designer must carefully select the most appropriate mixture given the level of traffic and the climate where the project is located.

<u>HMAC over Existing Flexible Pavement</u>. An HMAC overlay of an existing flexible pavement may be placed to improve ride quality and/or surface friction, or may be placed for the purpose of substantially increasing structural capacity. A thin AC overlay is appropriate for existing pavements with functional inadequacies only such as insufficient smoothness, poor surface friction, excessive rutting, and distresses such as bleeding, weathering, raveling, bumps, settlement, and heaves (5).

A thicker HMAC overlay is appropriate for exiting pavements with insufficient structural capacity for anticipated future traffic. HMAC overlays placed to correct structural inadequacies will also correct functional inadequacies. A thin functional overlay should not be placed when a structural deficiency exists.

<u>HMAC over Existing Rigid or Existing Composite Pavement (Intact PCC Slab).</u> An HMAC overlay of a rigid or composite pavement may improve ride quality and/or surface friction, or may be placed for the purpose of substantially increasing structural capacity. A relatively thin HMAC overlay (e.g., 1 to 3 in) is appropriate for existing pavements with functional inadequacies only, such as excessive loss of smoothness or poor surface friction. A thicker HMAC overlay is appropriate for existing pavements with insufficient structural capacity for anticipated future traffic (e.g., > 3 in). HMAC overlays placed to correct structural inadequacies will also correct functional inadequacies. HMAC overlays of existing rigid or composite pavements must be designed and constructed to withstand the development of reflection cracking because it is the most common form of premature failure for such rehabilitation. Existing rigid or composite pavements with excessive amounts of deteriorated cracks or joints may not be the best candidates for HMAC overlays (5).

<u>HMAC over Fractured Concrete Pavement.</u> The existing PCC pavement can be fractured to address the problem of reflection cracking. Fracturing the slab may be performed to reduce

reflection cracking and to reduce the amount of pre-overlay repair if the existing pavement is badly deteriorated. Fracturing can be done two different ways: rubblize or crack/break and seat.

Rubblizing can be done on all types of concrete pavements (JPCP, JRCP, and CRCP). The slab is pulverized into pieces that are less than 12 inches in length. Normally, any reinforcing steel is broken free from the rubblized concrete. Rubblizing is a reliable methodology to eliminate reflection cracking of an HMAC overlay. It is most cost-effective when the existing pavement is badly deteriorated. Criteria for rubblizing include subgrade and base condition and location of water table. Having soft and wet material beneath the slab may cause problems with rubblizing.

Crack and seating refers to JPCP only and involves fracturing the slab into pieces between 1 to 3 ft on a side and seated with a heavy roller. Break and seating refers only to JRCP where the fracturing must rupture the reinforcing steel so that the pieces are not tied together. Breaking may require more impact force than the cracking of JPCP. Breaking JRCP into acceptable pieces has been quite difficult and reflection cracking has reappeared on some projects.

PCC over Existing PCC. PCC overlays may be bonded or unbonded.

<u>Bonded.</u> Bonded PCC overlays are used primarily to increase pavement structural capacity. They consist of a thin PCC layer ($\leq$ 4 in) bonded to the top of the existing concrete surface to form a monolithic or composite section. Typically, pavements that have very little deterioration, but are too thin for an increasing traffic volume, are good candidates for a bonded overlay. Bonded concrete overlays are not recommended when the existing pavement is badly deteriorated and a substantial amount of removal and replacement of existing layers is necessary during rehabilitation (*3, 4*).

Bonded concrete overlays over an existing PCC are also not appropriate if there is significant deterioration of the existing pavement due to a material durability problem such as D-cracking or alkali-silica reaction (ASR) because the presence of such distress would make it difficult to bond the overlay to the existing pavement permanently (*1, 3, 4*).

<u>Unbonded or Separated</u>. Unbonded or separated PCC overlays consist of a relatively thick concrete layer (> 5 in) on top of an existing concrete pavement with a separation layer between the slabs. Unbonded overlays are generally most cost-effective when the existing concrete pavement is badly deteriorated and removal of existing pavement layers is not desirable. Unbonded overlays behave structurally as a new rigid pavement constructed on a strong, non-erodible base course (*1, 4, 6*).

Unbonded overlays do not require much pre-overlay repair before placement because of a separating layer used between the PCC overlay and existing PCC pavement. The *separation interlayer* is usually a thin AC layer of about 1.0 to 2.0 in thick. The layer is sometimes called a separation layer or stress relief layer. The purpose of the interlayer is to separate the existing and new PCC layers so that they may act independently of each other when subjected to climate-related and wheel loading. The separation interlayer also prevents distresses in the existing pavement from reflecting through into the PCC overlay. The PCC overlay should bond with the HMAC layer, however, to promote proper joint formation and increase strength (*1, 3, 4, 5, 6*).

PCC over Existing HMAC or Composite Pavement. Concrete overlays over existing flexible pavements can be categorized as follows:

- Conventional—Consists of a thick PCC layer ($\geq$ 8 in) on top of an existing flexible pavement.
- Thin—Consists of a thin PCC layer (4 to 8 in thick) on top of an existing flexible pavement.
- Ultra-thin—Consists of an ultra-thin PCC layer (2 to 4 in thick) on top of an existing flexible pavement.

When loaded by vehicles, concrete overlays over existing flexible pavements behave just like a new PCC pavement on asphalt treated base course. Concrete overlays over flexible pavements are effective for almost all applications and can be designed to accommodate a wide range of existing conditions (*7*).

