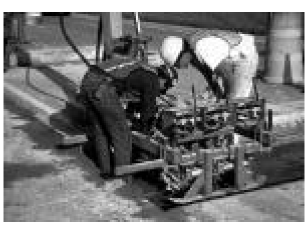
  

Techniques For Pavement Rehabilitation

A Training Course

Instructor's Manual

NHI National Highway Institute

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ADMINISTRATIVE/LOGISTICAL INFORMATION

PRE-CLASS ACTIVITIES

Preparations for this class started prior to the beginning of class. The host agency was informed about class requirements to include space, audio/visual (a/v) equipment, and writing materials. Manuals and other forms were sent to the class site. If anything is wrong, please contact Nichols Consulting Engineers (NCE) as quickly as possible.

During preliminary conversations with the host agency, there may have been some guidance provided regarding the desire for the host agency to have a customized presentation. If such a request has not been communicated, the instructors should still try to determine the interests of the class participants and orient the presentations and workshops to address those interests. There is more than enough information in this course, and it may be better to delete some content in order to keep the interest of the audience.

Before the class, it is also important to stress the logistics with the local coordinator. Ensure tables and chairs are arranged in a manner that is appropriate for the group. Familiarize yourself with the location of light switches, restrooms, etc. Ensure the a/v equipment is available and in working order. Check to see that all training materials are ready. The participant's manual is a teaching tool, and it is necessary for this class that all participants have one. Finally, verify the local training schedule for start and ending times, breaks, and lunches.

Presentation Equipment

The instructors will be supplied with the necessary transparencies, 35mm slides, and/or computer graphics. Instructors should find a multisync (computer image) and/or a slide projector and a screen in the classroom. An overhead projector is also necessary. Each projector should have an extra bulb. Also, a dry erase and/or chalkboard should be available. Please contact NCE if this is not completed.

STARTING CLASS

One of the instructors should assume responsibility for starting the class. This instructor handles any preliminary administrative activities such handing out the schedule and instructor biodata, distributing the manuals, confirming daily starting and ending times, and taking care of initial introductions.

Introductions

A senior manager from the host agency should introduce the class. This helps acknowledge the support for the course and materials by upper management. Instructors should briefly introduce themselves. This introduction should reiterate the informality of the course and should help provide participants with some valid reasons why the instructors are qualified. Instructors should state their background, their technical interests, their current employer, their experience in National Highway Institute (NHI) training courses, and anything else that they believe might be of interest to participants. Remember, however, that time is a precious resource. Please don't use too much time to describe instructor qualifications.

Next, the class participants should introduce themselves by giving their name, their employer, and job responsibilities. They should also express what they hope to learn from the course. Any information garnered here should help focus the course. Try to do this as quickly as possible without dismissing any concern as insignificant. Detailed discussions should be saved for the course.

Class Rosters

Following the introduction, a class sign-in sheet should be passed around. This should be part of the package of manuals and other course material that NHI sent to the host agency. Ask each attendee to print their name legibly as they would like to appear on their certificate. They should also put in their job title and their employer. This sheet is forwarded to NCE after the course is completed. It is also used by the instructors to prepare the course certificates. Please indicate this to the class as it will encourage more legible writing. Many State agencies also use this form to keep track of employee training. Social Security numbers may also be required, and this needs to be checked by the local coordinator. This would also be a good time to discuss the purpose of and procedures for completing the "NHI" Application for CEU's (Continuing Education Unit) form.

SETTING EXPECTATIONS

At this time, it will be necessary to establish class rules. Granted, these classes are considered to be informal, but without some rules or expectations, the class would be total anarchy. No successful class has been completed in this type of environment. Please take several minutes to review the following topics that can be helpful in expressing expectations for the class.

Interaction

It is a good idea to stress the informal nature of class. They best way to do this is to remind the participants about interaction. Encourage participation at all times. Students should feel free to ask questions of the instructors and share ideas amongst each other. There is no time set aside for formal questions and answers. Interaction will also help guide the instructor as to what issues are important to the group and thus, customize the class even further.

Breaks

One of the key ingredients in teaching adults is keeping their attention. Especially with technical material and small detail, an adult mind can wander quickly. Frequent breaks can assist in maintaining attention and interest. Formal breaks are is scheduled throughout the morning and afternoon sessions. Most instructors, however, will find that a 5-minute break each hour will help the students. The problem facing the instructor is getting the students back into their seats in a timely manner. Make a strong effort to keep breaks short. Establish expectations of breaks the first day, and be consistent throughout the course.

Lunch

The schedule will call for a 1-hour break at lunch. Some agencies, however, may only take 30 or 45 minutes. It is up to the instructor to identify any local variations in schedule or circumstance which might affect the prepared timetable and decide on appropriate modifications as needed.

Example Problems

Example problems have been included to provide topics of discussion at the start of each morning and afternoon session. These transparencies are intended to spark discussion of topics covered and relate them to local problems. This provides an easing into the training for the students returning from the previous day and lunch.

WORKSHOPS

Having the participants take the content and apply that information during the workshops is a key factor in the success of this course. The workshops help to tie together the information that is presented throughout the course and make it clearer. Furthermore, participants (as well as instructors) would likely have a difficult time remaining attentive during the entire presentation and absorbing all the information were it not for the workshops. The workshops have been developed to provide opportunities for participants to see how the course objectives are related in real world situations.

Since the workshops are so central to the success of the course, instructors should not attempt to cut short the workshops to get to the presentation material rather, if time becomes critical, every effort should be made to cut short the presentations to get to the workshops.

Participants will use information from the associated modules to meet the objectives of the workshop tasks. Every attempt has been made to keep the problems realistic.

During the workshop, instructors should make themselves available to answer questions and help provide guidance, if necessary. One key goal of these workshops is to get the groups to discuss amongst themselves solutions to problems addressing local concerns. Instructors should to pay attention to the discussions and make a concerted effort to tie the results and the discussion back to the practical aspects whenever possible.

The identification, selections, and design of rehabilitation for a given pavement requires a logical, step-by-step approach. To illustrate the recommended procedures in this process, several workshops are presented to provide participants with an opportunity for "hands on" training in applying those procedures. These workshops contain data from actual rehabilitation projects.

Workshop 1: Project Evaluation (60 minutes)

1. The participants are divided into groups of five or more persons, and each group is assigned a workshop problem. Each group then selects a chairperson and recorder. The recorder will take notes throughout the workshop and the chairperson will make the presentation to the rest of the class.

2. Each groups examines the background data, project survey, and evaluation data provided under *Information for Workshop 1* for their assigned workshop problem.

3. Each group evaluates the information provided and develops:

    a. A description of the defects or deficiencies that should be addressed in the rehabilitation design.
    b. A list of those deficiencies, defects, or other considerations that will control or constrain the rehabilitation design.
    c. A list of additional surveys, tests, and evaluations that are recommended or desired for a more thorough evaluation of the existing pavement.

4. Each group reports their results to the class, which discusses them briefly.

Workshop 2a: Identification of Feasible Alternatives (Asphalt) (60 minutes)
Workshop 2b: Identification of Feasible Alternatives (Concrete) (60 minutes)

1. Each workshop group will reform and review their information from Workshop 1.

2. Each group will develop three rehabilitation solutions or sets of feasible alternatives that address the problems identified in the previous workshop. One approach to this workshop is to develop solutions along the following lines:

   a. Develop one solution that the group believes will last for 10 years without rehabilitation.
   b. Develop a second solution that will last for 5 years without resurfacing or major rehabilitation.
   c. The third solution should be that which an agency would normally do for a pavement.

In developing these alternatives, participants are encouraged to be innovative in the development of these strategies. Do not let currently restrictive policies inhibit this activity. ***The final selection should not be made at this time.***

Workshop 3: Selection of the Preferred Alternative (60 minutes)

1. Each group will reform and review the information they have developed from workshops 1 and 2, including the rehabilitation alternatives they have developed for the assigned problem. Each group has the option of using the alternatives they identified in workshops 2a and 2b, which will require that they estimate appropriate costs and service lives for their alternatives, or they may use the rehabilitation alternatives and associated costs presented in Information for Workshop 2b for their problem that comes closest to their alternatives.

2. Using at least two of the alternative selected form this last exercise, the group will perform a basic life-cycle cost analysis (LCCA) comparing the long-term cost (in terms of present worth) of at least two of the alternatives using an analysis period of 30 years and a discount rate of 4 percent.

3. Each group then evaluates the results of their life-cycle cost analysis. The result should be a final tabulation of the life-cycle cost (LCC) of the alternatives and their associated strategies in their order of cost and the preference to the group if different based on special non-monitory factors.

4. Each group reports their results to the class, which discusses them briefly. The group's presentation should include:

   a. A brief review of the pavement design and evaluation conclusions.
   b. The alternative 4R strategies.
   c. The life-cycle cost comparison of the 4R strategies.
   d. The final selection of the preferred 4R strategy.

HOUSEKEEPING – LAST DAY

CEU Forms

Continuing Education Unit (CEU) credits are available through NHI by completing the computer coded forms supplied by NHI. In some states, CEUs are required to maintain licensing. On the last day, the instructions should be read for completing the forms to participants and hand out the forms provided. The number of this course is 13108. Pick up the CEU forms at the end of class and return them to NCE with the other paperwork.

Course Evaluation Forms

During the last day, the instructor should hand out the course evaluations. These are four-page forms that can be completed at the participant's leisure during the last day and handed in at the end of the class. Providing extra time helps to ensure aren't completed in a hurriedly fashion at the end of class.

The following instructions about the evaluations should be provided to the participants:

- Names are optional.
- Please write out the names of Instructor A and Instructor B on the board. This will help stem the confusion for tracking responses.
- Participants should be encouraged to take extra space to provide additional feedback. Explain that this does help the course.
- Completed forms should be left at the back of the class at the end of the presentation.

Certificates

Course certificates are given to the host agency to prepare prior to the end of the class. These are usually returned to the instructors during the morning of the last day. These certificates are then distributed after the class is completed. If misspellings occur, check with the course coordinator to get the certificate re-typed.

Final Responsibility

Instructors are responsible for sending the completed course roster, CEU forms, and course evaluations to NCE. This should be done immediately, as they must be processed and submitted to NHI within 15 days. Instructors will be sent a copy of their evaluations once they have been processed.

UPDATES TO THE COURSE

While a good deal of effort has gone into the development of this training course, it is inevitable that both instructors and participants will find errors, omissions, or other shortcomings that need to be addressed. Instructors should encourage the class participants to bring any problems with the course that they identify to the instructors' attention. Any problems identified should be noted and communicated to NCE at the end of each class. Corrections will be made and distributed on an errata sheet.

TECHNIQUES FOR PAVEMENT REHABILITATION
Training Course

INSTRUCTOR'S GUIDE

INTRODUCTION

This manual has been assembled to assist instructors in presenting the *Techniques for Pavement Rehabilitation* training course. New instructors are encouraged to thoroughly familiarize themselves with its content before teaching. Doing so will better prepare the instructor to teach the course and will help them benefit from the accumulated knowledge and experience gained from those who have gone before them.

The manual is divided into four sections. The first section provides general administrative and logistical information. Although the instructor might be familiar with many of the procedures, it is advisable to take a few minutes to refresh one's memory. Also included is a copy of the site coordinator's checklist to assist in preparing the instructor to know the role of the site coordinator.

The second section is the technical presentation. It contains a complete set of lesson plans for each block. The blocks are further broken down in modules with each module containing learning objectives, approximate instruction time, key points, and typical discussion questions. Instructor notes are provided for each slide.

The third section contains information necessary for presenting the workshops. It provides guidance on the workshop objectives and outlines many of the steps that participants may take to obtain desired results. The section also includes the answers to the workshops, which will be distributed to the participants at the conclusion of the class. Also included are a series of example problems to be used at the start of the morning and afternoon sessions. These should prompt interaction regarding local concerns.

The fourth section contains tips on instruction. While these may seem quite simple, practicing the mentioned techniques could make the difference between a standard class and a true learning experience for the participant. A discussion of the multimedia component is included as well.

Finally, the fifth section contains information for the multimedia modules. It is doubtful these will be demonstrated during class, but it might be helpful to review the installation and user instructions in the event there are questions.

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TECHNICAL PRESENTATION

Block One
Introduction and Course Objectives

Block Learning Objective(s):

With most highway programs emphasizing pavement rehabilitation, it is important that effective pavement rehabilitation strategies be employed so that agencies can maintain – and perhaps improve – the performance of the highways. Through the use of effective rehabilitation strategies, highway facilities will provide higher levels of service for longer periods of time, with resultant savings to both the agencies and the users.

This training course is offered as a tool to assist pavement engineers in developing the most effective and reliable rehabilitation alternatives for their highway pavements. The primary objective of the first block is to introduce the course. This block contains background information that will familiarize the participant with this training course and the 4R program.

Lesson	Learning Objectives	Time(s)	Delivery Method(s)	Cross Reference(s) For Module
Module 1-1 Introduction	1. Describe the overall objectives of the course 2. Restate the organization of the course 3. List other NHI related courses	30 minutes	Lecture Discussion	Pages 1-1.1 to 1.1.9 Slides 1-11

Block Two
Project Level Survey and Evaluation

Block Learning Objective(s):

Project surveys are performed to collect data on the existing condition of a pavement structure. Information collected on a particular project may include distress data, roughness data, surface friction values, deflection data, and drainage information. The data that is collected can be used for a variety of purposes that generally fall into one of the following categories:

- Development and selection of rehabilitation alternatives.
- Prioritization of projects for rehabilitation action.
- Development of performance prediction models and curves.

This training course focuses on the first category, the development and selection of cost-effective rehabilitation techniques for a specific pavement section that has already been identified as needing rehabilitation. The other two topics are gear more towards network-level (as opposed to project-level) pavement management system (PMS) activities, which are not a part of this training course.

The selection and design of the appropriate rehabilitation techniques for a pavement requires consideration of many factors. For instance, the techniques must address the causes of distress, must provide for an acceptable level of service for a reasonable time, and should be cost-effective. Some factors that may be considered in this process include the existing distress, the overall pavement roughness, future maintenance requirements, existing and future traffic levels, climatic conditions, safety elements, and available funding levels.

Other information may also be required, depending upon the type of rehabilitation alternatives considered for a particular project. It is imperative that the engineer identify and obtain all information that is needed to develop the most reliable, cost-effective design for a given project.
In order to identify appropriate rehabilitation measures for a particular project, the performance of that pavement must first be quantified. Pavement performance may be divided into either structural performance or functional performance. Structural performance is an indication of how well a pavement is able to support traffic and environmental loadings, while functional performance is a measure of how well the pavement is performing its intended function of providing a smooth, safe ride to the user. In this block, procedures for the conduct of the different types of field surveys are described so that the pavement's structural and functional performance may be assessed. These results may be used to select feasible, cost-effective 4$ repair methods.

This block will familiarize the participants with field surveys needed for a pavement evaluation, including those related to distress, roughness, drainage, structural, traffic, and subgrade. The distress survey is always conducted first, and the other surveys are based upon the results obtained from the distress survey.

Lesson	Learning Objectives	Time(s)	Delivery Method(s)	Cross Reference(s) For Module
Module 2-1 Pavement Types	1. Verbalize the role of each layer in the pavement structure. 2. Identify the key factors that affect pavement performance. 3. Identify the three major pavement classifications and the five specific pavement types they encompass.	1 hour	Lecture Discussion Slides	Page 2-1.1 through 2-1.35 Slides 12-72
Module 2-2 Condition Data Collection and Processing	1. Describe the three factors required to properly characterize distress. 2. List the field procedures necessary to perform a project distress survey. 3. Describe the information that can be obtained from a roughness survey and why roughness is an important aspect of pavement condition. 4. Be aware of the types of equipment commonly used to measure pavement roughness. 5. Describe the information that can be obtained from surface friction surveys and why surface friction is an important aspect of pavement conditions. 6. Be aware of the types of equipment commonly used to measure surface friction. 7. Recognize the way the information obtained from the Condition surveys can be used to aid in selecting Appropriate rehabilitation strategies to optimize Performance, funding levels, and safety	45 minutes	Lecture Discussion Slides	Page 2-2.1 through 2-2.17 Slides 73-123

Module 2-3 Nondestructive Data Collection & Interpretation	1. Show the nature of a pavement's response to load. 2. List some of the available pavement deflection measuring devices and their operating characteristics. 3. List the major factors that influence deflection in flexible and rigid pavements. 4. Describe the effects of seasonal conditions on NDT deflection results. 5. Describe the basic principles and procedures for characterizing in situ pavement layer material properties (specifically, elastic or Young's modulus) through "backcalculation".	45 minutes	Lecture Discussion Slides	Page 2-3.1 through 2-3.33 Slides 124-176
Module 2-4 Laboratory Materials Characterization	1. Describe the basic stress states of the in-service pavement layers and subgrade. Identify the major engineering properties and test procedures for soils and paving materials. 2. Describe the concept behind resilient modulus testing and its importance to mechanistic pavement design. 3. Indicate how moisture content, density, and freeze-thaw influence the repeated load behavior of a fine-grained soil. 4. Identify information sources for use in characterizing subgrade support and in evaluating problems such as frost heave and expansive soils.	20 minutes	Lecture Discussion Slides	Page 2-4.1 through 2-4.36 Slides 177-206

Module 2-5 Drainage Survey and Evaluation	1. List four distress types that are indicative of moisture damage in a pavement and discuss the importance of their severity levels. 2. Define external and internal drainage factors and list their major components. 3. Recall the principle behind drainage time for a flooded base course and discuss how this time influences pavement performance. 4. List the properties that influence the drainability of a subgrade. 5. Combine base and subgrade drainage criteria to develop the American Association of State Highway and Transportation Officials (AASHTO) drainage coefficient.	20 minutes	Lecture Discussion Slides	Page 2-5.1 through 2-5.31 Slides 207-231
Module 2-6 Traffic Loading Evaluation	1. Recognize the important role that traffic loadings play in rehabilitation design. 2. Define a load equivalency factor (LEF) in accordance with the American Association of State Highway and Transportation Officials (AASHTO) Design Guide. 3. Develop appropriate truck factors (TFs) for the various truck classifications. 4. Discuss the need to sample traffic, to convert general traffic data to project-specific data, and to improve the traffic loadings through the use of weigh-in-motion (WIM) and automatic-vehicle-classification (AVC) equipment.	25 minutes	Lecture Discussion Slides	Page 2-6.1 through 2-6.24 Slides 232-255

	5. Use growth factors to project future traffic and compute the future expected cumulative 80 kN ESALs for a pavement section over the rehabilitation design period (forecasting).			
Module 2-7 Overall Project Evaluation	1. Describe the potential benefits of conducting a thorough pavement evaluation and the typical consequences of not conducting such as evaluation 2. Outline a systematic step-by-step procedure to obtain the necessary data to conduct a pavement evaluation. 3. Develop an overall pavement evaluation checklist that provides a summary for the design engineer to use in determining causes of deterioration, in developing cost-effective alternatives, and in communicating the results of the evaluation to management. 4. Describe the approach to conducting a rational structural evaluation of the existing pavement	25 minutes	Lecture Discussion Slides	Page 2-7.1 through 2-7.18 Slides 256-278

Block Three
Flexible Pavement Rehabilitation Techniques

Block Learning Objective(s):

This block provides detailed information on the design and construction related issues for the most widely-used flexible pavement rehabilitation techniques. These techniques all fall under the standard 3R definitions of restoration, recycling and resurfacing. They are covered in a logical sequence of minimal to maximum impact on the existing pavement.

In addressing issues related to the most common method of rehabilitation (i.e., resurfacing), it should be understood that the information is more of a general nature and that the emphasis is more on the practices that surround the overlay design and construction operations. NHI offers several other courses that are targeted at addressing specific structural design, mix design and construction related issues.

The block concludes with a module on how to identify the most appropriate (candidate) rehabilitation treatments for a given project.

Lesson	Learning Objectives	Time(s)	Delivery Method(s)	Cross Reference(s) For Module
Module 3-1 Hot-Mix Asphalt Mixture Overview	1. List the basic components of asphalt binder. 2. Describe the basic viscoelastic properties of asphalt binder. 3. Describe what happens to the components of asphalt binder as it ages. 4. Describe the basic mix gradations that may be used in asphalt pavement (AP) and their attributes. 5. Describe the possible failure modes of the various AP mix types.	30 minutes	Lecture Discussion Slides	Page 3-1.1 through 3-1.21 Slides 279-320
Module 3-2 Crack Sealing	1. Identify the major factors that affect sealant performance.	30 minutes	Lecture Discussion Slides	Page 3-2.1 through 3-2.16 Slides 321-365

	2. Describe the procedures required to seal or reseal cracks in HMA pavements. 3. Identify the primary sealant types, appropriate specifications, and sealant properties.			
Module 3-3 Patching with Bituminous Mixtures	1. List the desirable properties of a bituminous patching mixture. 2. Differentiate between hot-mix HMA materials and cold-mix, stockpiled patching mixtures on the basis of quality, aggregate, and binder. 3. Describe the conditions that require patching and differentiate between temporary, semi-permanent patching, and localized reconstruction. 4. List the steps necessary to accomplish patching as part of a 4R project.	30 minutes	Lecture Discussion Slides	Page 3-3.1 through 3-3.15 Slides 366-394
Module 3-4 Cold Milling	1. Describe cold milling and its basic objective. 2. List the major reasons for cold milling hot-mix asphalt (HMA) pavement surfaces. 3. Describe equipment and construction problems Encountered in typical cold milling operations.	15 minutes	Lecture Discussion Slides	Page 3-4.1 through 3-4.7 Slides 395-419
Module 3-5 Surface Rehabilitation Techniques	1. Identify and differentiate the major types of surface rehabilitation techniques. 2. Demonstrate the design principles required for the successful application of chip seal and open-graded friction courses. 3. Employ the construction sequences and describe the equipment operating characteristics for the various surface rehabilitation techniques.	30 minutes	Lecture Discussion Slides	Page 3-5.1 through 3-5.31 Slides 420-468

Module 3-6 Recycling Overview	1. Identify the types of pavement recycling.	30 minutes	Lecture Discussion Slides	Page 3-6.1 through 3-6.8 Slides 469-484
Module 3-7 Hot In-Place Recycling	1. Identify the types of hot in-place recycling. 2. Define the types of equipment and their operational sequence for hot in-place recycling operations. 3. Describe mixtures design procedures for use in hot in-place recycling operations. 4. Describe performance of hot in-place recycled pavements. 5. Provide recommendations for appropriate use of hot in-place recycling techniques.	30 minutes	Lecture Discussion Slides	Page 3-7.1 through 3-7.20 Slides 485-530
Module 3-8 Cold In-Place Recycling	1. Identify the types of cold in-place recycling. 2. Define the types of equipment and their operational sequence for cold in-place recycling operations. 3. Describe mixture design procedures for use in cold in-place recycling operations. 4. Describe performance of cold in-place recycled pavement. 5. Provide recommendations for appropriate use of cold in-place recycling techniques.	30 minutes	Lecture Discussion Slides	Page 3-8.1 through 3-8.25 Slides 531-578
Module 3-9 Hot Central Plant Recycling	1. Identify the types of hot central plant recycling. 2. Define the types of equipment and their operational sequence for hot central plant recycling operations.	45 minutes	Lecture Discussion Slides	Page 3-9.1 through 3-9.28 Slides 579-646

	3. Describe mixture design procedures for use on hot central plant recycling operations. 4. Describe performance of hot central plant recycled pavements.			
Module 3-10 Hot Mix Asphalt Overlays	1. List the functional and structural deficiencies that can be corrected with a properly designed HMA overlay. 2. Identify the conditions for which an HMA overlay is best suited and most cost-effective. 3. Apply the various approaches for HMA overlay thickness design (as well as their strengths and weaknesses). 4. Determine the feasibility and extent of preoverlay repair. 5. Describe the consequences of deferring overlay placement.	45 minutes	Lecture Discussion Slides	Page 3-10.1 through 3-10.19 Slides 647-678
Module 3-11 Identification of Feasible Alternatives	1. Describe what a decision tree or chart is and how it is developed and used. 2. Describe the proper uses of decision trees. 3. Describe the limitations and potential problems that are associated with the strict use of a decision tree.	15 minutes	Lecture Discussion Slides	Page 3-11.1 through 3-11.18 Slides 679-712

Block Four
Rigid Pavement Rehabilitation Techniques

Block Learning Objective(s):

This block provides detailed information on the design and construction related issues for the most widely used rigid pavement rehabilitation techniques. These techniques all fall under the standard 3R definitions of restoration, recycling and resurfacing. They are covered in a logical sequence of minimal to maximum impact on the existing pavement.

In addressing issues related to the most common method of rehabilitation (i.e., resurfacing), it should be understood that the information is more of a general nature and that the emphasis is more on the practices that surround the overlay design and construction operations. NHI offers several other courses that are targeted at addressing specific structural design, mix design and construction related issues.

The block concludes with a module on how to identify the most appropriate (candidate) rehabilitation treatments for a given project.

Lesson	Learning Objectives	Time(s)	Delivery Method(s)	Cross Reference(s) For Module
Module 4-1 Rigid Pavement Overview	1. Identify the typical layers of PCC pavement. 2. Compare the response of a rigid pavement to applied loads. 3. Describe the fundamental materials that are used in PCC pavement construction and rehabilitation.	20 minutes	Lecture Discussion Slides	Page 4-1.1 through 4-1.7 Slides 713-730
Module 4-2 Joint Sealing	1. Identify the major factors that affect joint sealant performance. 2. Describe the steps involved in resealing PCC pavement joints. 3. Identify the primary sealant types, appropriate specifications, and sealant properties.	50 minutes	Lecture Discussion Slides	Page 4-2.1 through 4-2.22 Slides 731-785

Module 4-3 Pressure Relief Joints	1. Identify the causes of expansive pressures in PCC pavements and the resulting pressure-related distress. 2. Recognize situations where the installation of pressure relief joints may be warranted. 3. Describe procedures for properly constructing pressure relief joints. 4. Recognize the potential problems associated with the use of pressure relief joints.	5 minutes	Lecture Discussion Slides	Page 4-3.1 through 4-3.15 Slides 786-803
Module 4-4 Partial-Depth Repairs	1. Identify distress types that can be corrected with partial-depth repairs. 2. Be familiar with various materials used for partial-depth repairs. 3. Describe successful construction procedures for partial-depth repairs.	35 minutes	Lecture Discussion Slides	Page 4-4.1 through 4-4.17 Slides 804-845
Module 4-5 Full-Depth Repairs	1. Based on visual observations (and deflection testing), identify areas requiring full-depth repair and determine appropriate boundaries. 2. Determine when large areas should be completely removed and replaced rather than removing and replacing several adjacent smaller areas. 3. Select acceptable design and construction procedures for cast-in-place repairs at joints and cracks for typical pavement conditions. 4. Describe the design of a permanent, cast-in-place concrete repair that provides continuity of reinforcement and load transfer at transverse repair joints for CRCP.	75 minutes	Lecture Discussion Slides	Page 4-5.1 through 4-5.26 Slides 846-916

Module 4-6 Accelerated Rigid Paving Techniques	1. Identify conditions under which these techniques may be considered as a part of a rehabilitation project. 2. Discuss the various materials that can be used to achieve high early strengths, and how to select the appropriate material for the time available to perform the rehabilitation. 3. Discuss the special construction procedures that accompany the use of accelerated paving techniques. 4. List the innovative field testing procedures that can be used to monitor the strength of the concrete. 5. Determine the appropriate criteria for opening the pavement to traffic.	20 minutes	Lecture Discussion Slides	Page 4-6.1 through 4-6.14 Slides 917-938
Module 4-7 Slab Stabilization & Slab Jacking	1. State the purpose for and discuss the importance of slab stabilization. 2. Describe the cement grout mixtures and asphalt cements that have been used for slab stabilization and slab jacking and the problems associated with the use of each. 3. Describe procedures for performing slab stabilization, including how to locate areas that need slab stabilization, typical hole patterns, and how to determine if slab stabilization has been effective. 4. List the typical construction procedures for slab stabilization and slab jacking.	30 minutes	Lecture Discussion Slides	Page 4-7.1 through 4-7.22 Slides 939-987
Module 4-8 Diamond Grinding and Grooving	1. Differentiate between diamond-grinding and grooving, and describe the objectives of each.	30 minutes	Lecture Discussion Slides	Page 4-8.1 through 4-8.18 Slides 988-1012

	2. List existing pavement conditions for which diamond-grinding of a jointed concrete pavement surface may be beneficial. 3. Describe conditions under which grooving of a pavement surface would be beneficial in reducing wet weather accidents. 4. Be familiar with the uses of cold milling equipment for PCC pavement restoration.			
Module 4-9 Load Transfer Restoration	1. Identify the problems that can be addressed through the use of load transfer restoration devices. 2. Understand the techniques available for determining the need for load transfer restoration. 3. Describe procedures for properly installing load transfer restoration device.	30 minutes	Lecture Discussion Slides	Page 4-9.1 through 4-9.17 Slides 1013-1055
Module 4-10 Shoulder Rehabilitation Considerations	1. List the common distress types associated with bituminous and PCC shoulders adjacent to PCC mainline pavements. 2. Discuss procedures applicable to shoulder rehabilitation, and describe how the extent of deterioration of a shoulder can influence not only shoulder rehabilitation strategy selection, but also the rehabilitation of the mainline PCC pavement. 3. Describe the contributions that a tied PCC shoulder can have on the performance of the mainline PCC pavement.	5 minutes	Lecture Discussion Slides	Page 4-10.1 through 4-10.9 Slides 1056-1069
Module 4-11 Retrofitted Edge Drains	1. Identify the sources of water in pavement systems. 2. Name and identify the function of the major components of subdrainage systems.	10 minutes	Lecture Discussion Slides	Page 4-11.1 through 4-11.20 Slides 1070-1093

	3. Discuss the criteria for selection of a filter system (fabric or granular). 4. List the basic subdrainage design steps.			
Module 4-12 Recycling	1. Identify conditions when PCC recycling may be considered as part of a reconstruction project. 2. Identify potential benefits of concrete recycling and the potential uses of recycled concrete aggregate (RCA) in pavement reconstruction. 3. Describe the steps in the PCC pavement recycling process. 4. Discuss the properties of recycled concrete aggregate and PCC mixtures containing recycled concrete aggregate, and how those properties affect their potential applications.	35 minutes	Lecture Discussion Slides	Page 4-12.1 through 4-12.23 Slides 1094-1136
Module 4-13 PCC Overlays	1. List the types of PCC overlays. 2. Discuss the importance of the bonding condition for each PCC overlay type. 3. Identify the conditions for which each PCC overlay type is best suited and is most cost-effective. 4. Recognize the different design methodologies for PCC overlays. 5. Describe the level of preoverlay repair required for each PCC overlay type and its relative importance.	25 minutes	Lecture Discussion Slides	Page 4-13.1 through 4-13.17 Slides 1137-1158
Module 4-14 HMA Overlays	1. List the functional and structural deficiencies that can be corrected with properly designed HMA overlays. 2. Describe the conditions that affect the performance of an HMA overlay.	1 hour	Lecture Discussion Slides	Page 4-14.1 through 4-14.32 Slides 1159-1217

	3. List the causes of reflection cracking. 4. Discuss the various treatments that have been used to reduce reflection cracking and their relative effectiveness.			
Module 4-15 Identification of Feasible Alternatives	1. Recognize the importance of an overall framework for the identification of feasible PCC pavement rehabilitation alternatives. 2. Describe what a decision tree or chart is and how it is developed and used. 3. Describe the limitations and potential problems that are associated with the strict use of a decision tree.	15 minutes	Lecture Discussion Slides	Page 4-15.1 through 4-15.14 Slides 1218-1229

Block Five
Selection of Preferred Rehabilitation Alternative

Block Learning Objective(s):

Throughout this course, participants have become familiar with the various aspects of rehabilitation design. These include project survey and evaluation procedures (block 2) and the different rehabilitation alternatives that are available for a particular project (block 2) and the different rehabilitation alternatives that are available for a particular project (block 3 and 4). The next steps in the process are the identification of feasible rehabilitation alternatives and the selection of the preferred rehabilitation alternative, or the one that best addresses the needs and constraints of the project. This block provides additional information on the development and evaluation of various rehabilitation design alternatives that may be appropriate for a given project. Factors to be considered in the ultimate selection of the preferred rehabilitation alternative are discussed, including both monetary and nonmonetary issues.

Lesson	Learning Objectives	Time(s)	Delivery Method(s)	Cross Reference(s) For Module
Module 5-1 Selection of the Preferred Rehabilitation Alternatives	1. Describe the importance of developing alternative rehabilitation designs. 2. List the eight major steps required for rehabilitation selection and design. 3. List and briefly describe the major factors that should be used in deciding among alternative rehabilitation designs. 4. List the benefits of conducting a life-cycle cost analysis to determine the total cost of various pavement rehabilitation alternatives.	30 minutes	Lecture Discussion Slides	Page 5-1.1 through 5-1.27 Slides 1230-1251

Module 2-1
Pavement Types

Objectives	Activity
1. Verbalize the role of each layer in the pavement structure.	Each layer in a pavement structure serves a purpose and contributes to the performance structural response and durability of that pavement. Key points to consider are: • Surface layer • Base and subbase layer • Subgrade Key questions that may be asked are: • What does each pavement layer contribute to the bearing capacity of that pavement? • What typical materials do you use in this area for these layers. • Typically how thick are those layers.
2. Identify the key factors that affect pavement performance	There are a large number of factors that affect pavement performance. Key points to consider are: • Traffic loadings • Subgrade soil support • Materials used • Structural characteristics • Construction and maintenance variation Key questions that may be asked are: • What key factors that affect pavement performance in this area? • Which seem to be the most important from your experience? • Can you control the affect that they may have on pavement performance in your area?
3. Identify the three major pavement classifications and the five specific pavement types they encompass.	There are three major pavement categories, which have distinctly different structural responses and deterioration characteristics. Key points to consider are: • Rigid Pavement • Flexible Pavement • Composite Pavement

	Key questions which may be asked are: • Which of these basic pavement types to you have here? • Kan you describe how each pavement type carries traffic loads?

Module 2-2
Condition Data Collection and Processing

Objective	Activity
1. Describe the three factors required to properly characterize distress.	Flexible and Rigid pavements experience different types of distress yet each distress type is described using three basic criteria. Key points to consider are: • Distress type (description) • Distress severity • Distress extent Key questions that may be asked are: • What are the predominate distress you experience here in your flexible pavement? • What are the predominate distress you experience here in your rigid pavement? • How do you characterize those distresses?
2. List the field procedures necessary to perform a project distress survey.	Manual surveys are used to perform project design distress surveys. Key points to consider are: • SHRP Distress Identification Manual • Basic equipment • Data Sheets Key questions that may be asked are: • What do you do to conduct for project design surveys? • What condition data do you collect? • How is that information used?
3. Describe the information that can be obtained from a roughness survey and why roughness is an important aspect of pavement condition.	Roughness provides a measure of the service a pavement provides the user and is the major component in the pavement serviceability index. Key points to consider are: • How to define and quantify • How to measure Key questions that may be asked are: • What is roughness? • Why measure ride?
4. Be aware of the types of equipment commonly used to measure pavement roughness.	There is a wide range of equipment that has been used to measure ride from the “seat of the pants feel” to very precise pavement profile measuring equipment

	Key point to consider are: • Types of roughness measurements • Accuracy needed • Calibration Key questions that may be asked are: • Does your agency measure pavement roughness? • How does in measure pavement roughness? • How does it use this information?
5. Describe the information that can be obtained from surface friction surveys and why surface friction is an important aspect of pavement conditions.	Pavement surface friction, is the force that develops between the pavement and the tire during braking. Key points to consider are: • Pavement Macrotexture • Pavement Microtexture • Pavement surface drainage Key questions that may be asked are: • What is pavement surface friction? • Why is it important?
6. Be aware of the types of equipment commonly used to measure surface friction.	Pavement surface friction can be measures in a variety of ways but the most common method is with a locked-wheel trailer. Key points to consider are: • Smooth and ribbed tire • Wet pavement • Locked tires • Speed Key questions that may be asked are: • Does your agency measure pavement friction? • What testing equipment does it use? • How is the information used?
7. Recognize the way the information obtained from condition surveys can be used to aid in selecting appropriate rehabilitation strategies to optimize performance, funding levels, and safety.	The information obtained from condition surveys is used to help determine treatments, timing, location, and relative costs. Key points to consider are: • Causes and mechanisms of pavement deterioration • Repair location and costs • Safety • Pavement serviceability Key questions that may be asked are: • How do you use the information from the condition survey?

	• Can you provide local examples of its use? • Do you collect any additional information?

Module 2-3
Nondestructive Data Collection and Interpretation

Objectives	Activity
1. Show the nature of a pavement's response to load.	The deflection of a pavement represents an overall "system response" of the pavement layers and subgrade soil to an applied load. Key points to consider are: • Pavement layers • Load • Deflections Key questions that may be asked are: • How does a pavement's structure affect its deflection under load? • Can you determine how much a pavement will deflect?
2. List some of the available pavement deflection measuring devices and their operating characteristics.	There is a variety of equipment available to measure pavement deflection under load. Key points to consider are: • Static load • Steady state dynamic load • Impulse load Key questions that may be asked are: • Do you measure pavement deflections here? • What type of equipment do you use? • How do you use the deflection data?
3. List the major factors that influence deflection in flexible and rigid pavements.	There are many factors which influence measured pavement deflections which make interpretation of deflections results more difficult Key points to consider are: • Load factors • Pavement factors • Climate factors Key questions that may be asked are: • How do these factors influence pavement deflection? • How can you account for these factors?
4. Describe the effects of seasonal conditions on NDT deflection results	In regions of deep frost (1-2 meters) the seasonal differences in deflection test results is very large and must be accounted for in both the testing and the deflection analysis

	Key points to consider are: • Winter Deflections on frozen ground • Spring Deflections during thaw weakening • Summer Deflections Key questions that may be asked are: • How should you account deflection tests made in different seasons? • Do you see major changes in deflections seasonally here? • If so how do you account for those changes?
5. Describe the basic principles and procedures for characterizing in situ pavement layer material properties (specifically, elastic or Young's modulus) through "backcalculation".	Backcalculation is a process where fundamental engineering properties of the pavement structure are estimated based upon measured surface deflections. Key points to consider are: • Strength vs. stiffness • Elastic modulus • Deflection basin Area value Key questions that may be asked are: • Do you use deflection measurements to estimate pavement layer stiffness? • How do you estimate layer stiffness? • How do you use stiffness to design pavements?

Module 2-4
Laboratory Materials Characterization

Objective	Activity
1. Describe the basic stress states of the in-service pavement layers and subgrade. Identify the major engineering properties and test procedures for soils and paving materials.	Moving wheel loads impart dynamic load pulses to the pavement layers which results in a complex set of stresses and resulting strains within those layers. Key points to consider are: • Critical tensile stress • Critical compressive stress Key questions that may be ask are: • What is resilient modulus? • Where is the most critical stress in a pavement structure for fatigue cracking? • Where is the critical stress for rutting?
2. Describe the concept behind resilient modulus testing and its importance to mechanistic pavement design.	The Triaxial resilient modulus test procedure provides a material property that closely simulates the behavior of pavement layers under a moving wheel. Key points to consider are: • Deviator Stress • Confining stress • Resilient strain • Plastic strain Key questions that may be asked are: • What is resilient modulus? • How do you determine it?
3. Indicate how moisture content, density, and freeze-thaw influence the repeated load behavior of a fine-grained soil.	The stiffness of fine-grained soil is highly dependent on the relative density and moisture content of that material. Key points to consider are: • Stiffness increases with increased soil density • Stiffness decreases with increased moisture content Key questions that may be asked are: • What effect would an increase of 10% relative density have on the stiffness of a fine-grained soil? • What effect would an increase of 10% moisture content have on the stiffness of a fine-grained soil? • How would freeze thaw effect the stiffness of a fine-grained soil?

4. Identify information sources for use in characterizing subgrade support and in evaluating problems such as frost heave and expansive soils.	Many sources of information are available to aid in evaluating the different subgrade soil properties within a given project. Key points to consider are: • Previous engineering reports • Pedologic soil data • Geological data • Climatic Information Key questions that may be asked are: • Have you used other sources of information such as local soil maps? • What other types of soil information have you found? • How is this information used?

Module 2-5
Drainage Survey and Evaluation

Objective	Activity
1. List four distress types that are indicative of moisture damage in a pavement and discuss the importance of their severity levels.	Moisture will accelerate any deterioration; Tables 2-5.1 and 2-5.2 contain a list of moisture-related distress types for both flexible and rigid pavement. Key points to consider are: • Flexible Pavements • Structural properties • Material properties • Rigid Pavements • Structural properties Key questions that may be asked are: • What types of pavement distresses can be caused by poor drainage? • Can you give a local example of the distress caused by poor pavement drainage? • How do you measure the effects of poor drainage?
2. Define external and internal drainage factors and list their major components.	A given moisture state in a pavement structure is the product of both external and internal drainage factors. Key points to consider are: • List external drainage factors • List internal drainage factors Key questions that may be asked are: • Where does most of the moisture come from in a pavement section? • How does it effect the strength and stiffness of the pavement layers? • How could you measure this effect?
3. Recall the principle behind drainage time for a flooded base course and discuss how this time influences pavement performance.	The 85% saturation level is critical for granular base layers in terms of the large deflections experienced at or above that level. Key point to consider are: • Drainage time < 5 hr, 5 hr. to 10 hr., >10 hr.

	Key questions that may be asked are: • What effect does a near saturated condition have on granular base? • Can you measure this effect? • Can you account for this effect in your pavement design?
4. List the properties that influence the drainability of a subgrade.	The basic properties that influence the drainability of a subgrade soil are included in the drainage classification of a soil. Key points to consider are: • Soil grain size • Depth to water table • Soil plasticity • Topography Key questions that may be asked are: • How do you determine the drainability of a subgrade soil? • How do you determine the drainability of a granular base?
5. Combine base and subgrade drainage criteria to develop the American Association of State Highway and Transportation Officials (AASHTO) drainage coefficient.	The drainability of the base and subgrade soil must be combined to determine the overall drainability of the pavement structure. Key points to consider are: • AASHTO Drainage coefficient • Figure 2-5.15 Key questions that may be asked are: • How does the drainability of granular layers and subgrade soil effect each other? • Can this effect be determined? • What does the AASHTO Drainage coefficient do in the AASHTO pavement design procedure?

Module 2-6
Traffic Loading Evaluation

Objective	Activity
1. Recognize the important role that traffic loadings play in rehabilitation design.	An evaluation of traffic loadings is one of the more important factors to consider in pavement design and rehabilitation. Key points to consider are: • Impact on design thickness' • Impact on appropriate treatment • Impact on selection of appropriate paving materials Key questions that may be asked are: • How does traffic loadings effect pavement design? • Do you consider traffic loadings in your rehabilitation design? • How do you account for traffic loading in your design procedure?
2. Define a load equivalency factor (LEF) in accordance with the American Association of State Highway and Transportation Officials (AASHTO) Design Guide.	The AASHTO load equivalency factor is expressed in terms of a measured axle loads that causes a similar loss in serviceability compared to a standard axle. Key points to consider are: • Loss of serviceability • Standard single axle load • Mixed traffic loads Key questions that may be asked are: • Can you define what a load equivalency factor is? • How is a load equivalency factor determined? • What is loss of serviceability?
3. Develop appropriate truck factors (TFs) for the various truck classifications.	The average damage done by each axle on a vehicle are added together and expressed as the total amount of damage done by the passing of one vehicle in terms of a truck factor. Key points to consider are: • Average TF • Range in TF

<table>
<tr><td></td><td>Key questions that may be asked are:
What is a truck factor?
Do you know what the average truck factor for 5 axle trucks in this area?
What would cause truck factors to change in different areas?</td></tr>
<tr><td>4. Discuss the need to sample traffic, to convert general traffic data to project-specific data, and to improve the traffic loadings through the use of weigh-in-motion (WIM) and automatic-vehicle-classification (AVC) equipment.</td><td>Traffic loading is highly variable along a route within a region and at any day, which requires good sampling and load estimating procedures.