Conventional concrete overlays of flexible pavements offer several advantages. First, they require minimal pre-overlay repair because of concrete's ability to bridge deterioration. Second, the existing asphalt makes a good base course with the same advantages of other stabilized base materials—reduced potential for pumping and faulting for jointed plain concrete pavements (JPCP) and reduced loss of support for continuously reinforced concrete pavements (CRCP) (*3*, *6*, *7*).

An ultra-thin concrete overlay of flexible pavements is a thin PCC overlay placed on top of the prepared surface of an existing flexible pavement. In addition to being thinner, two other factors differentiate ultra-thin concrete overlay from conventional concrete overlay (*7*):

- Requirement for bonding between the concrete overlay and the existing flexible pavement.
- Very short joint spacing compared to normal (2 to 6 ft instead of 12 to 18 ft).

Bonding the ultra-thin concrete overlay to the existing flexible pavement creates a composite section in which the load is shared between the concrete and existing flexible pavement. The closer joint spacing allows the slabs to deflect instead of bend. This reduces bending stresses in the slabs (*7*).

Ultra-thin concrete overlays are applied where a substantial thickness of HMAC exists on the existing flexible pavement (e.g., full-depth AC pavements). They have been shown to perform well on residential streets with normal traffic loads and low-volume roads. Other applications include flexible pavement intersections where rutting and washboarding is a problem and parking areas with HMAC surfaces. The performance of ultra-thin concrete overlays is highly influenced by the extent of deterioration of the existing flexible pavement. They must therefore be designed for this condition (*7*).

3.5.2.3 Rehabilitation With Non-Structural Overlay

Nonstructural overlays may be placed on an existing flexible or rigid pavement to improve ride quality and/or surface friction. They are also placed to minimize the effects of HMAC aging (in flexible pavements) and minor surface irregularities in the vertical profile of the existing pavement. Nonstructural overlays should not be placed on existing pavements showing extensive signs of fatigue (longitudinal or alligator cracking in the wheel paths for flexible pavements and pumping, faulting, transverse cracking, and punchouts for rigid pavements). They should only be placed after the existing pavement surface has been restored either by sealing cracks or by milling of the deteriorated material. Nonstructural overlays are typically less than 3 in thick. Nonstructural overlays are effective only if the existing pavement is structurally adequate with little or no load/fatigue related distress or severe material durability problems. Nonstructural overlays are very commonly placed on HMAC /PCC composite pavements because they are often structurally adequate (1, 5).

Rehabilitation without overlays refers to a series of repair and preventative treatments used to bring the structural capacity or rideability of a deteriorating flexible or rigid pavement to an acceptable condition. The rehabilitation treatments each have a unique purpose to repair or replace a particular distress (kind of deterioration) found in the pavements, or to prevent or slow further deterioration. The most common repair treatments for flexible and rigid pavements are summarized as follows (1):

- Flexible pavements—patching and pothole repairs, crack sealing, placement of chips seal, micro-surfacing, and cold milling.
- Rigid pavements—slab stabilization, full-depth repair, partial-depth repair, retrofitting dowels, cross-stitching longitudinally-oriented cracks or longitudinal joints, diamond grinding, and joint and crack resealing.

Typically, only one treatment may be necessary for pavements with minor deterioration. However, one or more of the treatments may be required where pavement deterioration is more widespread and severe. Choosing what treatments to use depend on what distresses is present in the pavement. For rehabilitation without overlays to be most effective, proper engineering, construction and timing are critical. There exists a “window of opportunity” for rehabilitation without overlay beyond which poor performance is expected. Some of the repair treatments including preventive maintenance treatments that fall under rehabilitation without overlays are summarized in table 3.5.1 and described in greater detail in the following sections (*1*).

Full-Depth Repair. Full-depth repair entails removing and replacing at least a portion of an existing pavement to the bottom of the HMAC or PCC layer in order to restore areas of deterioration. Full-depth repairs improve pavement rideability and structural integrity and extend pavement service life (*3, 4, 8, 9*).

The most common problem that requires full-depth repair is fatigue cracking and transverse cracks for HMAC pavements and joint deterioration (e.g., cracking, breaking, or spalling of slab edges on either side of a transverse or longitudinal joint) for jointed PCC pavements, and punchouts for CRCP. Full-depth repair may be used for material durability related distresses

Table 3.5.1. Candidate repair and preventative treatments for flexible, rigid, and composite pavements (*1*).

Pavement Type	Distress	Repair Treatments	Preventative Treatments
Flexible and composite	Alligator (fatigue) cracking	Full-depth repair	Crack sealing
	Bleeding	Apply hot sand	
	Block cracking	Seal cracks	
	Depression	Level up overlay	
	Polished aggregate	Skid resistant surface treatment Slurry seal	
	Potholes	Full-depth repair	Crack sealing and seal coats
	Raveling	Seal coats	Rejuvenating seal
	Rutting	Level up overlay and/or cold milling	
	Reflective cracking	Full or partial depth repair	Saw and seal
Rigid	Jointed concrete pavement pumping (and low joint load transfer efficiency)	Subseal (effectiveness depends on materials and procedures)	Reseal joints Restore joint load transfer Subdrainage Edge support (tied PCC shoulder edge beam)
	Jointed concrete pavement joint faulting	Grind Structural overlay	Subseal Reseal joints Restore load transfer Subdrainage Edge support (tied PCC shoulder edge beam)
	Jointed concrete pavement slab cracking	Full-depth repair Replace/recycle lane	Subseal (loss of support) Restore load transfer Structural overlay
	Jointed concrete pavement joint or crack spalling	Full-depth repair Partial-depth repair	Reseal joints
	Punchout (CRCP)	Full-depth repair	Polymer or epoxy grouting Subseal (loss of support)
	PCC disintegration	Full-depth repair	None, thick overlay

where deterioration takes place at the bottom of the HMAC or PCC and may not be visible from the surface (*3*, *4*, *8*, *9*).