Key points to consider are:
Truck Classification varies with route and season.
Truck weights vary with route and season.
Larger growth rates than autos
Key questions that may be asked are:
How do you sample traffic loads in this area?
How is future traffic loading predicted?
Do you have any unique traffic loadings in this area?</td></tr>
<tr><td>5. Use growth factors to project future traffic and compute the future expected cumulative 80 kN ESALs for a pavement section over the rehabilitation design period (forecasting).</td><td>It has been found that truck loading, which is a product of truck volumes and truck loads, are increasing at much higher rates that the basic average daily traffic growth rate would indicate

Key points to consider are:
Average growth rate for all vehicles
Average growth rate for 5+ axle trucks
Effects of doubling compound growth
Key Questions that may be asked are:
Do you know what the average growth rate for all vehicles on the Interstate here?
What is the average growth rate for heavy trucks on the Interstate here?
What type of error would occur if you estimated 4% growth rate for 35 years but experienced 10 % a growth rate?</td></tr>
</table>

Module 2-7
Overall Project Evaluation

Objective	Activity
1. Describe the potential benefits of conducting a thorough pavement evaluation and the typical consequences of not conducting such as evaluation	The actual costs to conduct a thorough pavement evaluation on a typical project is in terms of the cost of one months service, ($10,000 to $50,000) while the potential benefits may be several years of additional service. Key points to consider are: • Cost of conducting a through pavement evaluation • Potential increase in the service life of the pavement. • Potential payback very high Key questions that may be asked are: • Do you conduct a pavement evaluation for rehabilitation projects? • What level of effort is involved? • How does it relate to project life?
2. Outline a systematic step-by-step procedure to obtain the necessary data to conduct a pavement evaluation.	The basic pavement evaluation process follows a basic set of steps or procedures as indicated on the flowchart in figure 2-7.1. Key points to consider are: • Office data collection • Initial field visit • Primary field survey • Initial data analysis • Secondary field survey • Laboratory materials characterization • Secondary data analysis • Structural capacity analysis Key questions that may be asked are: • Can you describe the analysis procedures you use in this area? • What level of effort and cost is involved? • Is it worth the effort?
3. Develop an overall pavement evaluation checklist that provides a summary for the design engineer to use in determining causes of deterioration, in developing cost-effective alternatives, and in communicating the results of the evaluation to management.	Table 2-7.2 presents a checklist of many of the factors that should be evaluated in a pavement evaluation program. Each agency should have developed a similar list that meets their needs.

	Key points to consider are: • Structural evaluation • Functional evaluation • Variation in conditions evaluated • Climatic effects • Pavement materials evaluation • Roadbed soil evaluation • Pervious maintenance performed • Rate of deterioration evaluation • Project traffic evaluation Key questions that may be asked are: • Has your agency developed a checklist for pavement evaluation? • If not would it be of value? • How would you go about developing a similar list?
4. Describe the approach to conducting a rationa Structural evaluation of the existing pavement	A pavements structural capacity refers to its ability to support current and future traffic loads and remain serviceable. Two basic structural assessment procedures are presented. Key points to consider are: • Structural evaluation by existing distress • Structural evaluation by nondestructive testing. Key questions that may be asked are: • How does your agency conduct a structural evaluation of the existing pavement? • Is that evaluation used to constrain rehabilitation treatments to those that are structurally adequate?

Module 3-1
Hot-Mix Asphalt Mixture Overview

<table>
<tr><th>Objective</th><th>Activity</th></tr>
<tr><td>1. List the basic components of asphalt binder.</td><td>Basic molecular components of asphalt are described as well as the physical attributes they contribute to the stiffness and strength properties of asphalt.

The key points to cover on molecular composition are:
Basic Rostler fractions and their physical properties
Asphaltenes
Maltenes
Asphalt Viscoelastic Behavior
Key questions that may be ask are:
Can you describe the basic structure forming molecular components that come from a Rostler separation?
Can you describe the basic structure inhibiting molecular components that come from a Rostler separation?
What effect does heat and or load have on the elastic properties of asphalt?</td></tr>
<tr><td>2. Describe the basic viscoelastic properties of asphalt binder.</td><td>The student should understand and be able to describe the effects of temperature and load on asphalt binder films.

The key point to cover on the viscoelastic properties of asphalt are:
How heat, load, and time effect the basic mechanical stiffness and strength of asphalt.
Key questions that may be ask are:
What stiffness properties does asphalt have at:
High temperatures,
Intermediate temperatures,
Low temperatures?
What effect does load have on these properties?</td></tr>
<tr><td>3. Describe what happens to the components of asphalt binder as it ages and its mechanical properties.</td><td>Discuss in general terms the effects of volatilization and oxidation on binder composition and mechanical properties.

Key points to cover on the effects of asphalt aging are:
The basic changes in the molecular composition that occurs as asphalt ages.
How those compositional changes effect the mechanical properties of the asphalt binder.
Key questions that may be ask are:
What effect does aging have on the molecular composition of asphalt?
How does these changes effect the mechanical properties of asphalt?</td></tr>
</table>

4. Describe the basic mix gradations that may be used in asphalt pavement (AP) and their attributes.	Dense graded aggregate has been use extensively over the years to construct standard hot mix asphalt pavement. More recently, open graded, and gap graded aggregate gradations are being used in asphalt pavements which have different attributes and properties. The key points to cover on the different aggregations used in hot mixed asphalt are: • Describe dense aggregate gradation using a 0.45 power curve and discuss the basic mechanical properties it provides. • Describe open aggregate gradation using a 0.45 power curve and discuss the basic mechanical properties it provides. The need for thick asphalt binder films in open graded mixes should be stressed. • Describe gap aggregate gradation using a 0.45 power curve and discuss the basic mechanical properties it provides. Introduce SMAs as an example of gap graded hot mix and discuss current experience with that material. Key questions that may be ask are: • What basic stiffness and aging attributes does a basic dense graded hot mixed asphalt pavement provide? • What attributes does open graded hot mixed asphalt provide? • What attributes does gap graded hot mixed asphalt provide?
5. Describe the possible failure modes of the various AP mix types.	The various types of aggregate gradations used in hot mix construction have different mechanical properties and failure modes. The key points to stress regarding the performance of dense, open, and gap graded hot mixed asphalt are: • The primary failure mode for dense graded hot mixed asphalt are, rutting, fatigue cracking, and thermal cracking. • The primary failure mode for open graded mixes is raveling. • The primary failure mode for gap graded mixes. Key questions that may be ask are:

	• What are the basic failure modes for dense graded HMA pavements? • How are open graded HMA pavements different from dense graded? • What are the possible advantages and risks associated with the use of gap graded HMA pavements?

Module 3-2
Crack Sealing

<table>
<tr><th>Objective</th><th>Activities</th></tr>
<tr><td>1. Identify the major factors that affect sealant performance.</td><td>Identify major factors that are considered in crack sealing design such as climate, traffic, crack characteristics, sealing materials, placement sealing configuration etc.

Key points to cover on asphalt crack sealing are:
Differentiate between crack sealing and crack filling.
Discuss the basic factors that should be considered in crack seal design such as:
Climate
Traffic
Crack characteristic and density
Sealant materials
Sealant configuration
Key questions that may be ask are:
What is crack sealing as compared to crack filling?
What types of sealing materials are available for crack sealing and how do you choose which is most appropriate for your project?
What sealant have you tried and how have they worked?
What sealant configurations have you tried and which has worked best?</td></tr>
<tr><td>2. Describe the procedures required to seal or reseal cracks in HMA pavements.</td><td>Discuss the basic requirements for the preparation and construction of crack sealing and crack filling projects.

The key points to cover in the crack sealing operation are:
How to prepare cracks for crack sealing and crack filling.
How to choose the most appropriate sealing material for the project.
What type of performance should you expect from proper cracks sealing?
Key questions that may be asked are:
What type of crack sealing procedures do you use in the area?
How has your recent crack sealing performed?
Do you crack seal as pavement preparation before you construct HMA overlays?
Can you stop reflection cracking with crack sealing?</td></tr>
</table>

3. Identify the primary sealant types, appropriate specifications, and sealant properties.	Discussion of the sealant material properties, specifications, and relative costs. The key points concerning sealant types and properties are to: • Describe the basic sealant types in terms of: Thermoplastic materials Thermosetting materials • Review Table 3-2.1 and the wide range of material in use. • Discuss the basic sealant properties such as Durability Extensibility Resilience Adhesives Cohesiveness Key questions that may be ask are: • How should you choose which sealant to use on a specific project? • What specific sealants have you used in this area? • How have they worked? • How do you determine what sealer may be the most cost effective?

Module 3-3
Patching with Bituminous Mixtures

<table>
<tr><th>Objectives</th><th>Activity</th></tr>
<tr><td>1. List the desirable properties of a bituminous patching mixture.</td><td>The basic material properties of the patching material should be described.

Key points to cover are the basic material properties such as:
stability,
adhesives,
resistance to stripping,
durability,
workability,
stability.
Key questions that may be ask are:
What material properties are considered most important?
How may these material properties effect patch performance?</td></tr>
<tr><td>2. Differentiate between hot-mix HMA materials and cold-mix, stockpiled patching mixtures on the basis of quality, aggregate, and binder.</td><td>Describe the basic difference between hot mix and cold mix patching materials as well as the basic attributes and utility of each material.

Key points to cover regarding the use of hot and cold mixed patching materials are:
Differentiate between temporary and semi-permanent patching
Cold mix patching material
Using cutback asphalt
Using emulsified asphalt
Aggregate requirements
Proprietary materials
Hot mix patching materials
Asphalt requirements
Aggregate requirements
Key questions that may be ask are:
How should you choose the most appropriate patch material for the intended use?
What type of patching materials have you used?
How have they worked?</td></tr>
<tr><td>3. Describe the conditions that require patching and differentiate between temporary, semi-permanent patching, and localized reconstruction.</td><td>Pavement patching is used over a wide range of pavement deterioration conditions so there needs to be some consideration regarding the relative application of patching material as to timing condition and performance.</td></tr>
</table>

	Key points to cover in patching pavements: • When is temporary patching used • When is semi permanent patching applicable • Discuss the stage where a pavement has deteriorated to the level that patching is ineffective and reconstruction is needed. Key questions that may be ask are: • When is temporary patching called for? • When is semi-permanent patching called for? • What types of patch materials have you used in the area, and how have they worked?
4. List the steps necessary to accomplish patching as part of a 4R project.	Successful semi-permanent patching requires careful control of the basic construction details is which are discussed in detail with an explanation for each step. Key point to cover regarding the construction of semi-permanent patches are: • Pennsylvania's patching construction guidelines described in section 3-3.7 Key question that may be asked are: • What construction procedures have you used to construct semi-permanent patches? • How have those patches worked?

Module 3-4
Cold Milling

Objective	Activity
1. Describe cold milling and its basic objective.	Describe cold milling equipment, including drum and tooth Configuration and how the equipment works. Key points regarding cold milling are: • Provide a basic description of cold milling equipment • Differentiate between cold milling and pavement Grinding • Potential limitations of cold milling Key questions that may asked are: • How and where do you using cold milling? • How well has it worked? • What problems have you had if any with cold milling
2. List the major reasons for cold milling hot-mix asphalt (HMA) pavement surfaces.	The most predominate use of cold milling is for mass removal of HMA and reprofiling the pavement surface. Key points to consider are: • Mass removal how, where, when. • Reprofiling • Rutted pavement • Rough pavement • Curb line • Drainage grade line Key questions that may be ask are: • How have you used cold milling? • How has it worked? • Have you had any particular problems with cold Milling
3. Describe equipment and construction problems encountered in typical cold milling operations.	Provide a discussion of basic drum and tooth configuration and how they effect the resulting pavement surface texture, as well as a discussion of basic specifications that can be used to obtain the surface textured needed. Key points to consider are: • Standard drum and tooth configuration • Resulting pavement texture • Multiple tooth configuration • Multiple warp configuration • Possible texture specifications

	Key questions that may be asked are: • What may determine the need for different cold milling textures? • Have you had any problems with the course texture left by standard cold milling operations? • Have you any experience with more texture control in your cold milling projects?

Module 3-5
Surface Rehabilitation Techniques

Objective	Activity
1. Identify and differentiate the major types of surface rehabilitation techniques.	Distinguish between the basic types of surface treatments and where they should be used. Key points to consider are: • A general description of surface treatments Fog seal Sand seal Chip seal Slurry seal Microsurfacing Cape seal Sandwich seal Open graded friction course • The basic functions of surface treatments Key questions that may be asked are: • How do you determine if a surface treatment is Appropriate for a project and how do you select whic surface treatment to use? • What surface treatments have you used? • How have they worked?
2. Demonstrate the design principles required for the successful application of chip seal and open-graded friction courses.	The basic requirements of chip seal design including aggregate and binder selections and application rates should be covered along with a basic discussion as to the need for strict adherence to the design requirements. Key points to consider are: • Design considerations for chip seals include Existing pavement condition Asphalt type Aggregates and availability Quality control Local conditions and experience General environment • Design considerations for open graded friction seals Key questions that may be asked are: • What design procedures do you use for your surface treatments? • What asphalt type do you use? • How do you adjust for pavement condition?

3. Employ the construction sequences and describe the necessary equipment operating characteristics for the various surface rehabilitation techniques.	Since the success of surface treatments are highly dependent upon how they are constructed, the construction process and required equipment used in the application of the surface treatment is discussed in some detail. Key points to consider are: • Typical construction sequence • Potential construction problems and causes • Key inspection points • Equipment requirements Key questions that may be asked are: • How are your surface treatments constructed? • How do they hold up? • Have you experienced any early problems? • Have they provided the service desired? • How do you select the particular treatment to use on a particular project?

Module 3-6
Recycling Overview

<table>
<tr><th>Objective</th><th>Activity</th></tr>
<tr><td>1. Identify the types of pavement recycling.</td><td>Describe the basic differences between the primary types of recycling treatments shown in figure 3-6.1 “Categorization of pavement recycling”.

Key points to consider are:
A general description of the various recycling options particularly differentiating between
Cold mix recycling
Hot mix recycling
Surface recycling
Review advantages and disadvantages of the different techniques covered in table 3-6.1
Key question that may be ask are:
What types of these recycling options have you used?
How have they worked?
How would you choose which treatment would be most appropriate for a particular project?</td></tr>
</table>

Module 3-7
Hot In-Place-Place Recycling

<table>
<tr><th>Objective</th><th>Activity</th></tr>
<tr><td>1. Identify the types of hot in-place recycling.</td><td>Provide detailed descriptions and differentiate between heater scarification, repaving, and remixing in hot in-place recycling.

Key points to consider are:
Description of heater scarification process
Description of repaving process
Description of remixing process
Key questions that may be ask are:
Can you describe the various hot in-place recycling processes?
Which of these processes have you used in this area?
How have those treatments worked.</td></tr>
<tr><td>2. Define the types of equipment and their operational sequence for hot in-place recycling operations.</td><td>Describe is some detail the basic types of equipment used in hot in-place recycling, how that equipment has evolved, as well as the possible advantages and disadvantages associated with the equipment.

Key points to consider are:
Describe the basic equipment that is used in heater scarification (Figure 3-7.1)
Describe the typical equipment used for repaving. (Figure 3-7.3)
Describe the evolving equipment used in remixing (Figures 3-7.6 and 3-7.9)
Key questions that may be ask are:
Of the various hot in-place recycling processes you have tried, what was the equipment like?
Have you used any of the three and four stage remixers?
If you have how did they work?</td></tr>
<tr><td>3. Describe mixtures design procedures for use in hot in-place recycling operations.</td><td>Refer to module 3-9 where recycled hot mix design procedures ar discussed in much greater detail.</td></tr>
<tr><td>4. Describe performance of hot in-place recycled pavements.</td><td>Performance information is still somewhat limited for hot in-place recycling compared to hot central plant recycling.

Key points to cover:
The reasons for this lack of information should be discussed as well as possible solutions.</td></tr>
</table>

	Key questions that may be ask are: • What has been the general performance of hot in place recycled pavements in this area? • Have any studies been performed looking at the performance of hot in place recycled pavements in this area? • If there has been what was the general finding?
5. Provide recommendations for appropriate use of hot in-place recycling techniques.	The general guidelines for use covered in 3-7.9 should be reviewed in some detail so that the students clearly understand the best application for this procedure. Key points to consider are: • Uniformity of existing pavement • Presence of patches and seals • Asphalt content and viscosity • Aggregate gradation • Traffic types and levels • Type and extent of pavement distress Key question that may be asked are: • How would you determine which projects would be reasonable candidates for hot in place recycling? • What criteria have you used in past projects? • Do you have any current formal guidelines? • If you have what are they?

Module 3-8
Cold In-Place Recycling

Objective	Activity
1. Identify the types of cold in-place recycling.	Discuss the basic differences between the cold in-place recycling procedures shown in figure 3-8.1. Key points to consider are: • Provide full description of the single machine and equipment train procedures • Provide only a general description of the other procedures shown in figure 3-8.1 Key questions that may be asked are: • What procedures have been used in this area? • How have they worked?
2. Define the types of equipment and their operational sequence for cold in-place recycling operations.	Provide a detailed description of the basic types of equipment used in cold in-place recycling, how that equipment has evolved, as well as the possible advantages and disadvantages associated with the equipment. Key points to consider are: • The nine basic steps common to cold in-place recycling. • The basic equipment and how it is used to accomplish the nine basic steps previously discussed. • Advantages and disadvantages of the different procedures. Key questions that may be asked are: • Can you describe the basic steps required for cold in-place recycling? • Have you used cold in-place recycling in this area? • What equipment and configuration was used?
3. Describe mixture design procedures for use in cold in-place recycling operations.	There has been a wide range of mixture designs developed for cold in-place recycling, with no clear indication that one design has been that much more successful than any other. Key points to consider are: • The number of agencies that have developed mix design procedures (10 listed) • The basic steps in most mix designs Sampling Processing Evaluation Asphalt and aggregate needs Trial mixture compaction and testing Job mix formula Field adjustment

	Key questions that may be ask are: • What mix design procedure have you used? • Can you describe that mixture design procedure? • Was their much field adjustment required?
4. Describe performance of cold in-place recycled pavement.	Actual documented performance of cold in-place recycling has been mixed. Key points to consider are: • Identify benefits of cold in-place recycling • Identify problem areas with cold in-place recycling Key questions that may be ask are: • How many cold in-place recycling projects have you constructed in the area? • Has there been any studies conducted on the performance of these projects? • How have they performed in general?
5. Provide recommendations for appropriate use of cold in-place recycling techniques.	The guidelines in 3-8.8 are very basic and limited but still needs to be reviewed. Key points to consider are: • Advantage and disadvantages of cold in-place Recycling • Possible causes of poor performance Key questions that may be asked are: • How should you determine if cold in-place recycling is appropriate for a given project? • If cold in-place recycling is appropriate how should you select the most appropriate procedure? • Do you have procedures in place to help with these determinations?

Module 3-9
Hot Central Plant Recycling

Objective	Activity
1. Identify the types of hot central plant recycling.	Only a general description of hot central plant recycling is required. Key points to consider are: • Provide a basic description of the hot central plant recycling procedures. • Advantages and disadvantages of hot central plant recycling • Basic procedures Pavement removal Crushing and sizing Stockpiling Mixing equipment Key questions that may be asked are: • Do you allow hot central plant recycling procedures? • How long have you allowed hot central plant recycling? • How has it worked?
2. Define the types of equipment and their operational sequence for hot central plant recycling operations.	There is a very large number of different hot mix plant designs with many variations in how they handle hot mix recycling. Review basic plant configurations and the flow of rap and virgin material through the plants including basic heat transfer aspects of each plant. Key points to consider are: • Provide a basic description of the hot central plant equipment used. Batch plants Continuous plants Drum plants • Conductive and convective heat transfer. Key questions that may be asked are: • What types of hot mix plants are used in this area For hot central plant recycling? • What percentage of recycle can they produce? • What percentage of recycle do you allow?
3. Describe mixture design procedures for use on hot central plant recycling operations.	Review the basic mixture design covered in 3-9.5 with some time spent on the blending chart figure 3-9.25 and the importance of proper viscosity blending of the liquid asphalt binder. <u>Do not walk the students through the design formulas.</u>

	Key point to cover are: • Recycle mixture design procedures • Field samples • Extract and recover asphalt and aggregate • Asphalt properties • Type and amount of modifiers needed • New aggregate needs • Asphalt demand • Conduct preliminary mix evaluations • Select optimum mixture design Key questions that may be asked are: • What mixture design procedure do you uses? • Who conducts the design? • How has it worked?
4. Describe performance of hot central plant recycled pavements.	Hot central plant recycling has only a little more documented performance history than the other recycling procedures discussed. Review some of the more basic information in Section 3-9.7 Key points to consider are: • Performance experience discussed in section 3-9.7 and shown in Table 3-9.7. • Possible reasons for general lack of performance data. Key questions that may be asked are: • What type of performance experience do you have for hot central plant recycling? • Has there been any specific studies made in this area regarding the performance of hot central plant recycling? • If you have no hard data what is your impressions as to how hot central plant recycling has performed in this area?

Module 3-10
Hot-Mix Asphalt Overlays

Objective	Activity
1. List the functional and structural deficiencies that can be corrected with a properly designed HMA overlay.	Define and differentiate between functional and structural Pavement deficiencies. Key points to consider are: • Definition of functional pavement performance • Definition of structural pavement performance Key questions that may be ask are: • Can you provide examples of possible functional pavement deficiencies you experience in this area? • Can you provide examples of possible structural pavement deficiencies you experience in this area? • Which of the deficiencies you listed cam be corrected with a HMA overlay?
2. Identify the conditions for which an HMA overlay is best suited and most cost-effective.	Review the "spectrum of pavement rehabilitation alternatives" shown in Figure 3-10.1 Key points to consider are: • Timing Maintenance Resurfacing Reconstruction • Constructibility • Traffic control • Clearances Key questions that may be ask are: • How do you determine when an overlay is feasible for a given project? • What conditions do you look at for this determination?
3. Apply the various approaches for HMA overlay thickness design (as well as their strengths and weaknesses).	Four basic overlay thickness design procedures are described in th section. Key points to consider are the basic approaches to: • Engineering Judgement to determine overlay thicknes • Deflection Approach to determine overlay thickness • Structural Deficiency to determine overlay thickness • Mechanistic Approach to determine overlay thickness Key questions that may be ask are: • What thickness design procedures do you use in this Area? • What information do you collect to support these Designs?

	• What is your typical overlay performance experience? • Does this fit with your thickness design procedure?

4. Determine the feasibility and extent of pre-overlay repair.	Repair of areas of unique distress prior to placement of an overlay may reduce the overall structural needs and reduce the thickness of the overlay needed.
	
	Key points to consider are:
	• Existing pavement condition
	  Distress
	  Severity
	  Extent
	• Types of pre-overlay treatments
	  Localized repair
	  Surface leveling
	  Reflection cracking control
	  Drainage corrections
	Key questions that may be asked are:
	• What type of pre-overlay treatments do you use?
	• Have you reduced overlay thicknesses using pre-overlay treatments?
	• How do you account for pre-overlay repair in your design process?

5. Describe the consequences of deferring overlay placement.	Delaying the placement of an overlay decreases the structural capacity of the existing pavement and increases the overlay thickness needed in an exponential trend. Key points to consider are: • Structural capacity loss over time • Resulting increase in overlay thickness and pre-overlay treatment. Key questions that may be asked are: • At what pavement condition level to you place your structural overlays? • Can you think of a recent example where you waited too long to place an overlay? • What were the consequences of delaying the overlay?

Module 3-11
Identification of Feasible Alternatives

Objective	Activity
1. Describe what a decision tree or chart is and how it is developed and used.	Decision trees or charts provide structured a framework for the identification of the more feasible treatment matched to defined conditions. Key points to consider are: • Basic framework for identifying potential treatments • Cause of distress vs. potential treatments Key questions that may be asked are: • Do you use a decision tree or table in your organizations? • If not would it be of benefit? • How would you develop it?
2. Describe the proper uses of decision trees.	Decision trees are used to aid in matching the various project conditions to the more reasonable treatments that meet the objectives of the project. They often are used as an aid for the beginning engineer who has a limited experience base Key points to consider are: • Structure of the decision process • Engineering experience • Agency policy Key questions that may be asked are: • Can you describe the proper uses of decision trees? • How can decision trees help you?
3. Describe the limitations and potential problems that are associated with the strict use of a decision tree.	Decision trees bring a basic structure to the design process but can also limit more creative and better solutions from being explored because of that structure. Key points to consider are: • Decision trees need to be updated • Decision trees should be considered as aids not rules. Key questions that may be asked are: • If you use decision trees how often are they reviewed and updated? • Have you experienced limitations on treatments considered because the other options were not included in the decision trees? • In general how have decision treatments worked here?

Module 4-1
Rigid Pavement Overview

Objective	Activity
1. Identify the typical layers of PCC pavement.	PCC Pavement has been used by being placed directly on subgrade or in conduction with bound and unbound granular layers. Most modern designs place the rigid pavement on a bound permeable base layer. Key points to consider are: • Rigid Pavement • Granular base layer • Cement or asphalt treated permeable layer. Key questions that may be asked are: • Can you describe the various layers used in a rigid pavement and explain the function of each layer? • What is the current layer configuration most often used today?
2. Compare the response of a rigid pavement to applied loads.	Rigid pavements distribute applied wheel loads over a very wide area, and provide most of the pavement structure. Base layers are used more to provide uniform support and drainage but contribute very little to the total load caring structure. Key points to consider are: • PCCP high stiffness and compressive strength • Base uniformity • Base drainage Key questions that may be asked are: • What is the typical layer configuration in your PCC pavement? • How does a PCC pavement distribute loads? • What structural value does the base course under a PCC pavement provide?
3. Describe the fundamental materials that are used in PCC pavement construction and rehabilitation.	PCC pavements are constructed from a fairly uniform gradation of aggregate and cement. The cement hydrates to form a rigid matrix that holds the aggregate in place. The compressive strength

	of the matrix depends upon the hardness of the aggregate how uniformly graded it is and the amount and fineness of cement and used. Key points to consider are: • Aggregate • Grading • Cement Key questions that may be asked are: • What materials are used in PCC Pavements? • What makes it rigid? • What material properties control Strength?

Module 4-2
Joint Sealing

Objective	Activity
1. Identify the major factors that affect joint sealant performance.	There are many factors that effect joint sealant performance. For joint sealing to work well requires an adequately designed joint seal project and sound construction procedures. Key points to consider are: • Existing conditions • Joint movement • Sealant properties • Construction procedures and controls. Key questions that may be asked are: • How do you design joint seals? • What type of material do you use? • How does your joint seals perform?
2. Describe the steps involved in resealing PCC pavement joints.	Resealing joints effectively requires very specific steps and procedures to provide the best long-term performance. Key points to consider are: • Removal of old sealant • Resurface of joint sidewalls • Cleaning of joint reservoir • Installation of the backer rod • Installation of the new sealant Key questions that may be asked are: • Can you describe the steps you use to reseal PCC joints? • How have your resealed joints performed?
3. Identify the primary sealant types, appropriate specifications, and sealant properties.	Successful resealing of joint requires the proper selection of sealant that meets the material, joint and environmental conditions found on the project. Key points to consider are: • Thermoplastic material Hot applied Cold applied • Thermosetting material Chemically cured Solvent release

	Key questions that may be asked are: • What type of sealant materials have you used? • What specifications have you used? • How have they worked?

Module 4-3
Pressure Relief Joints

Objective	Activity
1. Identify the causes of expansive pressures in PCC pavements and the resulting pressure-related distress.	Due to the accumulation of incompressibles in transverse joints, reactive aggregates, and to critical thermal and moisture conditions significant expansive pressures can build up in rigid pavements over time which can cause significant deterioration in PCC pavement. Key points to consider are: • Joint Spalling • Blow ups • Damage to adjacent structures. Key questions that may be asked are: • What caused PCC pavement blowups? • Do you experience many blowups in your pavement in this area? • How do you correct them?
2. Recognize situations where the installation of pressure relief joints may be warranted.	Pressure relief joints are generally recommended only for long-jointed rigid pavement that have a clear and extensive history of pressure related damage. Key points to consider are: • Use only on pavement with history of problems. • PRJ installed about 305 m spacing' • Limit PRJ to a width of 25 to 50 mm • PRJ are recommended to protect bridges and other structures Key questions that may be asked are: • What limitations should be placed on the used of PRJ? • Have you used PRJ and how have they worked?
3. Describe procedures for properly constructing pressure relief joints.	Pressure Relief Joints should be placed either in mid-slab or at the location of an existing transverse joint. Key points to consider are: • Joint cut with carbide tip or two cuts from diamond-bladed saw (25 – 100 mm) • Compressible filler installed

	• Filler capped with sealant Key questions that may be asked are: • Can you describe your PRJ design? • How are they constructed? • Have you had any particular construction problems?
4. Recognize the potential problems associated with the use of pressure relief joints.	PRJ tend to close up over time eliminating their benefit, and causing adjacent joints to open up over time. Key points to consider are: • Joint movement over time • Opening of adjacent joints • Loss of load transfer in adjacent joints Key questions that may be asked are: • Have you installed any PRJ? • How have they performed? • Have you changed how you design and build PRJ? • Why?

Module 4-4
Partial-Depth Repairs

Objective	Activity
1. Identify distress types that can be corrected with partial-depth repairs.	Partial depth repairs replace concrete only, and can not accommodate the movements of working joints and cracks, load transverse devices, or reinforcement steel with out experiencing high stresses and material damage. Key points to consider are: • Spalls caused by use of mechanical inserts • Spalls caused by intrusions of incompressibles • Spalls caused by scalling, and week concrete Key questions that may be asked are: • What forms of distress do you Construct partial depth repairs to Correct? • What type of distress does partial-depth repair not correct?
2. Be familiar with various materials used for partial-depth repairs.	A wide variety of materials are available for use in partial depth repair. Material selection depends on available curing time, ambient temperature, cost and size and depth of the repairs. Key points to consider are: • Cementitious Materials • Polymer-Based Concrete • Bituminous Material Key questions that may be asked are: • Which of these materials have you tried? • How have they worked? • Have you had any problems with partial depth repairs? • If you have, how could improve that performance?
3. Describe successful construction procedures for partial-depth repairs.	Ultimate the successful performance of partial depth repairs is highly dependent upon the use of proper construction procedures. Key points to consider are: • Location of repair boundaries

	• Removal of deteriorated concrete • Joint repair • Cleaning the repair • Application of bounding agent • Repair Material preparation • Placement and consolidation of material • Screeding and finishing • Curing • Joint sealing • Opening to traffic Key questions that may be asked are: • Can you describe the key steps to the placement of a partial depth patch? • Do your construction procedures match these steps? • If not how are the different? • How successful has your partial depth patching been?

Module 4-5
Full-Depth Repairs

Objective	Activity
1. Based on visual observations (and deflection testing), identify areas requiring full-depth repair and determine appropriate boundaries.	Distressed areas must be identified and marked with special consideration given to those areas of extensive distress that might require complete slab replacement. Key points to consider are: • Jointed Concrete Pavement • Continuously Reinforced Concrete • Sizing the repair Key questions that may be asked are: • How do you determine where full depth repair is needed? • What guidance do you have for sizing the repair?
2. Determine when large areas should be completely removed and replaced rather than removing and replacing several adjacent smaller areas.	Large areas should be removed when the existing distress is so extensive that the repair of every deteriorated area within short distances is either too expensive or impractical. Key points to consider are: • Size of patch • Distance to next patch • Contractors operations and costs Key questions that may be asked are: • How do you determine when to remove large areas and rebuild rather than do a lot of small patching? • Do you estimate the costs based on unit costs or actual contractor operations? • Are the contractors operations significantly different between the two processes?
3. Select acceptable design and construction procedures for cast-in-place repairs at joints and cracks for typical pavement conditions.	The design and constructions of cast-in place repairs generally follows a set of procedures that have provided the best overall performance. Key points to consider are: • Layout of repair location • Concrete sawing and removal • Area preparation • Load transfer installation where required for transverse and longitudinal joints

	• Concrete placement consolidation and finishing • Curing • Joint cleaning and sealing Key questions that may be asked are: • Do you design and construct you full depth patches along the lines described above? • If not can you describe your procedures?
4. Describe the design of a permanent, cast-in-place concrete repair that provides continuity of reinforcement and load transfer at transverse repair joints for CRCP.	For CRCP the design of permanent patches requires a special process where the distressed area is removed and then additional concrete is removed around the reinforcing steel to provide sufficient bond length to splice the new steel in the patch to the old steel in the pavement Key points to consider are: • Placing reinforcing steel • Steel splice length ♦ Tided splices Welded splices .1 Key questions that may be ask are: ♦ How do you construct full depth patches in your CRCP? ♦ Do you use tied or welded splices? ♦ How do your CRCP patches work?

Module 4-6
Accelerated Rigid Paving Techniques

Objective	Activity
1. Identify conditions under which these techniques may be considered as a part of a rehabilitation project.	The use of ARPT is appropriate only when the use of this technology results in some form of savings, such as reducing direct agency costs or user delay costs. .2 Key points to consider are: ♦ Urban Intersections ♦ Commercial Areas ♦ Single access roads ♦ Urban highways .3 Key questions that may be asks are: ♦ How do you determine when to use ARPT ♦ Can you give some examples? ♦ Where would ARPT not be appropriate?
2. Discuss the various materials that can be used to achieve high early strengths, and how to select the appropriate material for the time available to perform the rehabilitation.	A simple rule in selecting the material for an accelerated paving project is to use the least exotic (i.e., most conventional) material that will meet the demands of the job. .4 Key points to consider are: ♦ Scope of work ♦ Job site conditions ♦ Available equipment ♦ Costs ♦ Table 4-6.1 Key questions that may be asked are: ♦ What materials have you used for ARPT? ♦ Why did you choose them? ♦ How have they worked
3. Discuss the special construction procedures that accompany the use of accelerated paving techniques.	The success of an ARPT project depends on how well the whole repair/rehabilitation process is carried out. Key points to consider are: ♦ Concrete removal ♦ Concrete placement ♦ Curing ♦ Joint sawing and sealing Key questions that may be asked are: ♦ Can you describe the special

	construction procedures involved in ARPT? ♦ Is this how you conduct ARPTs? ♦ Can you provide any local examples?
4. List the innovative field testing procedures that can be used to monitor the strength of the concrete.	Because strength development of concrete is so sensitive to local project conditions, it is desirable to base the opening of concrete repairs on actual in-place strength of the repair rather than curing time. Key points to consider are: ♦ Beam breaks ♦ Cylinders ♦ Temperature matched curing ♦ Maturity ♦ Pulse Velocity Key questions that may be asked are: ♦ What strength tests do you use? ♦ Why did you select that test? ♦ How does it seem to work for you?
5. Determine the appropriate criteria for opening the pavement to traffic.	There is no cleat consensus on what strength is required before opening concrete repairs to traffic to assure adequate long-term performance. .4.1.1 Key points to consider are: ♦ Minimum compressive strength ♦ Minimum flexural strength ♦ Accepted ranges Key questions that may be asked are: ♦ What requirements have you used for opening to traffic? ♦ What was the basis for that requirement? ♦ How has it worked?

Module 4-7
Slab Stabilization & Slab Jacking

Objective	Activity
1. State the purpose for and discuss the importance of slab stabilization.	Where pumping has occurred and slab support is lost distresses such as joint faulting and corner brakes will develop. Slab stabilization has been use to extend the service life of the pavement when this occurs. Key point to consider are: • Pumping • Faulting • Corner cracking Key questions that may be asked are: • Do you experience any of these deficiencies in your PCC pavements? • Have you used slab stabilization? • Can you describe the projects? • How has it worked?
2. Describe the cement grout mixtures and asphalt cements that have been used for slab stabilization and slab jacking and the problems associated with the use of each.	The most comment materials used in conventional slab stabilization are asphalt cement and cement grouts. .5 Key points to consider are: • Asphalt cement • Cement grout mixtures Key questions that may be asked are: • What materials have you used? • How did you control the material used? • How did it perform?
3. Describe procedures for performing slab stabilization, including how to locate areas that need slab stabilization, typical hole patterns, and how to determine if slab stabilization has been effective.	Slab stabilization should only be performed at joints and working cracks where loss of support is demonstrated by in-situ deflections testing. Key points to consider are: • Visual distress survey • Deflection tests • Hole location Key questions that may be asked are: • Have you used slab stabilization? • Can you describe your procedure? • Has it been effective?
4. List the typical construction procedures for	Both slab stabilization and slab jacking require

slab stabilization and slab jacking.	very specific construction requirements to be effective. Key points to consider are: • Hole pattern • Mix design • Grout injection • Slab stabilization Slab jacking Key questions that may be asked are: • Have you used either slab stabilization jacking? • Can you describe the construction procedures you used? • Can you give examples? • How has it performed?

Module 4-8
Diamond Grinding and Grooving

Objective	Activity
1. Differentiate between diamond-grinding and grooving, and describe the objectives of each.	Diamond grinding and grooving are two different forms of surface restoration used to correct various rigid pavement surface distresses. Key points to consider are: • Diamond blade grinding • Diamond blade grooving Key questions that may be asked are: • Have you used either diamond grinding or grooving? • Can you describe why you used either treatment? • How did it work?
2. List existing pavement conditions for which diamond-grinding of a jointed concrete pavement surface may be beneficial.	Diamond grinding has been used to correct many surface distresses. Key points to consider are: • Joint and crack faulting • Wheel path rutting • Permanent slab warping • Texturing of polished concrete surface • Improve pavement cross slope for drainage Key questions that may be asked are: • What types of surface distress have you used diamond grinding to correct? • Can you describe specific examples? • How successful was it?
3. Describe conditions under which grooving of a pavement surface would be beneficial in reducing wet weather accidents.	Pavement grooving is an effective means of improving surface friction. Key points to consider are: • Improved macrotexture • Channels for water to escape • Reduced hydroplaning • Skid resistance. Key questions that may be asked are: • Have you used pavement grooving here? • Can you describe the projects. • Did it reduce the wet weather

	accident rate where used?
4. Be familiar with the uses of cold milling equipment for PCC pavement restoration.	Carbide grinding has been gaining wider acceptance as a rehabilitation method for rigid pavements.

Module 4-9
Load Transfer Restoration

Objective	Activity
1. Identify the problems that can be addressed through the use of load transfer restoration devices.	Load transfer restoration is the installation of a device at transverse joints and cracks in order to transfer loads and reduce deflections and pumping. Key points to consider are: • Deflection load transfer • Deflection stress transfer Key questions that may be asked are: • What problems can load transfer restoration address? • How does LTR reduce critical load induced stress? • How does this extend service life?
2. Understand the techniques available for determining the need for load transfer restoration.	Heavy load deflection testing devices capable of simulating slab bending caused by traffic loads should be used to obtain deflection data to determine load transfer needs. Key points to consider are: • Deflection testing • Load transfer ratios. • Load Deflection intercept Key questions that may be asked are: • How do you determine if LTR is needed? • Have you constructed a LTR project? • How did you determine if LTR was needed?
3. Describe procedures for properly installing load transfer restoration devices.	The installation of retrofitted dowel bars is a relatively simple procedure, however it is very laborious and expensive in that it involves a time-consuming process of cutting and preparing slots. Key points to consider are: • Cut slots • Prepare slots • Place dowel bars • Fill slots • Grind pavement

	Key questions that may be asked are: • Have you constructed any LTR project? • What construction procedures did you follow? • How did it work?

Module 4-10
Shoulder Rehabilitation Considerations

Objective	Activity
1. List the common distress types associated with bituminous and PCC shoulders adjacent to PCC mainline pavements.	Because of their reduced structural capacity, shoulders can often deteriorate rapidly due to encroaching and parked traffic. Key points to consider are: • Traffic loading • Structural distress • Deferential movement Key questions that may be asked are: • Have you experienced any problems with shoulders next to PCC Pavement? • What were those problems? • What caused the problem?
2. Discuss procedures applicable to shoulder rehabilitation, and describe how the extent of deterioration of a shoulder can influence not only shoulder rehabilitation strategy selection, but also the rehabilitation of the mainline PCC pavement.	It is generally recommended that mainline rigid pavement have shoulder of like material. Key points to consider are: • General recommendations on table 4-10.1 Key questions that may be asked are: • How has your pavements performed where ACP shoulders used with PCC mainline pavement? • Has the condition of the shoulders affected the PCC mainline pavement? • Have you replaced the ACP shoulder next to PCC pavement mainline with a PCC shoulder?
3. Describe the contributions that a tied PCC shoulder can have on the performance of the mainline PCC pavement.	A tied PCC shoulder can provide additional lateral support to the adjacent PCC mainline pavement thus reducing deflections and edge stresses. Key points to consider are: • Increased edge support • Reduced edge stress • Improved crack sealing Key questions that may be asked are: • Have you reconstructed an ACP shoulder with a PCC shoulder? • What was the purpose of the project?

	• How has it performed?

Module 4-11
Retrofitted Edge Drains

<table>
<tr><th>Objective</th><th>Activity</th></tr>
<tr><td>1. Identify the sources of water in pavement systems.</td><td>An understanding of the potential sources of water is fundamental to the decision to retrofit subdrainage and to design a drainage system.

Key points to consider are:
Seepage from higher ground
Groundwater table
Surface infiltration through joints and cracks
Capillary movement of water
Vapor movement
Key questions that may be asked are:
What is the primary source of water in pavements?
Does this fit with your experience.
What are possible secondary sources?</td></tr>
<tr><td>2. Name and identify the function of the major components of subdrainage systems.</td><td>Pavement subdrainage systems may be grouped into three general categories based on their geometry, longitudinal drains, transverse drains and permeable bases.

Key points to consider are:
Collection system
Filters
Outlets
Key questions that may be asked are:
What are the major components of a drainage system?
What are their functions?</td></tr>
<tr><td>3. Discuss the criteria for selection of a filter system (fabric or granular).</td><td>There are specific procedures available to design the backfill/filler to ensure that the drainage feature does not become clogged with fines.

Key points to consider are:
Filter durability
Filter criteria
Filter orientation
Key questions that may be asked are:
What is the purpose of a drainage filter?
What may cause it to fail?
How do you design the filter?</td></tr>
</table>

4. List the basic subdrainage design steps.	Subdrainage design steps determines the basic pipe size and configuration. Key points to consider are: • Drainage survey and evaluation • Longitudinal pipe sizing, grade, and outlet spacing • Pipe outlets • Backfill/filter material Key questions that may be asked are: • Can you describe the subdrainage design process? • Have you performed a subdrainage design? • What did you learn from that process?

Module 4-12
Recycling

Objective	Activity
1. Identify conditions when PCC recycling may be considered as part of a reconstruction project.	There are a verity of conditions that may indicate the need for reconstruction of the existing rigid pavement. Key points to consider are: • Little or no remaining structural life • Extensive joint deterioration • Extensive concrete deterioration • Outdated geometric design Key questions that may be asked are: • What conditions may indicate a need for pavement reconstruction? • Have you reconstructed a PCC pavement for any of these reasons? • Did you recycle the PCC as part of that reconstruction?
2. Identify potential benefits of concrete recycling and the potential uses of recycled concrete aggregate (RCA) in pavement reconstruction.	Rigid pavement recycling produces an aggregate that may be used in the reconstruction of the pavement> Key points to consider are: • Benefits of concrete recycling • Potential uses of recycled concrete Key questions that may be asked are: • Have you recycled PCC in this area? • What are the potential benefits of recycling PCC that you considered in this area? • What was the recycled PCC used for?
3. Describe the steps in the PCC pavement recycling process.	The basic steps that constitute PCC Pavement recycling follow a fairly standard process. Key points to consider are: • PCC demolition and removal • Crushing • Steel removal • Sizing Key questions that may be asked are: • Can you describe the basic PCC recycling process? • Can you give local examples of this process?