Partial-Depth Repair. The purpose of partial-depth patching is to restore localized areas of deterioration that do not extend through the entire HMAC or PCC layer. This treatment is most commonly used to patch potholes in HMAC pavements. Partial-depth patches are acceptable for most surface problems at joints, cracks, and midslab locations that are within the upper one-third of the slab for PCC pavements (*3, 4, 8, 9*).

Partial-depth patches are usually relatively small, usually covering an area less than about 10 ft^2. They are often only 2 to 3 in deep. Partial-depth patches can be used to replace unsound HMAC or PCC material (such as small areas with severe scaling) to restore rideability and deter further deterioration (*3, 4, 8, 9*).

Preventive Treatments. Preventive treatments are applied to existing pavement systems and appurtenances to preserve the system, retard future deterioration, and maintain or improve functional condition without significantly increasing structural capacity. Examples of preventive treatments are presented in table 3.5.1 (*1*).

Repair/Retrofit Subsurface Drainage. Subdrainage improvement, for both flexible and rigid pavements, may involve such activities as installation of longitudinal subdrains and outlets alongside an existing pavement structure, or daylighting a base layer by replacing base material under the shoulders with better-draining material (*10*).

Whether retrofit subdrainage improvements are beneficial to the performance of the existing pavement depends on whether water in the pavement structure can be removed effectively, and how well the subdrainage system is designed, constructed, and maintained. In extreme situations, the entire pavement can be reconstructed with a permeable base/edgedrain subdrainage system (*1, 10*).

Shoulder Rehabilitation. In general, shoulders should be rehabilitated when they start showing serious signs of load-related or other distresses such as raveling and settlement. Flexible shoulders need repair if they are cracked, or there is gap along the pavement edge, while rigid shoulders need repair if they are cracked or there are signs of pumping at the shoulder pavement joint. Other conditions of concern include:

- The shoulder surface shows ruts and corrugations.
- The slope is too flat to provide good drainage.
- The shoulder has deteriorated to the extent that it is causing cracks or erosion of material at the pavement edge.
- There is a significant drop-off from the pavement to the shoulder.

Shoulder rehabilitation consists of all the full-depth, partial-depth, placement of a wedge overlay near the longitudinal joint, and other repair activities applied to the actual pavement (*1, 5, 8, 9*).

3.5.3 RECYCLING OF EXISTING PAVEMENT OR OTHER MATERIALS

Recycling has become very common with the increase in the volume of waste and byproduct materials generated in society, increased cost of disposal, and increasing incentives to recover and recycle these materials for use in secondary applications. Several years of research into the properties of such materials has also made it possible to better understand recycled materials and to consider their use in pavement construction.

The cost-effectiveness of all the treatments described could be enhanced greatly by the application of recycled portions of the existing pavement layers or other “waste” products during rehabilitation construction. Recycling processes include (*11*):

- Hot mixing of the existing HMAC layer materials with or without new materials.
- Breaking of existing PCC to recover fine and course aggregate materials.
- Cold mixing of exiting stabilized or unbound material with or without new materials.

Mixing of the recycled and new materials can be done in-situ, on-site, or off-site.

From a pavement engineering perspective, recovered materials should be used in such a manner that the expected performance of the pavement will not be compromised. Waste and byproduct materials differ vastly in their types and properties and, as a result, in the pavement applications for which they may be suited. Experience and knowledge regarding the use of these materials vary from material to material, as well as from State to State. To recover these materials for potential use, engineers, researchers, generators, and regulators need to be aware of the properties of the materials, how they can be used, and what limitations may be associated with their use (*11*).

Several guidelines, including the FHWA *User Guidelines for Waste and Byproduct Material in Pavement Construction,* have been developed to assist engineers with an interest in using or increasing their understanding of the types of waste and byproduct materials that may be recovered and used in pavement construction applications (*11*). They provide users with sufficient information on common materials used in recycling such recovered HMAC and PCC, stabilized materials, and industrial waste materials such as fly ash. Information provided relates to engineering evaluation requirements, environmental issues, and economic considerations for determining the suitability of using recovered materials in pavement applications.

Specific information provided cover the use of recycled paving materials and “waste or byproduct” materials in six major highway layer construction applications, namely (*11*):

- Hot mix asphalt concrete or asphalt treated layers.
- PCC or cement treated layers.
- Pozzolan stabilized base/subbase.
- Granular unbound base and subbase.
- Embankment or fill.
- Flowable fill.

Table 3.5.2 lists the recycle material types commonly applied to these categories. It must be noted that the omission of a particular material-application match in table 3.5.2 is not to be construed as a prohibition against its use. And also because of the ongoing development and publication of new information regarding the use of recovered materials in highway applications most of the guidelines provided are tentative and periodic revisions and updates must be expected (*11*).

Table 3.5.2. Highway and pavement applications and material uses (*11*).