	• Was the resulting material satisfactory for its intended use?
4. Discuss the properties of recycled concrete aggregate and PCC mixtures containing recycled concrete aggregate, and how those properties affect their potential applications.	Typical properties of RCA are different than the virgin material and the differences are summarized in table 4-12.2. Key points to consider are: • Particle shape and texture • Absorption capacity • Specific gravity • Abrasion and soundness Key question that may be asked are: • How is RCA different from virgin aggregate? • Has the ACP and PCC mix design changed when you used RCA? • Can you describe the differences and give examples?

Module 4-13
PCC Overlays

Objective	Activity
1. List the types of PCC overlays.	A variety of rigid pavement overlays are used on existing pavements, depending upon the type of existing pavement and the proposed bonding condition between the rigid overlay and the existing pavement. Key point to consider are: • Table 4-13.1 Summary of rigid pavement overlay types Key questions that may be asked are: • Which of the overlays listed in table 4-13.1 have you used here? • How did you choose which type of overlay to use?
2. Discuss the importance of the bonding condition for each PCC overlay type.	The bonding condition between the new rigid overlay and the existing pavement rigid pavement is a primary design concern for rigid overlays of existing rigid pavements. Key points to consider are: • Bonded • Partially Bonded • Unbonded Key questions that may be asked are: • Can you describe where each type of bonding condition should be used? • Can you give examples from past or current projects in this area?
3. Identify the conditions for which each PCC overlay type is best suited and is most cost-effective.	In determining the suitability of a rigid pavement for an existing pavement, a detailed evaluation of the pavement must be performed. Key points to consider are: • Review Figure 4-13.4 The spectrum of pavement rehabilitation alternatives. Key questions that may be asked are: • How do you determine when a bonded or a unbonded rigid pavement overlay is most appropriate? • Can you give specific examples from projects in this area?

	• Have you used a bonded overlay on a pavement which had experienced extensive distress? • If you have how did the overlay perform?
4. Recognize the different design methodologies for PCC overlays.	There is no universally accepted design procedure for rigid overlays. Key points to consider are: • Engineering Judgment • Structural Deficiency • Mechanistic Fatigue Damage Approach Key questions that may be asked are: • Which design procedure have you used to design rigid overlays? • How confident were you in the results?
5. Describe the level of preoverlay repair required for each PCC overlay type and its relative importance.	The amount of repair and treatment that is perform pavement prior to receiving a rigid overlay can be a factor in influencing the future performance of the overlay, particularly for bonded rigid overlays. Key points to consider are: • Type of overlay • Structural adequacies of the existing pavement • Distress type exhibited by the existing pavement • Future traffic loadings • Physical constraints such as traffic control • Overall combined costs Key questions that may be asked are: • What pre overlay treatments have you used on your projects? • Were their cost a significant part of the project? • How did the work?

Module 4-14
HMA Overlays

Objective	Activity
1. List the functional and structural deficiencies that can be corrected with properly designed HMA overlays.	Hot mixed asphalt overlays are used to correct both functional and structural deficiencies in rigid pavements. Key points to consider are: • Functional deficiencies 3.1 Polishing of the surface Roughness Cross slope Noise / surface texture • Structural deficiencies 3.1 Deteriorated cracks Corner and transverse cracking Punchouts Key questions that may be asked are: • What rigid pavement deficiencies have you treated with HMA overlays in this area? • How has it worked?
2. Describe the conditions that affect the performance of an HMA overlay.	The potential service life of a HMA overlay of a rigid pavement depends upon many factors. Key points to consider are: • Condition of the rigid pavement • Structural adequacy • Material deterioration within the pavement • Climate • Subdrainage adequacy • Presence of swelling soils Key questions that may be asked are: • How have your HMA overlays of rigid pavements performed? • Can you attribute any short service to the factors just discussed? • Can you give some specific examples from this area?
3. List the causes of reflection cracking.	Reflection cracking is a result of horizontal and vertical movements at the joints and cracks in the underlying pavement that create high stress concentrations in the overlay. Key points to consider are: • Low temperature

	• Traffic loads Key questions that may be asked are: • Can you describe the mechanical processes that causes reflection cracking. • Can you provide any examples?
4. Discuss the various treatments that have been used to reduce reflection cracking and their relative effectiveness.	A number of techniques have been tried in order to reduce the rate or severity of reflection cracking. Key points to consider are: • Fabrics • Stress relieving interlayers • Crack arresting interlayers • Pre-overlay treatments • Slab repair and replacement reflection crack severity control • Increased overlay thickness .1 Key questions that may be asked are: • Have you tried any of these treatments? • Can you give any local examples? • How did they perform?

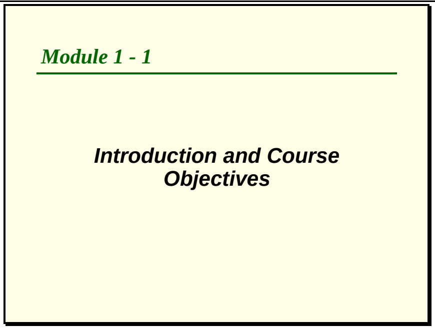
Module 4-15
Identification of Feasible Alternatives

Objective	Activity
1. Recognize the importance of an overall framework for the identification of feasible PCC pavement rehabilitation alternatives.	Decision tables or trees have been developed that provide a general framework for developing the appropriate strategy by matching distress with possible repairs. Key points to consider are: • Table 4-15.1 Key questions that may be asked are: • Have you used decision aids in determining possible treatments? • Can you give some examples?
2. Describe what a decision tree or chart is and how it is developed and used.	Decision trees can be thought of as flow charts, they are a graphical representation that is assembled to represent the logic in a decision making process. Key points to consider are: • Distress mechanisms • Feasible alternatives Key questions that may be asked are: • Do you use decision trees and can you give an example? • How does it work for you?
3. Describe the limitations and potential problems that are associated with the strict use of a decision tree.	Decision trees have their limitations, which should always be considered when they are used. Key points to consider are: • Issues in module 3-11 • Need to be updated • Aid in selecting treatments not a strict rule. Key questions that may be asked are: • What are the potential limitations in using decision trees or tables? • Can you provide local examples?

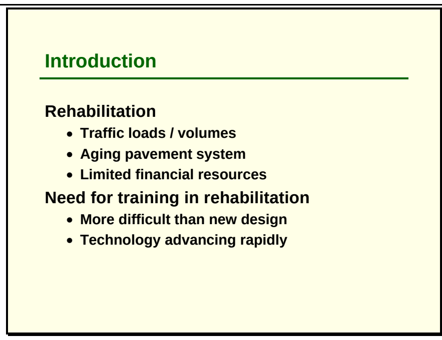
Module 5-1
Selection of the Preferred Rehabilitation Alternatives

Objective	Activity
1. Describe the importance of developing alternative rehabilitation designs.	There is always more than one alternative rehabilitation design available for a given project It is desirable to select the preferred alternative from several possible treatments and not be limited to just one alternative which may not meet all needs. Key points to consider are: • Selected alternative should be cost effective • Selected alternative should address specific pavement related problems • Selected alternative should meet any existing project constraints. Key questions to consider are: • Do you consider multiple alternatives in you rehabilitation design process? • Can you provide specific examples? • What were the benefits of considering multiple alternatives for the project?
2. List the eight major steps required for rehabilitation selection and design.	The recommended approach to the development and selection of the preferred rehabilitation design consists of eight specific steps. Key points to consider are: • Review the eight steps described in section 5-5. Key questions that may be asked are: • Can you describe the basic steps that your agency used in developing a rehabilitation design for a project? • Do you usually follow all of the steps? • How does the process work for developing the best available strategy for each project?
3. List and briefly describe the major factors that should be used in deciding among alternative rehabilitation designs.	The final preferred alternative may not be the best or optimum strategy rather the preferred alternative will be the one that best addresses the needs of the pavement while meeting all functional, structural, and monitory constraints that exist for the project.

	Key points to consider are: • Overriding factors or constraints Limited funding Staged construction Traffic control requirements Limited life of project Future maintenance requirements Geometric problems and constraints Right of way restrictions Regulation restrictions Key questions that may be asked are: • What kind of constraints do you find on your local projects? • What are your most common constraints? • How does this effect the selected treatment?
4. List the benefits of conducting a life-cycle cost analysis to determine the total cost of various pavement rehabilitation alternatives major cost items related to both the highway agency and the users that should be considered in a life cycle economic analysis.	There are very specific items covered in a lifecycle cost analysis for highway facilities particularly for the pavements. Key points to consider are: • Costs to the highway agency Initial rehabilitation construction Future maintenance and rehabilitation Future salvage value • Costs to the highway user 3.1 Traffic delay costs Vehicle operation costs Accident costs Discomfort costs Damage goods costs Key questions that may be asked are: • What specific costs do you consider in you lifecycle cost analysis on paving projects. • Where do you get the costs for the various items?

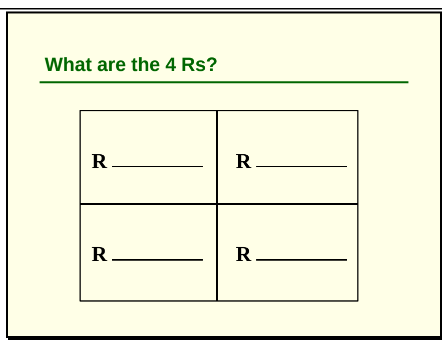


Begin Module 1-1



Discuss factors influencing increase in rehabilitation needs:

- Why the need for rehab training?



Explain the 4Rs:

1. Restoration
2. Resurfacing
3. Recycling
4. Reconstruction

Evolution of 4R / TFPR Course **Since 1980** • Over 160 presentations • Over 5,000 participants • NHI's most popular course **Six Editions** • 1980 • 1982 • 1984 • 1987 • 1993 • 1998	Explain evolution of training course: 1. Statistics Six editions-1980
Course Objectives **Overall -** Provide assistance in developing the best rehabilitation alternatives **Specific** • Describe typical performance • Recognize common distress types and their causes • Be familiar with field surveys • Describe design considerations and processes	Objective – steps in developing rehabilitation alternatives: 1. Typical pavement performance 2. Distress types & causes 3. Field surveys 4. Design types & methods (continued on next slide)
Course Objectives **Specific** • Recognize principles and importance of proper preparation of existing pavement • Develop, evaluate and select the most cost-effective 4R alternative • Identify better types of rehabilitation	Continued Objectives: 5. Preparation of existing pavement for 3R techniques 6. Developing & selecting cost-effective alternatives 7. Best rehabilitation techniques

Course Organization

1. Introduction and Course Objectives
2. Project Survey and Evaluation
3. Flexible Pavement Rehabilitation Techniques
4. Rigid Pavement Rehabilitation Techniques
5. Selection of the Preferred Alternative
6. Workshops on 4R Project Design

Course Organization – 6 blocks:

1. Introduction & course objectives
2. Project survey & evaluation
3. Flexible pavement rehab techniques
4. Rigid pavement rehab techniques
5. Selection of preferred alternative
6. Workshops on 4R project design

Steps In The Rehabilitation Process

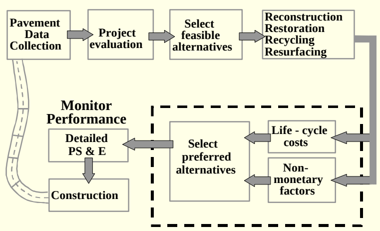


Diagram of the various stages in the design & construction of rehabilitation projects

Other Related NHI Courses

(13127) Pavement Deflection Analysis

(13126) Pavement Subsurface Drainage Design

(13129) AASHTO Pavement Overlay Design

(13130) Pavement Analysis and Design Checks

Describe other NHI Courses:

1. Pavement deflection analysis
2. Pavement subsurface drainage design
3. AASHTO pavement overlay design
4. Pavement analysis and design checks

NHI Warehouse Course Catalogs Participant's Manuals Phone: (301) 577-0818 Fax: (301) 577-1421	Information about NHI warehouse: 1. Course catalogs 2. Course manuals 3. Contact numbers Participant's Manuals for all courses are provided free to individuals that call and request (1 copy)
Summary Introduction / Background Course Objectives Course Organization Other NHI Courses	Review/summarize key points: 1. Introduction 2. Objectives 3. Organization 4. Other courses

Module 2-1 ***Pavement Types***	Begin module 2-1
Objectives **Understand role of each pavement layer** **Identify factors that affect performance** **Identify pavement classifications / types** **Describe characteristics** **Describe typical performance and distress mechanisms**	Participant will identify & understand: 1. Purpose of each pavement layer 2. Key pavement performance factors 3. Pavement classifications/types 4. Pavement characteristics 5. Typical performance & distress mechanisms
Definitions **Distress (manifestation)** **Mechanism**	Definitions: 1. Distress – Some observable, measurable manifestation of a poor pavement condition 2. Mechanism – Set of physical conditions and/or mechanical processes that leads to particular types of distress

Introduction

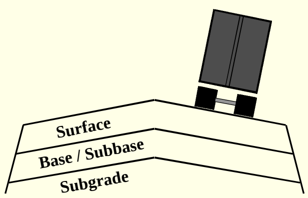
Categories (classifications)

- Flexible
- Rigid
- Composite

Describe pavement types:

1. Flexible
   – HMA, BST
2. Rigid
   – JPCP, JRCP, CRCP
3. Composite
   – HMA/Rigid, Rigid/HMA

Role of Pavement / Soil Layers



Function of pavement layers:

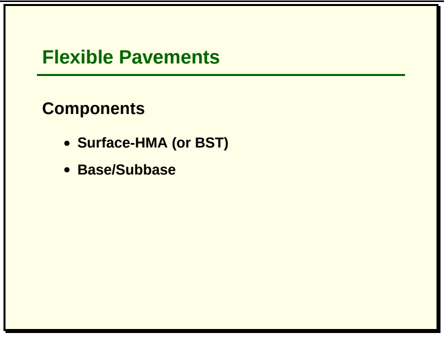
1. Surface (structural layer)
   – Tough to resist distortion, smooth riding surface, waterproof & sloped, resist wear, anti-skid
2. Base/Subbase (structural layer)
   – Help distribute wheel load over subgrade
3. Subgrade (not structural layer)
   – Carries all load from traffic

Factors Affecting Pavement Performance

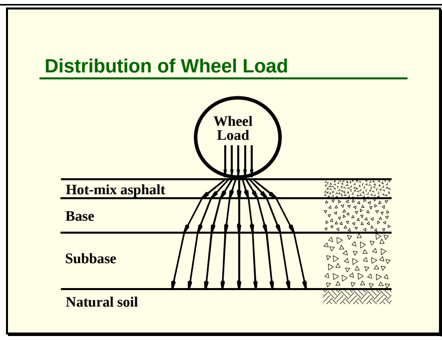
Traffic
Subgrade soil support
Materials of construction
Structural characteristics
Construction and maintenance variation
Moisture
Maintenance / rehabilitation programs

Discuss pavement performance factors:

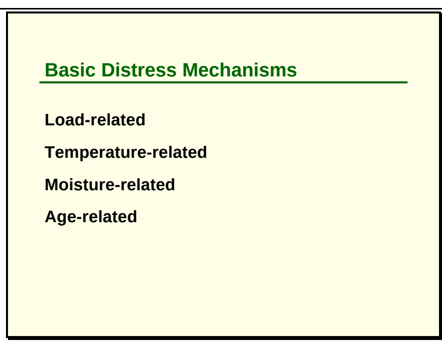
1. Traffic loading- (Module 2-5)
2. Subgrade-classification & strength
3. Materials-asphalt, Portland cement, aggregate, water, additive, steel
4. Structural characteristics- are no. & thickness of layers, joint spacing & geometry, load transfer
5. Variation-control with specs
6. Moisture-attention to drainage
7. M&R programs-maintenance preserves pavement life; rehab extends



Define components of a flexible pavement structure

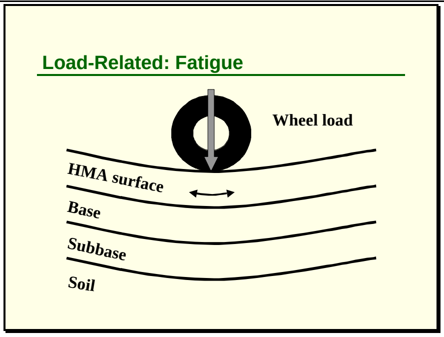
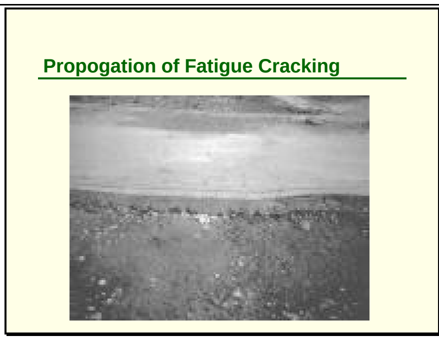
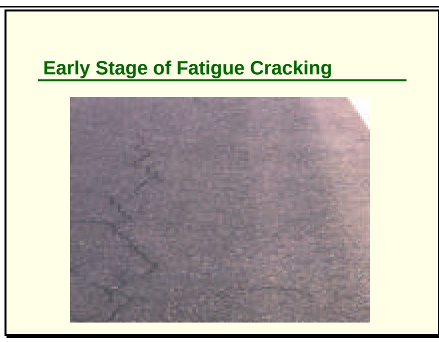


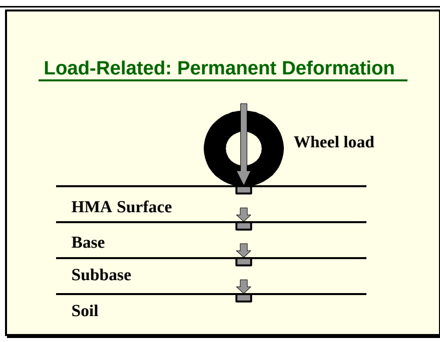
Explain how each layer distributes the wheel load through flexible pavement



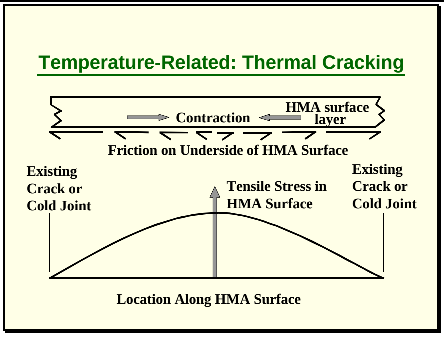
Distress Mechanisms:

1. Load--fatigue & permanent deformation
2. Low temperature--thermal cracking, frost heave; High temperature--permanent deformation
3. Moisture--strength loss, stripping, & intrusion of fines
4. Age--oxidation

	Distress Mechanism - Fatigue: 1. Load causes bending in each layer 2. Develops tensile strain at bottom of surface layer 3. Tensile strain > tensile strength of surface = crack 4. Repeated load causes crack to propagate from bottom of surface layer to the surface
	Example of cracks propagating from bottom to surface: 1. Surface will not likely exhibit same extent of cracking as bottom of layer 2. Important when considering amount of area to patch prior to an overlay
	Low to moderate fatigue cracking in the wheelpath: 1. Forms as intermittent longitudinal cracks in the wheelpath

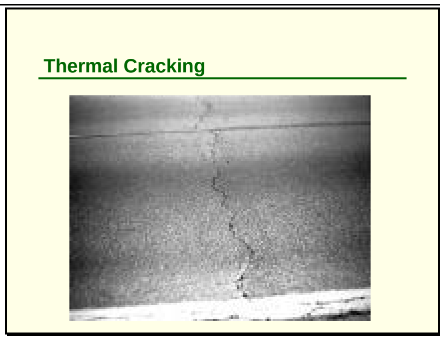
	Moderate fatigue cracking over a large extent of the pavement area: 1. Short sections of longitudinal cracks join & start forming alligator crack pattern in the wheelpath
	High severity fatigue cracking covering approximately 100% of the wheelpath area: 1. Large areas of cracking have formed in the typical alligator/chicken wire pattern 2. Individual cracks have widened & spalled
	Permanent deformation (rutting) 1. Caused by compressive load on each layer 2. Material & thicknesses should control or limit maximum strains to underlying layers 3. Approach is component analysis; (AASHTO Design Guide) 4. Ruts increase hydroplaning (safety)

	Example of typical rutting at stop bar
	Example of severe rutting at stop bar at road intersection: – Always more pronounced where trucks move slowly or stop
	Example of dual tire rutting: – Note lift & shoving of mix along edge of rut – Pattern indicates that rutting is occurring in top 2-3 inches of HMA – This section’s HMA was found to have 0.5% too much AC

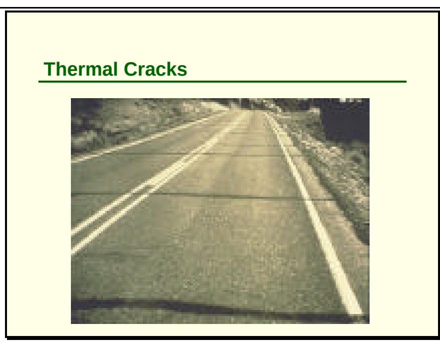


Development of thermal cracking:

1. Forces acting on HMA as it undergoes a temperature drop
2. HMA tensile stress>HMA strength
3. Tensile stress reaches a maximum between two existing cracks (cold joints)
4. Thermal crack develops at the mid-point

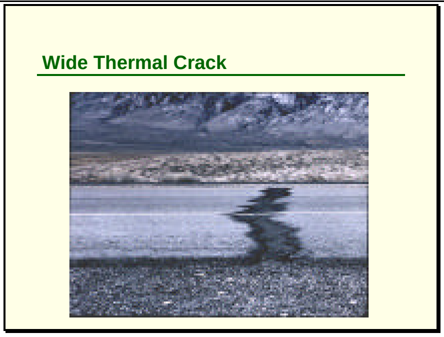


Example of typical thermal crack



Example of thermal cracks:

1. Typical uniform spacing as discussed previously

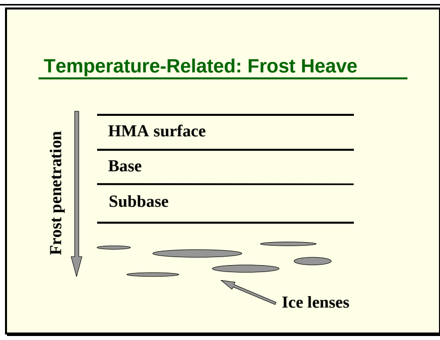


High severity thermal crack:

1. Approx. 200mm wide
2. Unique but do occur
3. Materials & environment

In this case, AC has:

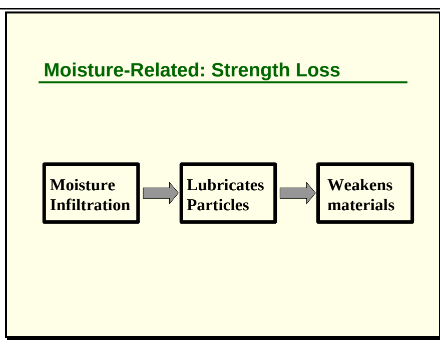
1. High temp. susceptibility; high tensile strength; subjected to severe temperature drops



Explain process of frost-heave:

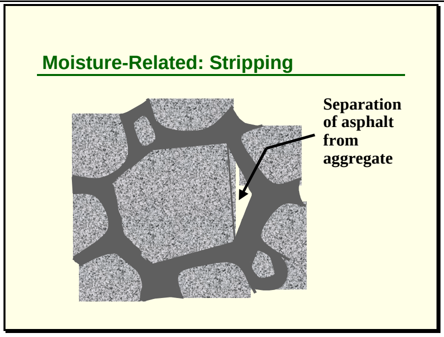
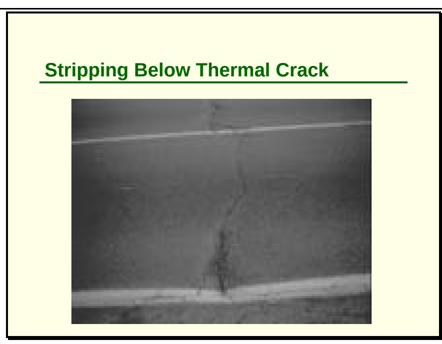
1. Freezing temperatures penetrate structure
2. Moisture collects
3. Ice lenses develop & grow
4. Pavement surface rises vertically

In many cases, frost heave occurs uniformly; if non-uniform occurs then poor ride quality results

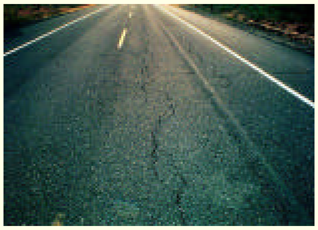


Any increase in moisture above optimum decreases soil strength:

1. May be caused by
   – High rainfall, thawing frozen soil, or rising water table

	Explain stripping process: 1. Moisture-susceptible HMA is exposed to high moisture conditions over long period 2. Moisture infiltrates from above; (can infiltrate from below due to capillary action of water table) 3. Due to inherent chemistry, some aggregates are better strippers
	Example of HMA core that exhibits severe stripping: 1. Note the absence of asphalt on larger rocks
	Example of stripping: – Distortion of transverse crack indicates probable stripping of HMA near crack

Oxidized HMA Surface Layer



Example of a heavily oxidized pavement:

1. Prolonged exposure of asphalt (bitumen) to sun
   – Lose its aromatics, become stiffer, more susceptible to cracking
   – Block & fatigue cracking

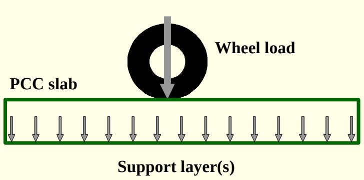
Rigid Pavements

Components
- Surface - PCC
- Base / Subbase
- Reinforcement
- Joints (configuration)
- Load transfer devices

Discuss key components:

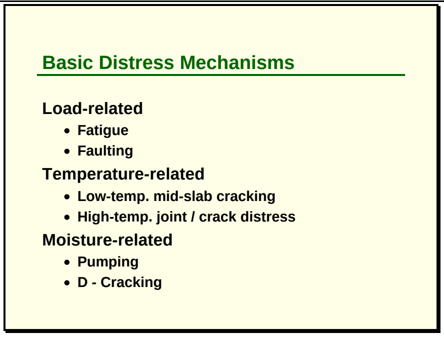
1. PCC Surface
   – Bending of slab
2. Base/Subbase
   – Maintain uniform support of slab
   – Minimize any moisture damage
   – Additional layer against frost penetration
3. Reinforcement
   – Keeps midslab cracks closed
   – Does not carry load stresses
4. Joints (configuration)
   – Allows horizontal movement to alleviate expansive & contractive stresses
5. Load Transfer Devices
   – Transfers wheel loads from one side of joint (crack) to other
   – Steel dowel bars at mid-depth across transverse joint

Distribution of Wheel Load

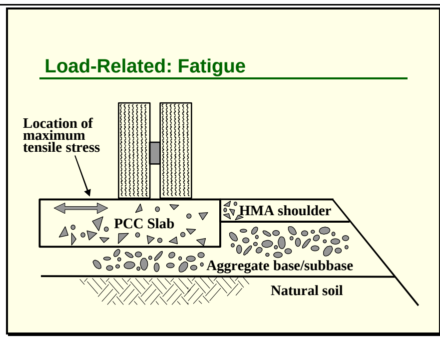


Distribution of wheel load:

1. Rigidity distributes load more uniformly over underlying support layers

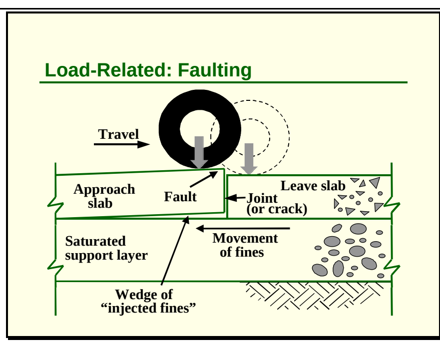


Describe distress mechanisms



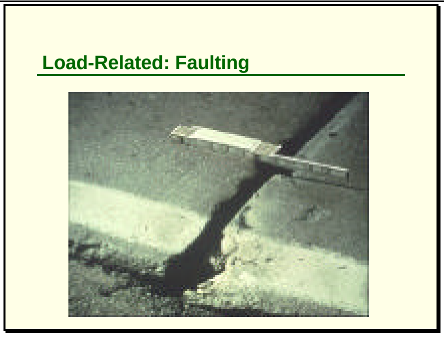
Load related fatigue cracking:

1. Maximum stress occurs at edge of pavement in middle 1/3 of slab
2. Typical fatigue crack occurs as transverse crack in middle 1/3 of slab



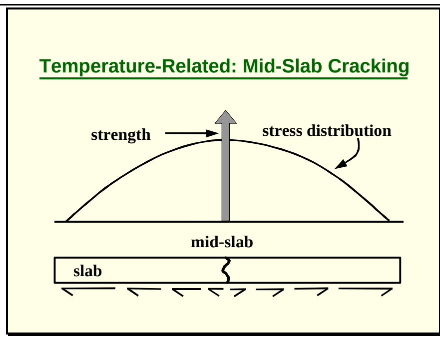
Load-related faulting

1. Develops over time as fines are ejected from beneath leave slab & deposited under approach slab
2. Wedge of injected fines under approach slab lifts approach slab causing fault to develop



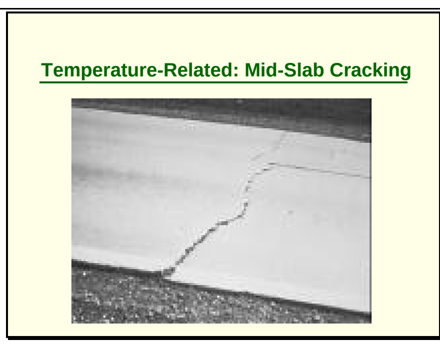
Example of typical load-related faulting

- End of slab is lifted by wedge of fines built up over time & repeated wheel loads



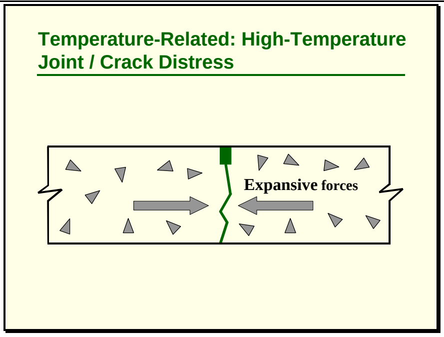
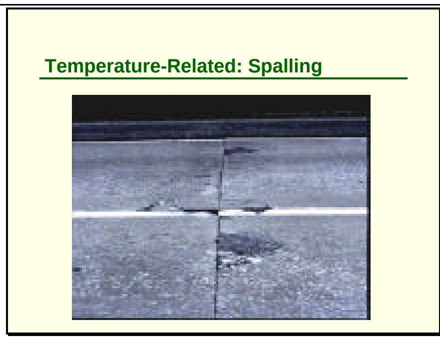
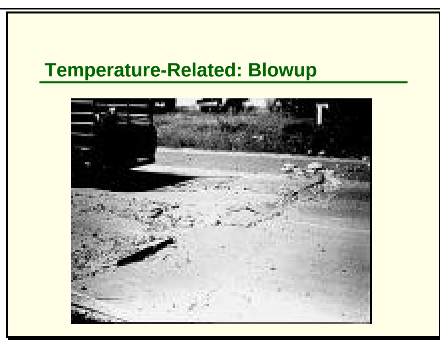
Mid-Slab Cracking:

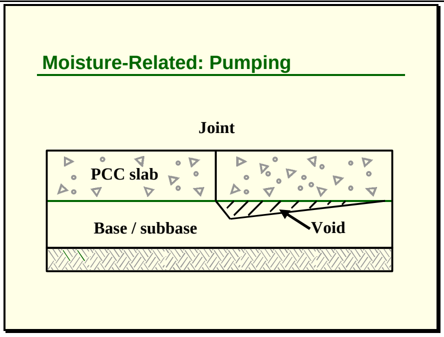
1. Tensile stress>slab strength, crack develops
   - Can occur without traffic loading
2. Slab undergoes temperature drop, tries to contract
3. Contraction restrained by friction along underside of slab
4. Almost identical to mechanism which causes thermal cracking in flexible pavements



Severely faulted mid-slab crack:

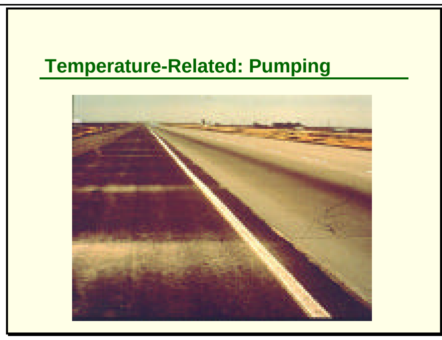
- Probably a JPCP that has no reinforcement to hold crack together

	Joint/Crack Distresses: 1. Associated with thermal expansion as it undergoes an increase in temperature 2. Expansive forces can cause spalling at joints or cracks, joint crushing, and blowups
	Example of severe spalling at joint caused by compressive forces
	Example of blowup and some joint crushing caused by high compressive forces

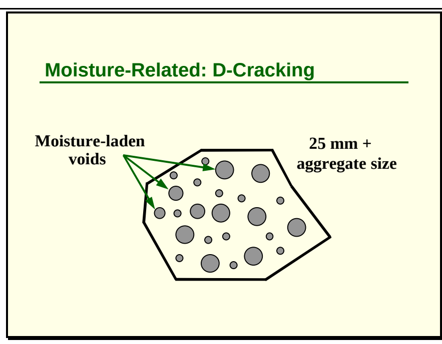


Pumping:

1. Similar to faulting mechanism
2. Primary difference is ejected materials pump up through joint or along slab edge and onto pavement
3. Progression leads to voids under leave slab
4. This loss of support develops corner breaks



Example fines pumped from beneath the ends of the slab that are ejected onto the shoulder surface

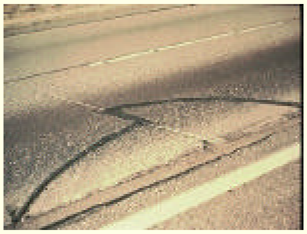


Durability Cracking:

1. Both moisture & temperature related mechanism
2. Conditions that encourage D-cracks
   - Significant freeze/thaw environments
   - Prolonged moisture exposure
   - Pavement built with porous aggregates (fill with water)
   - Temperatures drop, moisture in aggregates freeze & cause expansive forces that gradually deteriorate slab

Moisture-Related: D-Cracking 	Example of severe D-Cracking at transverse joint – Note D-cracking forming around joints or cracks where water is most available
Rigid Pavement Types JPCP JRCP CRCP Pre-stressed concrete pavement	Describe rigid pavement types: 1. JPCP-jointed plain concrete pavement 2. JRCP-jointed reinforced concrete pavement 3. CRCP-continuously reinforced concrete pavement 4. Pre-stressed (not covered here)
Jointed Plain Concrete Pavement No steel mesh Joint spacing: 4 to 7 m Slab thickness: 200 to 400 mm Contraction joints: with and without dowels Granular or stabilized base	Characteristics of JPCP-self explanatory

Jointed Plain Concrete Pavement



Example of JPCP:

1. Corner breaks on both sides of joint
2. Typical for JPCP
3. Usually caused by loss of support from pumping of fines beneath the slab

Jointed Reinforced Concrete Pavement

Steel mesh: 0.1 to 0.2% of cross-sectional area

Joint spacing: 7.5 to 30 m

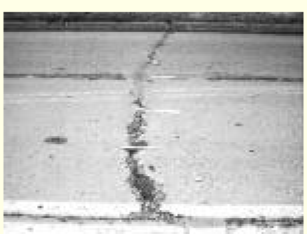
Slab thickness: 150 to 400 mm

Contraction joints with dowels

Granular or stabilized base

Characteristics of JRCP (compare to JPCP)

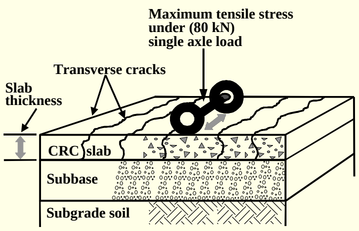
Jointed Reinforced Concrete Pavement

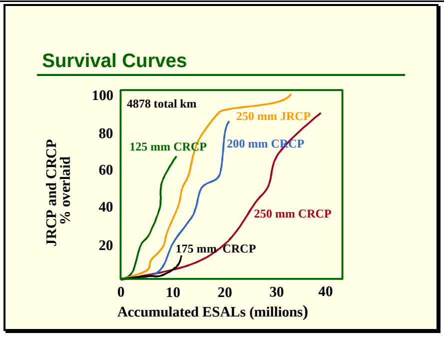
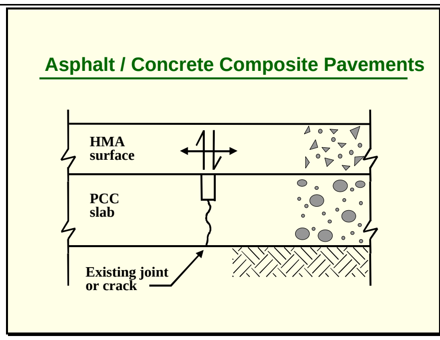
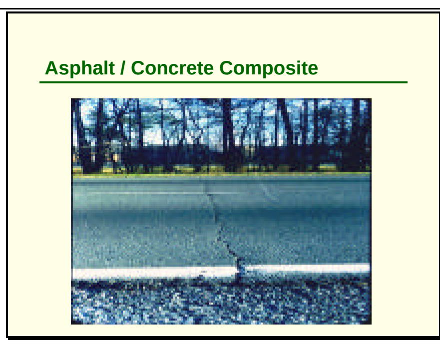


Example of JRCP mid-panel crack:

1. Caused by a combination of warping & tensile stresses exceeding the tensile strength
2. The 0.1 to 0.2 % reinforcement is used to hold the mid-panel cracks together

In this case, stresses were so great that not just cracks developed, but steel ruptured and developed severe spalling

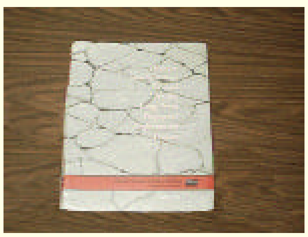
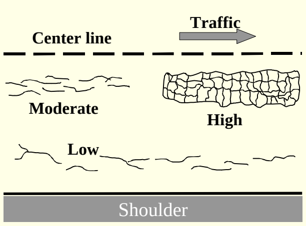
Continuously Reinforced Concrete Pavement **Reinforcement: 0.5 to 0.8% of cross-sectional area** **Slab thickness: 200 to 400 mm** **Granular or stabilized base**	Characteristics of CRCP-self explanatory (compare to JRCP)
CRCP Cutaway  	Describe typical loading of CRCP Cutaway: 1. Transverse cracking forms a series of transverse beams 2. Applied axle loads cause tensile stresses within the individual beams 3. Repeated loading causes longitudinal crack to form between the transverse cracks in the CRCP slab
CRCP Punchout 	Example of CRCP punchout: 1. Heavy repeated loading and free water beneath slab 2. Causes pumping, erosion and loss of support 3. Leads to breakdown of transverse cracks 4. Eventually punchout (structural deterioration)

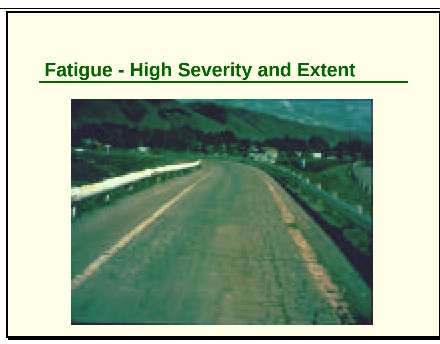
	Performance of CRCP and JRCP in several Midwestern states: 1. CRCP outperforms JRCP
	Describe composite pavements: 1. Usually HMA overlay/PCC pavement 2. Performance affected by joint movement of PCC slab underneath 3. Movements can be horizontal & vertical 4. This sets up tensile & shear forces which can cause reflection cracking in HMA surface
	Example of moderate severity reflection crack in composite pavement

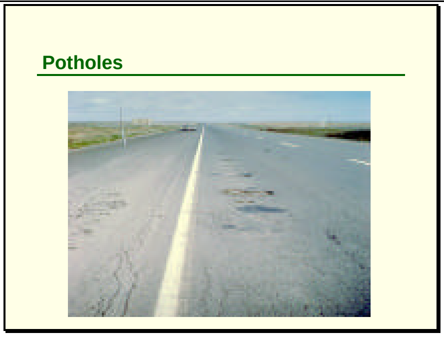
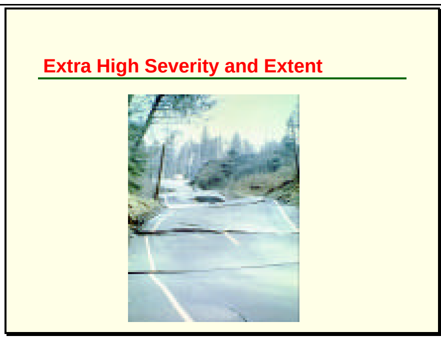
Summary Role of each pavement layer Factors that affect performance Three pavement classifications • Five types • Characteristics • Typical performance • Basic mechanisms	Review/ summarize key points in this module

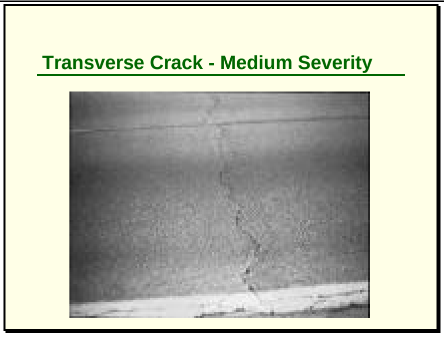
Module 2-2 ***Condition Data Collection and Processing***	Begin Module 2-2
Objectives Describe factors that characterize distress List field procedures for distress survey Describe roughness measurement Describe roughness survey equipment Describe friction measurement	Assess Pavement Condition: 1. Distress surveys (primary emphasis) 2. Road roughness surveys 3. Surface friction surveys
Definitions Pavement condition Pavement distress Pavement roughness Pavement surface friction	Definitions of pavement condition (does not refer just to distress): 1. Distress 2. Roughness 3. Surface friction

Condition Survey Overview Essential to identify feasible maintenance and rehabilitation alternatives Involves distress, roughness, and friction Functional vs. structural performance	Discuss Pavement Condition Surveys: 1. How it is used 2. Essential data 3. Importance
Utility Identify repair locations and quantities Quantify variations in condition Document existing condition Identify additional testing needs Determine causes and mechanisms of deterioration	Uses for condition surveys: 1. Repairs 2. Variations 3. Existing condition 4. Testing needs 5. Causes of deterioration
Distress Surveys Characterization of distress by • Type • Severity • Extent	Explain distress characteristics: 1. What types 2. Severity levels 3. How much

Distress Identification Manual **Benefits** • Consistent definitions • Standardized • Calibration **Degree of sophistication** • LTPP (research oriented) • Project Level (design oriented)	Project level evaluation--distress data collection are preferred & common. Distress identification manuals insure surveyors & data are: 1. Consistent 2. Standardized 3. Calibration Degree of sophistication can vary: 1. Research (LTPP) Distress Identification Manual too much detail for project level 2. Manual used should be oriented toward rehab design
Distress Identification Manual 	Example of SHRP DIM: Research oriented but good for starting point to develop own project-level distress identification manual
Fatigue Severity  	Example from DIM showing how distresses are defined by severity levels

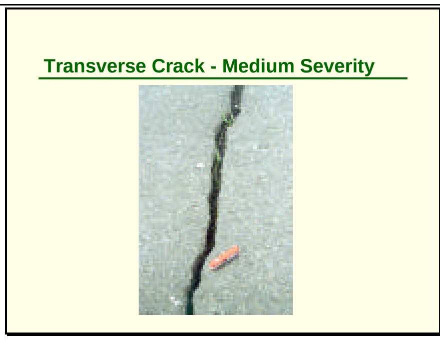
	Example of low severity fatigue: 1. Load related distress – Longitudinal cracking in wheelpath
	Example of moderate severity, high extent fatigue: 1. Measurement of extent will help in estimate of patching required 2. Would a thin HMA overlay be a feasible alternative for this project?
	Example of high severity and high extent fatigue: 1. Almost 100% of pavement area 2. When condition this bad, condition survey is easier 3. Interpretation of data easier because many typical rehab treatments are eliminated