Major Layer Category	**Primary Application of Recycled Paving or Byproduct Material**	**Recycled Paving or Byproduct Material**
Asphalt concrete or AC-treated layers	Aggregate in AC	Blast furnace slag, coal bottom ash, coal boiler slag, foundry sand mineral processing wastes, nonferrous slag, recycled asphalt pavement, scrap tires, steel slag
	Aggregate in cold mix AC	Coal bottom ash Recycled asphalt pavement
	Aggregate in seal coat or surface treatment	Blast furnace slag Coal boiler slag
	Mineral filler	Cement kiln dust, lime kiln dust, coal fly ash
PCC or cement-treated layers	Aggregate	Recycled concrete
	Supplementary cementitious materials	Coal fly ash Blast furnace slag
Pozzolan stabilized base/subbase	Aggregate	Coal bottom ash Coal boiler slag
	Cementitious material • Pozzolan • Pozzolan activator • Self-cementing material	Coal fly ash Cement kiln dust Lime kiln dust
Granular unbound base and subbase	Granular base	Blast furnace slag, coal boiler slag, mineral processing wastes Nonferrous slag, cycled asphalt pavement, Recycled concrete
Embankment or fill	Embankment or fill	Coal fly ash, mineral processing wastes, nonferrous slag Recycled asphalt pavement, Recycled concrete
Flowable fill	Aggregate	Coal fly ash Foundry sand Quarry fines
	Cementitious material • Pozzolan • Pozzolan activator • Self-cementing material	Coal fly ash Cement kiln dust Lime kiln dust

3.5.4 IDENTIFICATION OF FEASIBLE REHABILITATION STRATEGIES

A considerable amount of analysis and engineering judgment is required when determining specific treatments required to make up a feasible rehabilitation strategy for a given pavement condition. The steps listed in table 3.5.3 are used in developing feasible rehabilitation strategies. The procedure is presented in figure 3.5.2 and discussed in greater detail in the next few sections.

Table 3.5.3. Steps used in determining feasible rehabilitation strategies.

Step	Description	Reference Chapter
1	Determine existing pavement condition—the extent and severity of specific pavement distresses	PART 2, Chapter 5
2	Determine causes of distress	PART 2, Chapter 5
3	Define problems and inadequacies of existing pavement	PART 2, Chapter 5
4	Identify all possible constraints	PART 2, Chapter 5 PART 3, Chapter 5, 6, 7
5	Using the information gathered in steps 1 through 4 select feasible rehabilitation strategies	PART 3, Chapter 5
6	Develop preliminary design of each feasible rehabilitation strategy	PART 2, Chapter 2, 3, 4, 5 PART 3, Chapter 5, 6, 7
7	Perform a life cycle cost analysis of the possible rehabilitation strategies	Appendix C
8	Determine relevant non-monetary factors that influence rehabilitation	PART 3, Chapter 5
9	Using the information gathered in steps 5 through 8, determine the most feasible or preferred rehabilitation strategy	PART 3, Chapter 5

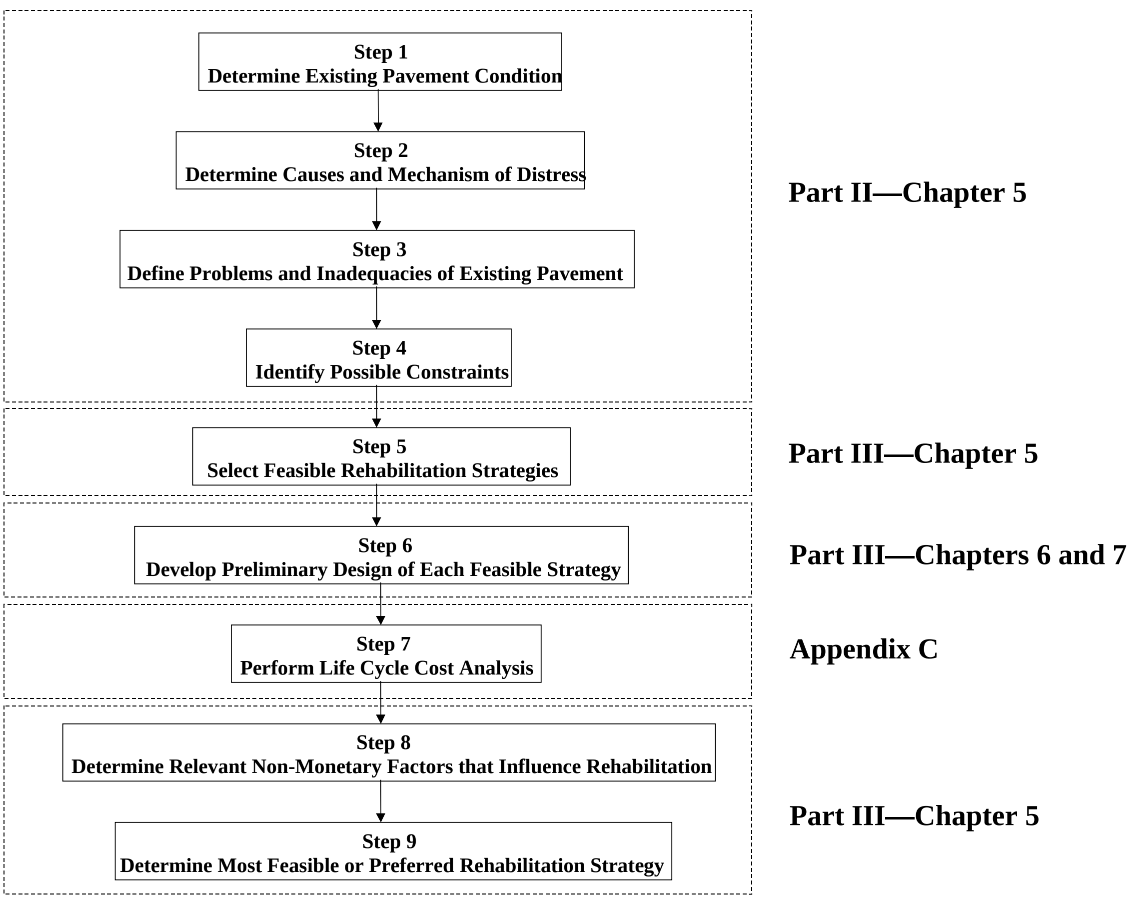

Figure 3.5.2. Procedure for selecting preferred rehabilitation strategy.