	Example of Potholes: 1. Form as alligator cracked pavement breaks into pieces & is picked up or kicked out by traffic
	Extreme Case of Potholes? – Warning sign for road end & ferry crossing in Sweden
	Extreme Case of distress? – Large slide on SR112 in Washington State – Road is now under several fathom of salt water

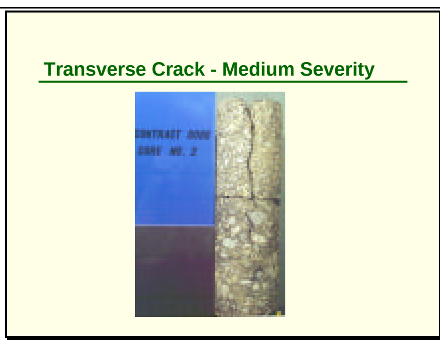


Example of medium severity transverse crack:

1. Extent is measured by number of cracks
2. Severity is classified by width and/or extent of spalling at crack

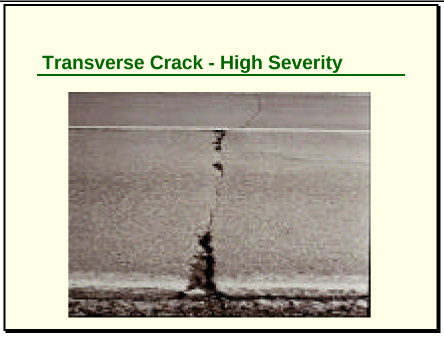
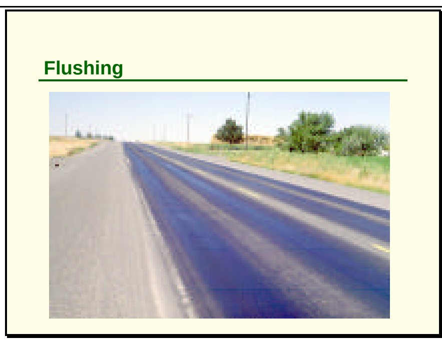


Close up of medium severity transverse crack

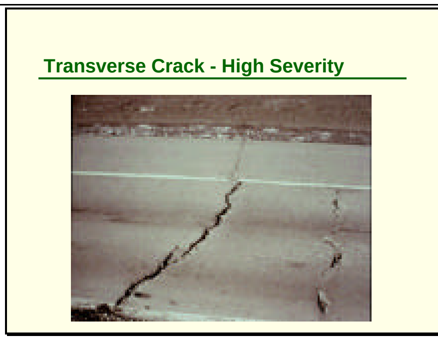


Example of a core displaying medium severity transverse crack

1. Thermal cracks normally start at top of the pavement & progress downward

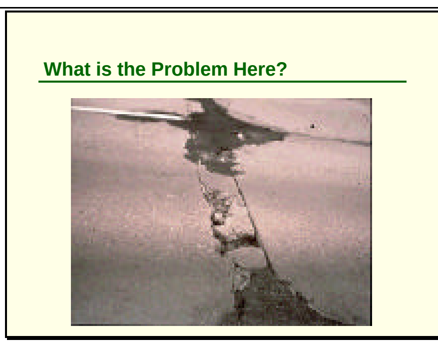
	Example of a high severity transverse crack: 1. Many states (South Dakota, Minnesota) find thermal cracking primary, if not only, concern – Effects of extended cold weather tend to out-weigh effects of pavement's exposure to traffic loading
	Example of HMA surface exhibiting permanent deformation (rutting): 1. Quantifying severity is important – Triggers when need for profile correction (cold milling) 2. Often indicative of weak base or subgrade soils
	Example of flushing: – Excess asphalt in wheelpaths

Example of moderate to high severity transverse crack in plain doweled concrete pavement



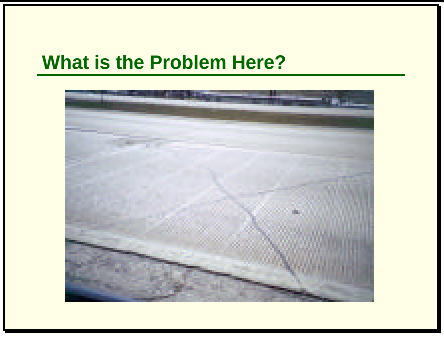
Example of closely spaced, high severity transverse crack:

1. Deterioration requires full-depth repair (or even full slab replacement)



What is the problem here?

1. It is caused by corrosion of the dowel bars and related lock-up of the transverse joint
2. A new working crack forms just beyond the ends of the old dowels



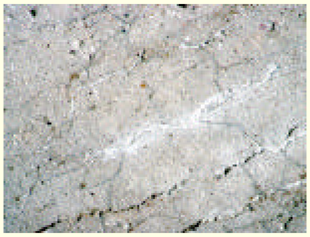
What is the problem here?

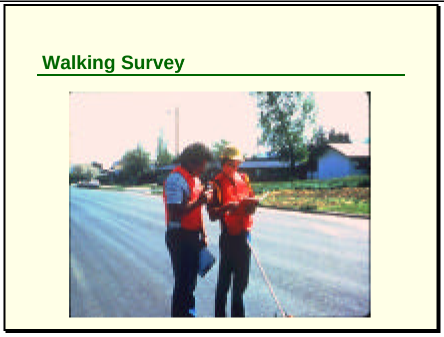
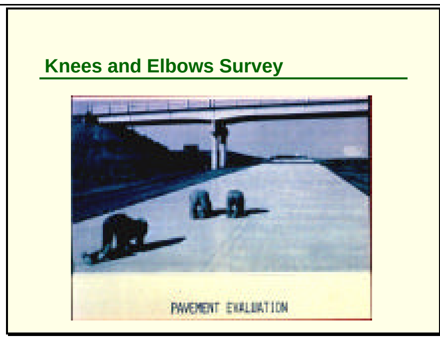
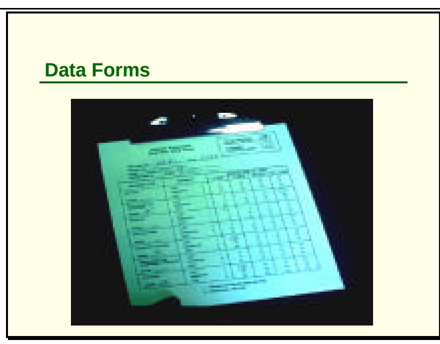
1. Typical crack pattern caused by frost heaving

Example of high severity pumping:

1. Evidenced by stains on shoulder
2. Helps specify locations where undersealing might be required to fill voids
3. Use to identify where NDT measurements should be made
   – Can use to quantify extent of erosion problem & need for undersealing

Example of severe ASR damage

Close Up View of ASR Distress 	Close up of ASR
Manual Distress Surveys Preferred methodology Equipment Pre-survey activities Initial windshield survey Detailed distress survey Examples of distress	Introduce components to be discussed: 1. Methodology 2. Equipment 3. Pre-survey 4. Windshield survey 5. Detailed survey 6. Examples of distress
Windshield Survey 	Example of what a rater would see in a windshield survey: 1. Not recommended for project level evaluation – Speed of vehicle too fast – Sun position If safety is concern, then try to do from shoulder at very low speeds

	Example of condition surveyors conducting a walking survey: – Emphasis equipment
	This is preferred method for detailed distress survey (photo taken during AASHO road test almost 40 years ago when researchers insisted upon a "close-up" look at the pavement) Point here is that it takes 2-3 surveyors to get productivity & accuracy of data
	Example of a typical distress data collection form: 1. Forms used for PMS data collection are not necessarily forms for project-level evaluation – PMS is used for development of prediction models – Project level data is used to identify rehab measures

Hand-Held Computer

Optional equipment that can be used are hand-held computers to record data directly into a database

Flexible Pavement Distress:

Load-related
- Fatigue cracking
- Permanent deformation
- Potholes

Climate and materials-related
- Bleeding
- Transverse cracking
- Raveling / weathering

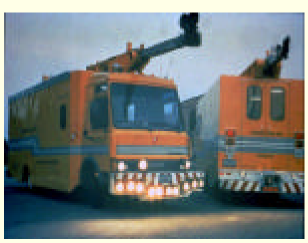
Describe flexible pavement distresses recorded as part of condition survey:

JCP / JRCP Distress

Load-related
- Corner breaks
- Faulting
- Pumping

Climate and materials-related
- Blowups
- D-cracking
- Longitudinal / transverse cracking
- Spalling

Describe typical distress data collected for rigid pavement (JCP/JRCP)

CRCP Distress **Load-related** • Punchouts • Transverse crack deterioration • Pumping **Climate / materials-related** • Blowups • D-cracking • Longitudinal / transverse cracking	Describe typical distress data that is collected for rigid pavement (CRCP)
Automated Distress Surveys **Equipment** **Advantages** **Limitations**	Describe automated distress surveys: 1. Equipment 2. Advantages 3. Disadvantages
Pasco Equipment 	Example of the PASCO automated equipment that is used in LTPP to collect distress data: 1. Uses high speed 35mm camera mounted on boom in front of the vehicle 2. All photos are taken at night (due to light contrast) 3. High intensity lights mounted on front to provide illumination 4. Data is considered very good 5. Does require examination & interpretation by surveyor in office

Pave Tech Equipment 	Example of automated equipment to record distress data: 1. Video cameras are mounted on both front & rear of vehicle (to avoid some problems associated with direction of light from sun) 2. Data is evaluated & process in office
Roughness Surveys **Roughness** • Deviations in pavement surface that affect ride quality • Caused by: Built-in surface irregularities Irregularities caused by traffic and environment • Standard measure: IRI	Introduce & discuss road roughness concept: 1. Definition 2. Causes 3. Standard measure
Serviceability **Measure of user's perception of pavement rideability** • Scale Zero (very poor) to Five (very good) Working range: 1.5 to 4.5 • Trigger levels High traffic Medium traffic Low traffic • Highly correlated with roughness	Pavement Serviceability Index developed at AASHO Road Test: 1. Definition 2. Scale 3. Trigger levels 4. Relationship to roughness

Typical Ride Measuring Equipment

IRPS
- K.J. Law Profilometer
- South Dakota Profiler
- PURD

RTRRM
- Maysmeter
- PCA Roadmeter
- Cox Meter
- BPR Roughometer

Describe the road roughness automated equipment types:

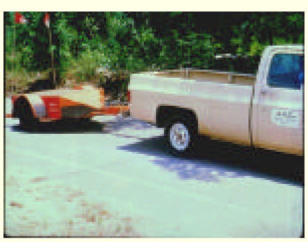
1. Most accurate & expensive is IRPS
2. RTRRM is less costly but also requires frequent calibration
   - If calibrated, adequate for project level evaluation

K.J. Law Profilometer

Example of IRPS equipment:

1. KJ Law Profilometer
   - Combination of lasers & accelerometers to record an accurate longitudinal profile of the road
   - IRI

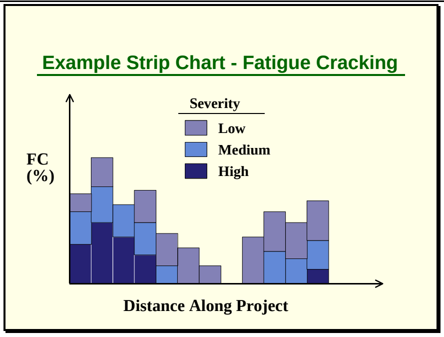
Maysmeter



Example of more common RTRRM devices (Maysmeter):

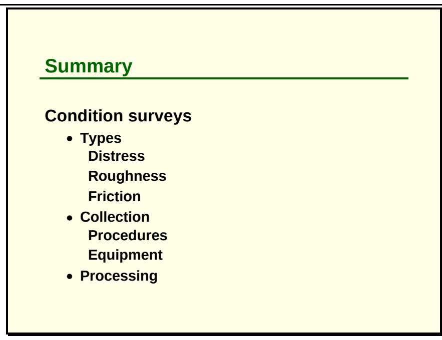
1. Measures road roughness by sensing response of axle relative to body of the trailer

Surface Friction Surveys Surface friction • a.k.a. Skid resistance • Safety concerns Hydroplaning Wet weather accidents • Influenced by Microtexture Macrotexture Cross-slope	Review aspects of surface friction (skid resistance): 1. Safety concerns 2. Key factors influenced by
Measurement Equipment Primary: locked wheel skid Mu meter British Pendulum Tester	Typical types of surface friction equipment
Condition Data Processing Summarize for evaluation Strip charts	Participant's Manual discusses steps to process condition data: 1. Summarize the evaluation & determine rehab treatment – One of best ways to summarize is to develop strip charts



Example of strip chart for fatigue cracking:

1. Discuss uses for engineer in identifying sections for rehab treatments



Review/Summarize key point in this module:

1. Types
2. Data Collection
3. Data Processing

Module 2-3

Nondestructive Data Collection and Interpretation

Begin Module 2-3

Objectives

- Describe the nature of a pavement's response to load
- List NDT devices and characteristics
- List factors that influence deflection
- Describe procedures for conducting NDT program
- Describe effects of season on NDT
- Describe principles and procedures for in-situ materials characterization

NDT refers to a wide variety of in-situ tests that can be done with no physical damage to structure. These objectives are readily understood by instructor

Here NDT refers to specific testing to quantify ability to support traffic loading

Introduction

NDT - Valuable engineering tool in assessing uniformity and structural adequacy

Useful

- Identify subsections
- Identify locations for sampling / testing
- Characterize material properties
- Rational basis for structural capacity assessment

NDT is used to assess:

1. Section uniformity
2. Subsections
3. Sampling/testing
4. Material properties
5. Structural capacity

The use of various forms of mechanistic tools (backcalculation) provide sound basis for determining structural adequacy

Introduction

Productive - 200 to 400 measurements per day

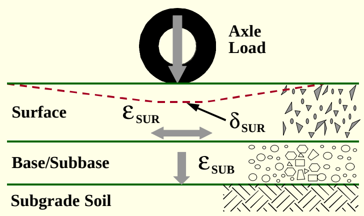
Repeatable

Used by most states for project and some network evaluations.

NDT Equipment:

1. Productive
2. Repeatable-equipment is not source of variability that might be observed in the data
3. Current technology

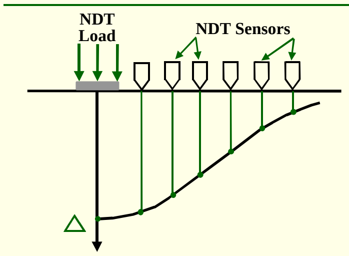
Pavement Responses Under Load



Example of ways that pavement responds to axle loads

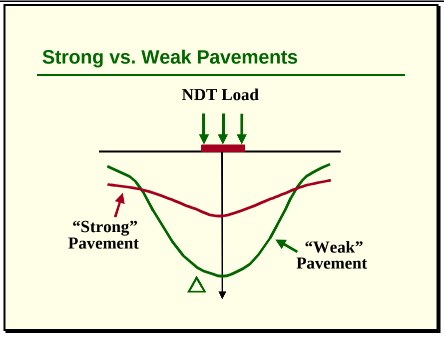
1. Surface deflection-easiest to understand but not best predictor of how structure will perform
2. Tensile strain at bottom of HMA & compressive stress at top of subgrade are discussed in Module 2-1 (better explicit predictors)

Measurement of Surface Deflection



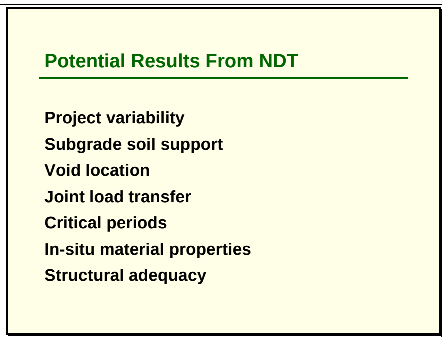
Example of measurement of surface deflection profile as result of wheel load applied:

1. One sensor on plate measures maximum deflection
2. Other sensors record remaining deflection basin (up to distance of about two meters from load)



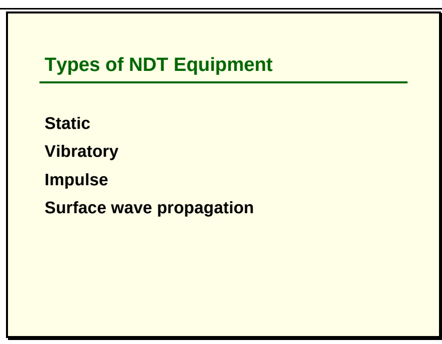
Example of differences in deflection profiles between strong vs. weak pavements:

1. Deflections are higher for weak
2. In this example, deflection furthest from load for weak are smaller than deflections furthest from load for strong pavement
3. This indicates weak pavement may have stronger underlying soil



Describe information that can be obtained from NDT data results:

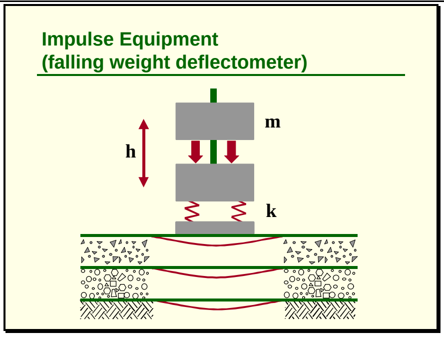
1. Emphasis that structural adequacy is what NDT is all about
   – Provides some basis for estimating how much life is left in pavement



Introduce types NDT equipment
(all will be covered in following slides)

"Static" Load Devices Benkelman beam California Traveling Deflectometer La Croix Deflectograph	NDT equipment – Static Load: 1. Benkelman beam – manual method 2. California Traveling Deflectometer – automated 3. La Croix Deflectograph – automated
Benkelman Beam 	Example of deflection measurements using a Benkelman Beam: 1. beam is used to measure the pavement rebound
Vibratory (steady state dynamic) Equipment Dynaflect Road Rater (3 models)	NDT Equipment – Vibratory: 1. Dynaflect – Trailer mounted, light load (1000 lb) – Uses electromechanical device to generate load – Seismic-type sensors to measure deflection 2. Road Rater – Generate varying load ranges – Is a electrohydraulic device which generates surface load hydraulically – Uses seismic-type sensors for recording deflection

Dynaflect 	Example Vibratory NDT Equipment: 1. Dynaflect with load wheels down & seismic sensors raised
Dynaflect - Close-up of Sensors 	Example Dynaflect: 1. Loads wheels and geophone sensors used to measure deflections
Road Rater 	Example of Road Rater showing load plate and location of sensors



Explain concept of impulse-type equipment (typically FWD):

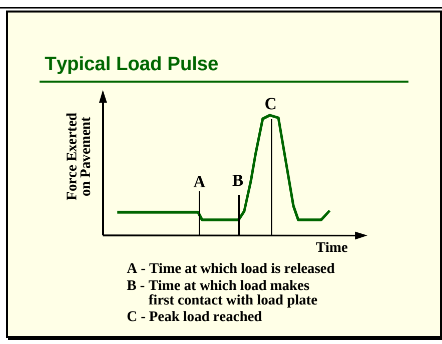
1. Simulates passing of truck axle load
2. Mass is raised a designated height & then dropped onto a system of buffers & springs
3. End result is impulse-type load which creates deflection that is measured by series of seismic-type geophones, or LVDTs

FWD Manufacturers

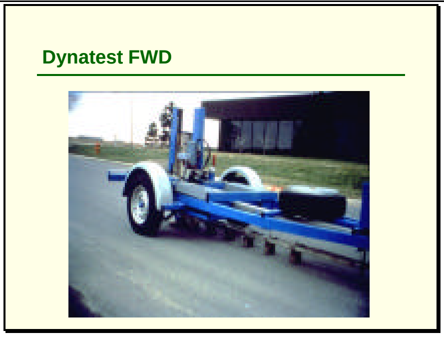
Dynatest
KUAB
Phonix
JILS

NDT Equipment – Impulse Load:
Falling Weight Deflectometer

1. Dynatest-most common in US
2. KUAB
3. Phonix
4. JILS



Explain load time history of pavement subjected to a FWD Load

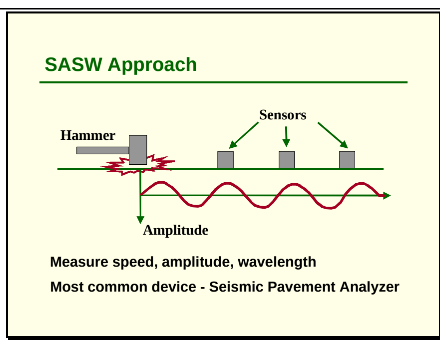


Example Dynatest (Danish) FWD showing (most common in U.S.):

1. Location of sensors
2. Load plate
3. Hydraulic equipment used to raise & drop the falling weight load

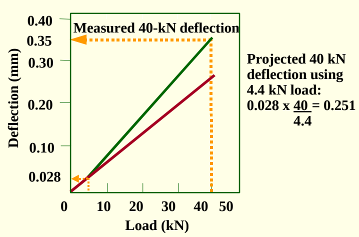
Example of KUAB (Swedish) FWD:

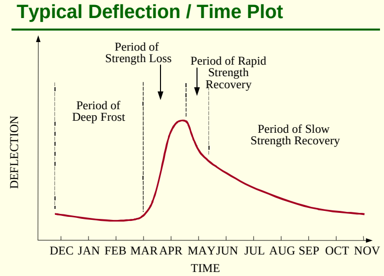
1. Main difference between KUAB & Dynatest has been way each is used to measure deflection
2. KUAB relies on use of linear velocity displaced transducers (LVDTs) to measure surface deflections
3. KUAB most common in other countries



NDT Equipment – Seismic Analysis Surface Wave:

1. Hammer of certain weight hits pavement
2. Generates spectrum of surface waves
3. Recorded by sensors at designated locations on pavement surface
   – Record speed, amplitude, & wavelengths of surface waves
4. Most common Seismic Pavement Analyzer (automated)