3.5.4.1 Steps 1 through 4—Determine Existing Pavement Condition, Causes of Distress, and Identify All Possible Rehabilitation Constraints

Step 1 through 4 in the pavement rehabilitation treatment selection process describes existing pavement evaluation, overall condition assessment, and overall problem definition. This process was described in detail in PART 2, Chapter 5 of this Guide.

Overall pavement condition assessment and problem definition was determined by evaluating the following major aspects of the existing pavement:

- Structural adequacy.
- Functional adequacy (user related).
- Subsurface drainage adequacy.
- Material durability.
- Shoulder condition.
- Variation of pavement condition or performance within a project.
- Miscellaneous factors.
- Constraints (e.g., bridge and lateral clearance).

The structural category relates to those properties and features that define the response of the pavement to traffic loads. The functional category relates to the surface and subsurface characteristics and properties that define the smoothness of the roadway or to those surface characteristics that define the frictional resistance or other safety characteristics of the pavement's surface.

Poor subdrainage is often a cause of deterioration. Material durability problems can lead to serious structural and functional failure. Shoulder condition is important to safety and traffic control options. Variation within a project refers to areas where there is a significant likelihood of variability in pavement condition or performance. Miscellaneous factors, such as joint condition for jointed concrete pavements and reflection cracking for composite pavements are evaluated only where relevant. All possible constraints that may be encountered during rehabilitation (such as the availability of adequate bridge clearance for placing overlays) must be documented.

Assessing the overall state of a pavement and defining its key problems is vital to the preparation of feasible, cost-effective rehabilitation strategies. As illustrated in table 3.5.4, information gathered from the various surveys and tests during the pavement evaluation phase (PART 2, Chapter 5) is used in assessing overall pavement condition and for rating the pavement condition in the areas of assessment as adequate, marginal, or inadequate.

A pavement that was considered to have failed in any of the areas of assessment was categorized as inadequate. Such a pavement exhibits extreme levels of distress and is most likely that the rate of deterioration is such that maintenance treatments will be cost-prohibitive requiring excessive lane closures and hence a larger-scale (and more permanent) remedial action is required.

Table 3.5.4. Areas of overall condition assessment and corresponding data sources.

Area of Assessment	Data Source						Condition Rating
	Distress Survey	Smoothness Testing	Friction Testing	Drainage Survey	Nondestructive Testing	Destructive Testing	
Structural Adequacy	√			√	√	√	Adequate Marginal Inadequate
Functional Adequacy	√	√	√				Adequate Marginal Inadequate
Drainage Adequacy	√			√	√	√	Adequate Marginal Inadequate
Materials Durability	√			√	√	√	Adequate Marginal Inadequate
Maintenance Applications	√						Adequate Marginal Inadequate
Shoulders Adequacy	√				√	√	Adequate Marginal Inadequate
Variability Along Project	√			√	√	√	Adequate Marginal Inadequate
Misc.	√			√		√	Adequate Marginal Inadequate

A pavement with one or more of the areas of assessment in the marginal category is one that will soon need some sort of rehabilitation. However, because such pavements have not yet failed it allows an agency time to plan, design, and implement a rehabilitation activity prior to the pavement reaching an inadequate condition. A pavement categorized as adequate is generally sound in the area of assessment and therefore requires no treatments.

3.5.4.2 Step 5—Selection of Major Rehabilitation Strategies and Rehabilitation Treatments

Step 5 consists of the identification of potential rehabilitation strategies. The first task in step 5 is the identification of various combinations of candidate treatments that may be applied in solving a pavement deterioration problem. Each combination of treatments is then defined as a given rehabilitation strategy. Next, candidate strategies are subjected to the project constraints and those that meet the constraints are considered feasible rehabilitation strategies. The procedure for determining the feasible rehabilitation strategies depends on:

- Results of overall pavement condition assessment and problems definition.
- Rating in the specific areas of assessment.
- Specific distresses or defects identified as the causes of pavement inadequacies.

The procedures involved in determining existing pavement adequacy have been described in detail in PART 2, Chapter 5. After completion of the pavement evaluation and problem definition phase, the design engineer should be able to suggest the causes of the problems with the existing pavement. Possible causes of structural, functional, and other inadequacies are presented in table 3.5.5.

The specific causes and their mechanisms of identified problems should be used as the basis for selecting candidate rehabilitation strategies. The candidate strategies should address the causes of the distresses and pavement deterioration and should be effective in repairing the existing distress and preventing as much as possible, recurrence. Tables 3.5.6 and 3.5.7 present summaries of candidate strategies (i.e., combination of treatments) for repairing and preventing the different problems that may be identified on existing pavements.

3.5.4.3 Step 6—Develop Preliminary Design of Feasible Rehabilitation Strategies

This step consists of developing preliminary designs for the feasible strategies identified in step 5. Preliminary design information should consist of the following information:

- Location of project (information must be complete and accurate).
- Right of way and control of access.
- Description of rehabilitation strategy (work involved for all treatments must be described).
- Project layout.
- Layout of all repair work that must be done prior to placing of overlays or diamond grinding (for rigid pavements).
- Design data and typical sections should include all necessary layer dimensions and details (e.g., base/subbase, existing surface, overlay, shoulders, slopes, lane widths, medians, curb and gutter).
- Estimates of preliminary earthwork (if necessary).
- Estimates of materials required for repair/preventive treatments.
- Preliminary subdrainage designs (if necessary).

It must be noted that design of the feasible rehabilitation strategies is highly influenced by the amount of future traffic expected on the pavement and the effect of climate. Future traffic is a key consideration in selecting future rehabilitation strategies because traffic directly influences rehabilitated pavement structural capacity and performance for the anticipated design life. Excessive traffic could also cause the premature failure of the rehabilitated pavement through the early occurrence of load-related distresses. Along with future traffic, climatic condition can also cause the premature failure of rehabilitation, especially when non-durable materials are used. An accurate estimate of the expected life and reliability of the rehabilitation strategy must also be determined using performance models or past local experience as part of design.

Premature failures in rehabilitated pavements can therefore be minimized by selecting the rehabilitation strategy that will withstand deterioration caused by expected future traffic and by using materials that are durable enough to last through the anticipated rehabilitation design life.

Table 3.5.5. Summary of information required for determining feasible rehabilitation solutions for flexible and rigid pavements.

Existing Pavement Surface	Possible Problem or Inadequacy	Rating*	Specific Distress Type, Extent, and Severity
PCC	Structural	Adequate	Minor distresses
		Marginal	Varying quantities and severities of fatigue cracking, rutting, pumping, faulting, transverse cracking, punchouts, etc.
		Inadequate	
	Functional	Adequate	Minor distresses
		Marginal	Varying levels of smoothness and surface friction
		Inadequate	
	Drainage	Adequate	Minor distresses
		Marginal	Varying quantities and severities of pumping, faulting, fatigue cracking, etc.
		Inadequate	
	Materials durability	Adequate	Minor distresses
		Marginal	Varying quantities and severities of D cracking, ASR, raveling, stripping, etc.
		Inadequate	
	Maintenance applications	Adequate	Minor distresses
		Marginal	Varying quantities and severities of AC and PCC patching
		Inadequate	
	Shoulder	Adequate	Minor distresses
		Marginal	Varying quantities and severities of fatigue cracking, rutting, pumping, faulting, transverse cracking, etc.
		Inadequate	
AC or AC/PCC	Structural	Adequate	Minor distresses
		Marginal	Varying quantities and severities of fatigue cracking, rutting, longitudinal cracking in the wheelpath, shoving, etc.
		Inadequate	
	Functional	Adequate	Minor distresses
		Marginal	Varying levels of smoothness and surface friction
		Inadequate	
	Drainage	Adequate	Minor distresses
		Marginal	Varying quantities and severities of pumping, stripping, and fatigue cracking, etc.
		Inadequate	
	Materials durability	Adequate	Minor distresses
		Marginal	Varying quantities and severities of raveling, rutting, shoving, bleeding, frost heave, etc.
		Inadequate	
	Maintenance applications	Adequate	Minor distresses
		Marginal	Varying quantities and severities of AC patching, etc.
		Inadequate	
	Shoulder	Adequate	Minor distresses
		Marginal	Varying quantities and severities of fatigue cracking, rutting, pumping, transverse cracking, etc.
		Inadequate	

*See tables 2.5.15 through 2.5.24 in PART 2, Chapter 5 for definitions of adequate, marginal, and inadequate.

Table 3.5.6. Summary of major rehabilitation strategies and treatments for existing AC and AC/PCC pavements rated as inadequate (adapted after *5*).

Pavement Condition	**Distress Types**	**Candidate Treatments for Developing Rehabilitation Strategy**											
		Full-Depth Asphalt Repair	**Partial-Depth Asphalt Repair**	**Cold Milling**	**Hot or Cold In-place Recycling**	**Crack Sealing**	**Chip Seal**	**AC Overlay**	**AC Overlay of Fractured Slab**	**Bonded PCC Overlay**	**Unbonded PCC Overlay**	**Subdrainage Improvement**	**Reconstruction (AC or PCC)**
Structural	Fatigue cracking	√	√	√	√	√		√		√	√		√
	Longitudinal cracking in wheel path (low severity)	√			√	√		√		√	√		√
	Thermal cracking	√		√	√	√		√		√	√		√
	Rutting			√	√			√		√	√		√
	Reflection cracking	√	√	√				√	√	√	√		√
Functional	Excessive patching							√			√		
	Smoothness			√				√		√	√		
Drainage	Raveling		√	√	√			√					
	Stripping	√	√	√				√					
Durability	Raveling		√	√	√		√	√					
	Bleeding	√	√	√	√			√					
	Block cracking		√	√	√	√		√		√	√		√
	Shoving						√						
	Rutting			√	√			√		√	√		√
Shoulders	Same as traveled lanes	Same treatments as recommended for traveled lanes											

Table 3.5.7. Summary of major rehabilitation strategies and treatments for inadequate existing PCC pavements rated as inadequate (adapted after *5*).

Pavement Condition	**Distress Types**	**Candidate Treatments for Developing Rehabilitation Strategy**												
		Full-Depth Repair and Slab Replacement	**Partial-Depth Repair**	**Undersealing/Slab Jacking**	**Load Transfer Restoration**	**Joint Resealing**	**Diamond Grinding**	**Pressure Relief Joints**	**AC Overlay**	**AC Overlay of Fractured PCC Slab**	**Bonded PCC Overlay**	**Unbonded PCC Overlay**	**Subdrainage Improvement**	**Reconstruction**
Structural	JPC and JRC deteriorated cracked slabs	√								√		√		√
	CRC longitudinal cracking	√								√		√		√
	JPC and JRC transverse joint/crack faulting				√		√		√	√	√	√	√	
	CRC punchouts	√								√		√		√
	JPC, JRC, and CRC patch/patch deterioration	√	√							√		√		√
Functional	Excessive patching								√			√		√
	Smoothness								√			√		√
Drainage	JPC and JRC pumping													
	JPC and JRC transverse joint/crack faulting				√		√		√	√	√	√	√	
	PCC durability (D-cracking and reactive aggregates)	√							√	√		√		√
	JPC and JRC corner breaks	√								√		√		√
Durability	PCC Durability (D-cracking and ASR)	√							√	√		√		√
	JPC, JRC, and CRC Patch/Patch Deterioration	√	√							√		√		√
	PCC Longitudinal Joint Spalling	√	√							√		√		√
	JPC and JRC Transverse Joint Spalling	√	√							√		√		√
	Treated base/subbase durability													√
Shoulders	Same as traveled lanes													
Joint condition	JPC and JRC load transfer deterioration				√									
	JPC and JRC transverse joint seal damage					√								
	JPC and JRC pumping			√	√								√	
	JPC and JRC transverse joint/crack faulting,				√		√		√	√	√	√	√	
	Joint surround cracking	√								√		√		√

Performance periods of typical pavement rehabilitation strategies should be determined using performance models or past experience (*1*, *5*).

3.5.4.4 Step 7—Perform Life Cycle Cost Analysis for Possible Rehabilitation Strategies

Life cycle cost analysis (LCCA) ideally computes all costs that a rehabilitation strategy will accumulate over its performance period, and can be categorized as:

- Costs to the highway agency.
    - Initial rehabilitation construction.
    - Future maintenance and rehabilitation.
    - Future salvage value.
- Costs to the highway user.
    - Traffic delay costs.
    - Vehicle operation costs.
    - Accident and discomfort costs.

A key issue in performing LCCA is determining the life of the different rehabilitation strategies. It is best to compare all rehabilitation strategies over the same analysis period. If the analysis period is set to 15 years, for example, and the maximum initial life that one rehabilitation strategy can provide is 10 years, another rehabilitation project would have to be applied at 10 years into the future, so that the costs at 15 years can be calculated. If the life of a given strategy exceeds the analysis period, then a salvage value can be considered so that a fair comparison can be made between strategies. A detailed description of the LCCA procedure and concepts is presented in Appendix C of this Design Guide.

3.5.4.5 Step 8—Determine Relevant Non-Monetary Factors that Influence Rehabilitation

The life cycle cost of a rehabilitation strategy is only one of several factors that should be considered in the overall evaluation of the different design strategies. Other factors that should be considered include (*1*):

- Overall pavement management of network (policies).
- Future rehabilitation options and needs.
- Auto and truck traffic volume.
- Future maintenance requirements.
- Traffic control during construction (safety and congestion).
- Construction considerations (duration of construction).
- Conservation of materials and energy.
- Potential foundation problems.
- Potential climatic problems.
- Performance of similar pavements in the area.
- Availability of local materials and contractor capabilities.
- Worker safety during construction.
- Incorporation of experimental features.

- Stimulation of competition.
- Municipal preference, local government preference, and recognition of local industry.

These factors are difficult to quantify in monetary terms but should be considered in the evaluation process. This can be achieved by adopting policies and criteria within a highway agency for assigning weights to them after which they are considered either in a general way (as tie breakers when different strategies produce equal costs) or in a more structured decision matrix. Appendix B includes discussions on this topic.

3.5.4.6 Step 9—Determine Preferred Rehabilitation Strategy

The preferred rehabilitation strategy can be defined as one that most adequately addresses the cause of the distress and is effective in both repairing the existing deterioration and preventing its recurrence, while satisfying all the imposed constraints. One of the most challenging aspects of rehabilitation is the identification of the preferred rehabilitation strategy from a number of feasible strategies available. In general, the "preferred" rehabilitation strategy for a given project must:

- Be cost-effective.
- Repair the specific problems of the existing pavement.
- Prevent future problems.
- Meet all existing constraints of the project.

The preferred strategy must be determined by weighing candidate strategies against project constraints and life cycle costs.

It is very tempting to perform a "quick fix" or a cosmetic treatment on a deteriorated pavement. However, this is most unwise because the funds spent on such superficial repairs are essentially wasted. If the mechanisms that cause distress are not halted as part of the rehabilitation process the distresses will continue to appear with increasing severity leading to more repairs, lane closures, and additional cost to the highway agency. Thus, the short-lived benefits achieved from superficial repairs never justify the costs.

Once several distinct feasible strategies have been developed, they must be evaluated to determine cost, constraints, and all other relevant factors before the preferred rehabilitation strategy can be selected. There is, however, no absolute and indisputable method for selecting the preferred rehabilitation strategy for a given project, and considerable professional engineering judgment must be applied to each project. Also, the preferred strategy must fit in with the overall management and policies of the highway pavement network.

Also, the preferred strategy does not necessarily imply "optimal," since the various constraints (e.g., available funds) may limit optimization of each project in favor of optimization at the network level. Rather, the preferred strategy will be the one that best addresses the needs of the pavement while meeting all physical and monetary constraints that exist.

One practical approach that is used to select the preferred rehabilitation strategy considering all the relevant selection criteria is a decision table. An example decision table is shown in table 3.5.8. In this approach, evaluation factors such as life cycle costs, rehabilitation design life, and other constraints are selected and the relative importance of each factor is assigned. Each rehabilitation strategy or treatment is then rated under each evaluation criterion (the number on the upper left corner of each cell in table 3.5.8) on a fixed scale according to how well it meets the criteria (a scale of 0 to 100 is used in the example shown in table 3.5.8). The total score for each rehabilitation strategy is obtained by summing the individual scores and the strategies are ranked according to the total score to determine the preferred strategy.

Table 3.5.8. Example decision table to determine the preferred rehabilitation strategy (*1*).

	Criteria							
	Initial Cost	Duration of Construction	Service Life	Rehabilitation and Maintenance Effort	Rideability and Traffic Orientation	Proven Design in State Climate	Total Cost	Rank
Relative Importance	20%	20%	25%	15%	5 %	15%	100%	
Alternative 1	60 / 12	60 / 12	100 / 25	80 / 12	90 / 4.5	100 / 15	80.5	1
Alternative 1a	60 / 12	60 / 12	100 / 25	80 / 12	90 / 4.5	100 / 15	80.5	1
Alternative 2	60 / 12	60 / 12	70 / 17.5	50 / 7.5	60 / 3	40 / 6	58	5
Alternative 2a	60 / 12	60 / 12	70 / 17.5	50 / 7.5	60 / 3	40 / 6	58	5
Alternative 3	60 / 12	40 / 8	100 / 25	80 / 12	100 / 5	90 / 13.5	75.5	2
Alternative 4	60 / 12	80 / 6	40 / 10	20 / 3	40 / 2	20 / 3	44	8
Alternative 5	40 / 8	60 / 12	40 / 10	50 / 7.5	50 / 2.5	30 / 4.5	44.5	7
Alternative 6	70 / 14	80 / 16	60 / 12.5	50 / 7.5	80 / 4	40 / 6	60	4
Alternative 7	100 / 20	100 / 20	20 / 5	20 / 3	40 / 2	40 / 6	56	6
Alternative 8	30 / 20	60 / 12	100 / 25	100 / 15	100 / 5	30 / 4.5	67.5	3

The decision table approach outlines can be a useful tool for selecting the preferred rehabilitation strategy that satisfies all the evaluation criteria stated. One limitation of this method is that the ratings under some evaluation criteria do not necessarily reflect the relative merits of the different strategies. However, this is not true for criteria such as cost and performance, where the actual calculated or predicted numbers may be used.

3.5.5 SUMMARY

A step-by-step procedure for selecting the preferred rehabilitation strategy was presented. It provides the engineer with guidance in organizing and evaluating the data obtained about the pavement, identifying needs for further information and evaluation, developing feasible rehabilitation strategies, and selecting the preferred strategy from among these using sound engineering principles.

In general, rehabilitation should not be considered only for significantly damaged pavements with high-severity distress. It should also be considered for pavements close to being inadequate (or marginal). In some instances, it may be economically justifiable to spend additional funds repairing some lower-severity distress at the same time as adjacent high-severity distresses are being corrected. The additional cost must be weighed against the benefit obtained by "intercepting" distress at an earlier stage in its development. Also, in terms of convenience, it may be beneficial to carry out simultaneous repairs on both high- and low-severity distress on a high-volume road if major rehabilitation work creates significant traffic-handling problems.

Also, feasible rehabilitation strategies may encompass one or more rehabilitation treatments. Combined rehabilitation treatments may be necessary to repair or prevent either single- or multiple-distress types for a particular project. It is the engineer's responsibility, based on project evaluation results, to determine the treatment or combination of treatments to be considered as feasible rehabilitation strategy for a particular pavement.

The stepwise procedure presented in this chapter helps the engineer to conserve time and money in selecting the rehabilitation method that best meets the pavement's needs while satisfying all the projects constraints. This procedure, if tempered by good engineering judgment, will provide highway agencies with a method for selecting the preferred rehabilitation strategy for a given project. However, the most important benefit to highway agencies will be the shift from the traditional "standard fix" approach of rehabilitating its pavements, toward a policy of custom designing rehabilitation to truly meet the pavement’s needs and minimize life cycle costs.

REFERENCES

1. American Association of State Highway and Transportation Officials (1993). *AASHTO Guide for Design of Pavement Structures—1993*. AASHTO, Washington, D.C.
2. Shahin, M. Y. (1994). *Pavement Management for Airports, Roads and Parking Lots*, Chapman and Hall.
3. American Concrete Pavement Association (1990). *Guidelines for Bonded Concrete Overlays*. Publication No. TB-007P, American Concrete Pavement Association, Skokie, IL.
4. American Concrete Pavement Association (1990). *Guidelines for Unbonded Concrete Overlays*. Publication No. TB-005P, American Concrete Pavement Association, Skokie, IL.
5. Hall, K. T., Correa, C. E., Carpenter, S. H., and R. P. Elliot (2001). “Rehabilitation Strategies for Highway Pavements,” NCHRP 1-38, NCHRP Web Document 35.
6. ERES Consultants, Inc. (1998). “Evaluation of Portland Cement Concrete Overlays,” NCHRP 10-41, Final Report.
7. American Concrete Pavement Association (1990). *Ultra-thin Whitetopping for Roadways*. Publication No. CD015P, American Concrete Pavement Association, Skokie, IL.
8. American Concrete Pavement Association (1990). *Concrete Pavement Restoration (BINDER)*. Publication No. TB400P, American Concrete Pavement Association, Skokie, IL.
9. American Concrete Pavement Association (1990). *Repair of Ultra-Thin Whitetopping*. Publication No. PA397P, American Concrete Pavement Association, Skokie, IL.
10. ERES Consultants, Inc. (1999). *Pavement Subsurface Drainage Design—Reference Manual*. Federal Highway Administration, Washington D.C.
11. Federal Highway Administration (1998). *User Guidelines for Waste and By-Product Materials in Pavement Construction*, Publication No. FHWA RD-97-148, Federal Highway Administration, McLean, VA.