SASW Equipment - SPA 	Example Impulse NDT Equipment, Seismic Pavement Analyzer: 1. Very limited use at this time compared to FWD
Factors That Influence Measured Deflections Load factors Pavement factors Climatic factors	Factors influencing deflection measurements: – These are important to understand so they can be part of structural capacity assessment
Load Factors - Stress Sensitivity 	Explain load related factor –stress sensitivity: 1. Devices that measure deflection at light loads can create problems when deflection is extrapolated to condition under which pavement would be designed for

Pavement Factors Distress Transverse location Surface discontinuities Subsurface variations Underlying voids Random variability	Pavement factors that have significant influence on measured deflections: 1. Ask participant's to describe how factors might influence deflection 2. To what extent
Climatic Factors Moisture Temperature Frost penetration	Discuss climatic factors & how seasonal changes have major influence on deflections measured at surface: 1. Important to measure deflection representative of year-round conditions (avoid frozen winter & freeze-that periods)
Typical Deflection / Time Plot  	Illustrates seasonal influence

Conducting NDT Surveys **Temperature measurements** • Hourly • Multiple locations • Air and pavement • Correction to standard (e.g., 21° C)	Aspects to consider when conducting NDT field test survey: 1. Temperature measurements – Measure air & pavement as testing progresses – Charts have been developed to correct the measured deflections to a standard temperature
Testing Locations / Frequency 30 to 150 m intervals Typically outer lane only Both directions - staggered Flexible - outer wheel path JPCP / JRCP - midslab, joint, corner CRCP - outer wheel path - between cracks and at cracks	Explain NDT testing locations & frequency
Testing at Joints 	Example of test at joints for load transfer: – Load plate – geophones

Interpretation of NDT Data

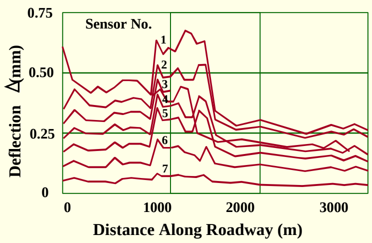
Uniformity of project
- Design sections for rehabilitation
- Locations for sampling / testing

Determining pavement layer moduli
- Insitu characterization
- "Backcalculation" process

Interpretation of NDT data can determine:
1. uniformity along the project
2. loss of support (voids)
3. joint/crack load transfer

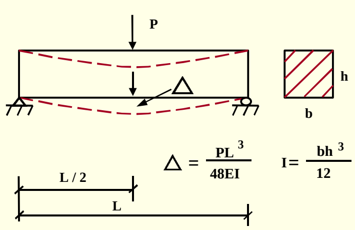
Discuss backcalculation of moduli

Uniformity (Non-uniformity) of Project

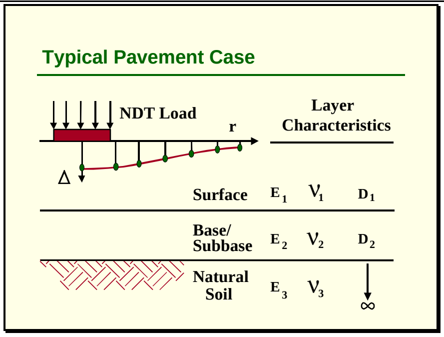


Example of deflection variation along a project:
1. Participant's should discuss where weak & strong pavement structure areas are

Simple Backcalculation Case



Illustrates the backcalculation process using a simply supported beam with concentrated load at mid-span:
1. Given dimensions of beam, magnitude of load, & measured deflection, can rearrange equation to solve for modulus of elasticity of beam



Unlike example in previous slide, equations for predicting surface deflection as function of applied load & characteristics of individual layers is not closed-form solution:

1. A mathematical or iterative process is required
2. Solves for in-situ layer moduli as function of all other characteristics & deflection measurements

Typical Poisson's Ratios

Material	Range	Typical
PCC	0.10 - 0.20	0.15
HMA / ATB	0.15 - 0.45	0.35
Cement Stab. Base	0.15 - 0.30	0.20
Granular Base / Subbase	0.30 - 0.40	0.35
Subgrade Soil	0.30 - 0.50	0.40

Typical Poisson's Ratios

Typical Modulus Values

Material	Range (mPa)	Typical (mPa)
HMA	1,500 - 3,500	3,000
PCC	20,000 - 55,000	30,000
ATB	500 - 3,000	1,000
CTB	3,500 - 7,000	5,000
Lean concrete	7,000 - 20,000	10,000
Granular base	100 - 350	200
Granular soil	50 - 150	100
Fine-grained soil	20 - 50	30

Provides a range of possible Young's modulus values as function of its material:

1. Instructor should compare these with typical modulus of steel (4.2 mPa)

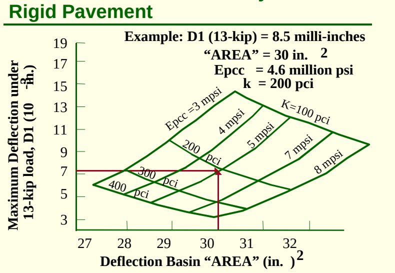
Example Iterative Process

Iterat.	Trial Moduli (mPa)				Predicted Deflections (mm)							Avg. % Diff.
	E_1	E_2	E_3	E_4	Δ_1	Δ_2	Δ_3	Δ_4	Δ_5	Δ_6	Δ_7	
1	1724	276	138	690	.276	.201	.166	.132	.108	.075	.040	20.5
2	1724	276	207	345	.238	.167	.136	.105	.083	.055	.031	36.4
3	1724	207	103	276	.335	.257	.218	.177	.147	.104	.058	5.9
4	1793	224	107	297	.320	.245	.208	.169	.141	.100	.056	1.3
5	1862	224	107	297	.316	.243	.207	.169	.141	.100	.056	0.9
	Measured Defl. (mm):				.309	.243	.208	.171	.140	.099	.054	

Example of an iterative process where 5 iterations were required to solve for final layer moduli of a four-layer structure

1. Most common method for determining moduli
2. Trial moduli are used to predict theoretical deflections
3. These deflections are compared with measured deflections
4. Produces another set of trial moduli
5. Iteration continues until convergence criteria are satisfied

Backcalculation for Two-Layer Rigid Pavement



Example of a backcalculation for two-layer rigid pavement:

1. Simple
2. Can be done graphically
3. Use measured maximum deflection & area of deflection basin

Rules of Thumb

E_{bottom} = is a function of the deflection beyond one meter

Effect of underlying "rigid" layers

Effect of more than one bound layer

Effect of "thin" layers

When applying backcalculation or examining results some rules of thumb can be found in participant's manual, page 2-3.24

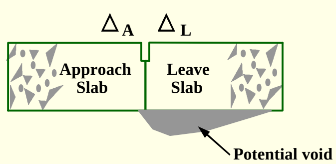
Backcalculation Programs

BISDEF	MODCOMP
ELSDEF	BOUSDEF
CHEVDEF	ELMOD
MODULUS	EVERCALC
COMDEF	ILLI-BACK
WESDEF	

Discuss table 2-3.5 in particpant's manual detailing backcalculation programs. Also NHI course Pavement Deflection Analysis

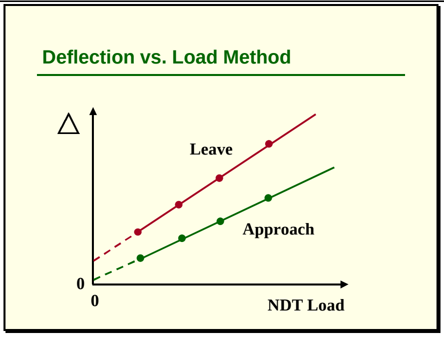
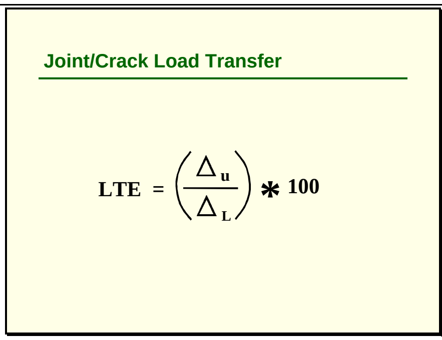
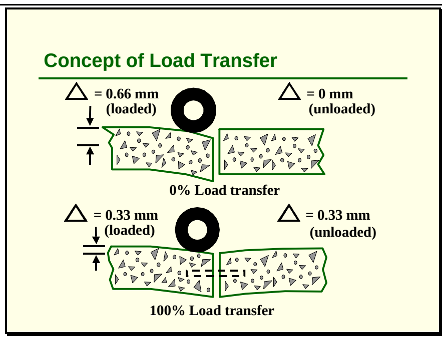
Location of Loss of Support (voids)

Examine difference between deflections on approach slab and leave slab



By comparing the deferential deflections on either side of joint, the presence of voids can be determined:

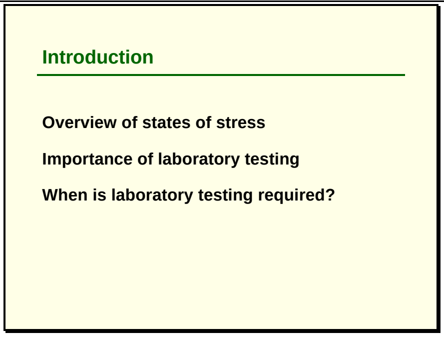
1. The potential increases as the deferential between two measurements increases

	Example of void assessment using deflection vs. load method: 1. Measure deflections on upstream side (approach slab) 2. Best fit line drawn through these point & extrapolated to origin – Approach slab will almost always intersect near origin – Means void does not exist under approach slab 3. For leave slab, does not always produce same desirable results – Further extrapolation of line intercepts is from origin, more likely a void
	Interpretation of joint/crack load transfer efficiency: 1. Dependent upon measured deflection on loaded side of joint & simultaneous value of deflection on unloaded side 2. Load transfer efficiency<50%=bad 3. Load transfer efficiency>75%=good
	Load transfer is illustrated by examining extreme case: 1. 0% load transfer 2. 100% load transfer

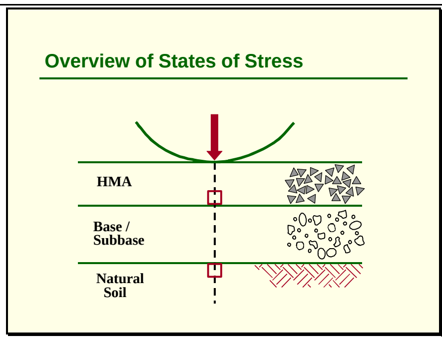
Summary **Background** **NDT equipment** **Influential factors** **Conducting field surveys** **Interpretation of NDT data**	Review key points covered on NDT data collection and interpretation
	Load Transfer Determination
	Load Transfer Configuration

	Review/Summarize NDT data collection

Module 2-4 ***Laboratory Materials Characterization***	Begin Module 2-4
Objectives **Describe stress states, identify major material property test procedures** **Describe basic terminology** **Describe concept and importance of resilient modulus testing** **Identify major material tests for PCC and HMA; describe use in rehabilitation design**	Give participant an idea when lab testing is appropriate & what tests are applicable Participant will identify lab testing: 1. Procedures 2. Terminology 3. Resilient Modulus 4. Tests for PCC, HMA 5. Use in rehabilitation design
Definitions **Resilient modulus** **Resilient strain** **Permanent strain**	Definitions: 1. Resilient modulus (Young's) – Ratio of amplitude of repeated axial stress to amplitude of the resultant recoverable strain 2. Resilient (elastic) strain – Deformation recovered when load is removed – Key in determining resilient modulus 3. Permanent (plastic) strain – Deformation that is not recovered when load is removed



Introduction of three topics related to laboratory testing

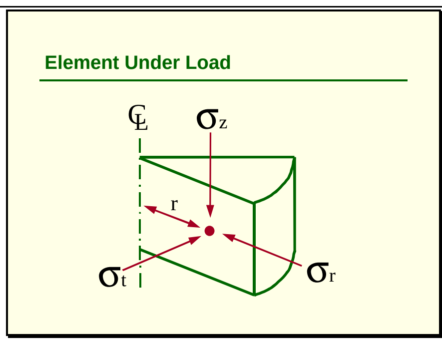


States of Stress – Configuration

1. Simulation of state of stress
2. Axial load as result of wheel load

Not shown:

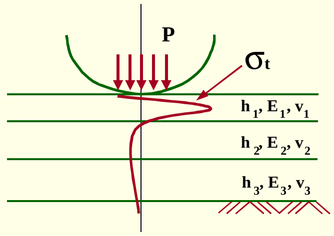
1. Components of stress and/or strain as result of overburden pressures
2. These create vertical & horizontal stresses on elements at various depths



Example of typical element subjected to a triaxial state of stress

1. These include vertical, tangential and radial components when evaluated using an axi-symmetric model

Typical Distribution of Tensile Stress



This graphic depicts the distribution of tensile stress along an axis representing the centerline of the load:

1. Various computer programs for predicting the state of stress
2. Usually based on elastic layer theory or finite element analysis
3. Requires basic properties & characteristics about the structure
   – Thickness, modulus values, Poisson’s ratios, etc.

Importance of Laboratory Testing

Economics
Recycling
Emphasis on rehabilitation
Verification of NDT results

Why is laboratory testing important?

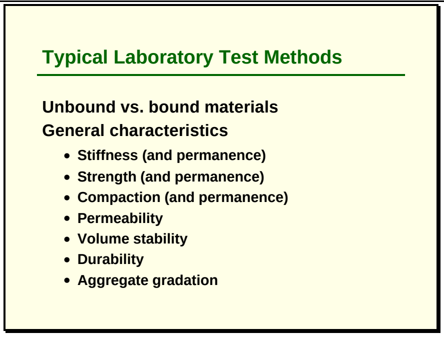
1. Economics
   – Testing is small portion of millions spent on rehab
   – Can help ensure rehab has longer life
2. Recycling
   – Helps reduce premature failure of recycled material
3. Rehabilitation
   – Design requires more characterization of existing material properties than new pavement design
4. Verification
   – Sometimes used to supplement NDT and backcalculation

When is Lab Testing Required ?

Complement NDT (low level)
Absence of NDT (high level)
Diagnose causes / mechanisms of distress

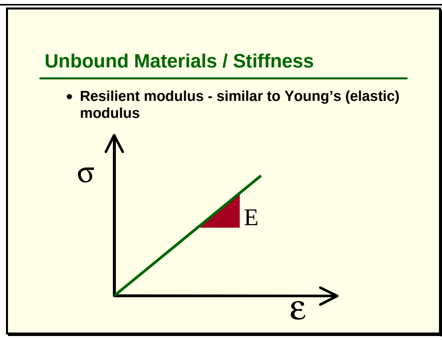
Require lab testing when:

1. information about a performance-related material property is either unavailable or cannot be determined through other means



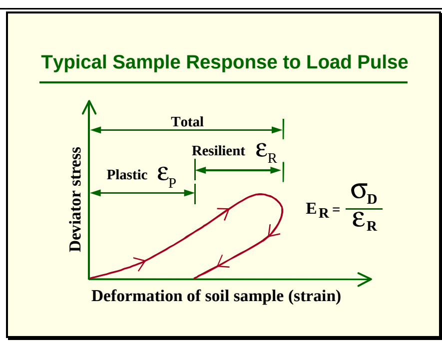
Laboratory test methods:

1. Bound vs. unbound
2. Introduce general characteristics
   – Focus here will be on stiffness and strength



This example shows that elastic modulus is the slope of a line on stress-strain diagram

1. Because many materials are non-linear & experience permanent deformation, term Resilient Modulus was adopted
1. Resilient Modulus (surrogate for Young's Modulus) preferred test for stiffness of unbound materials

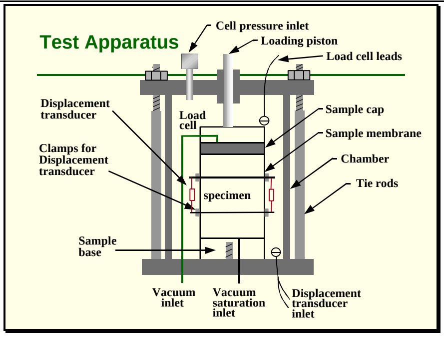


Example of cycle of stress

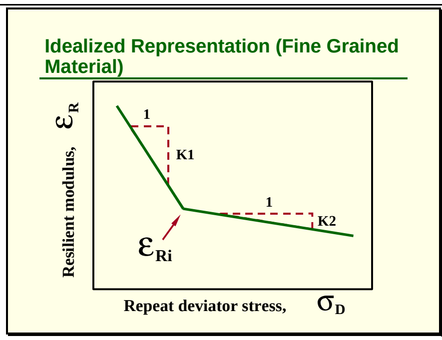
1. With each cycle, sample undergoes resilient (recoverable) strain & plastic (non-recoverable) strain

Resilient Modulus calculated by:

1. Axial stress applied (also called deviator stress) divided by resilient strain (after at least 500 cycles of load)

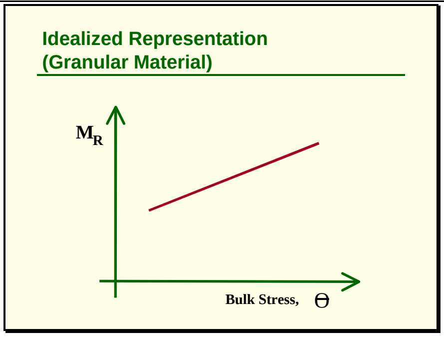


Resilient Modulus Testing Equipment
(designed to apply a triaxial state of loading)



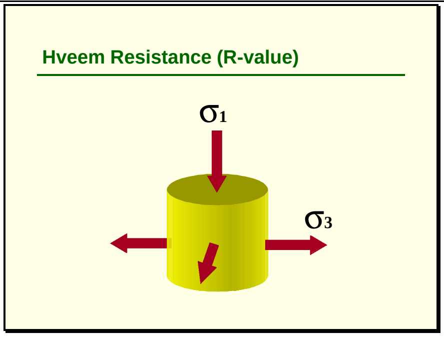
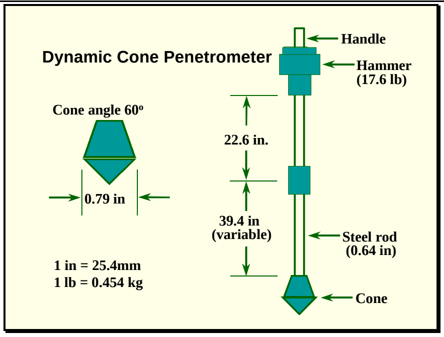
Example of typical stress-strain diagram for cohesive fine-grained soil

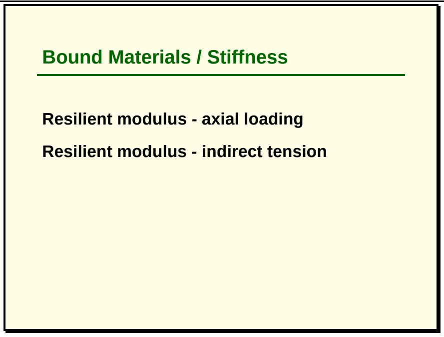
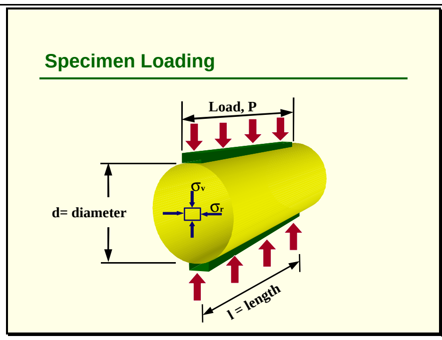
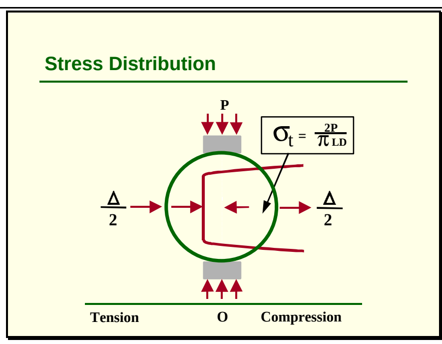
1. Relationship has two slopes
2. Greatest sensitivity to load typically in the low stress-low strain portion



Example of an idealized representation:

1. relationship between resilient modulus & bulk stress
2. unbound granular material
3. modulus generally increases as both bulk stress and confining pressure increase

	Example of a Hveem resistance (R-value) test: 1. Stiffness test category 2. Although R-value is an index property, it is tested in state of stress similar to material experience in field 3. Axial load applied to sample 4. Horizontal displacement is measured to characterize stiffness 5. The less the sample responds in outward direction, greater stiffness
Unbound Materials / Strength CBR Unconfined compressive strength Plate bearing (field test) Dynamic cone penetrometer (field test)	Introduce methods used to characterize strength in unbound materials 1. Because unbound materials are not intended to carry loads near their ultimate strength, questions as to applicability of these tests 2. Recent emphasis on DCP due to correlation with resilient modulus than other strength tests
	Example of strength test for unbound material using DCP: 1. Destructive type test 2. Tests are done in field—no samples need to be taken back to lab 3. Easy to perform 4. Provides immediate feedback on characteristics of unbound materials (to a given depth) 5. Used to calculate CBR values

	Introduce bound materials testing methods for stiffness: 1. Resilient Modulus–axial (compressive) loading 2. Resilient Modulus – indirect tension 3. Neither is done in triaxial state 4. Indirect tension is believed to be unnecessary for bound materials
	Example of the method of loading used to achieve indirect tension for bound material testing for stiffness 1. Fatigue cracking occurs as result of tensile strains, therefore, this test is the preferred method for resilient modulus of bound materials
	Example of the distribution of tensile stress in a sample

Bound Materials / Strength Unconfined compression Direct tension Indirect tension	Introduce typical test methods used to characterize strength for bound materials testing: 1. Strength of PCC slabs are critical due to mechanism by which cracks develop (under tension) 2. In this case, indirect tension due to simplicity & repeatability of test
Bound Materials / Stability Marshall Hveem	Discuss importance of stability in bound materials (especially HMA): 1. Marshall 2. Hveem Discuss the evolution of SuperPave & other design procedures that measure performance related characteristics 1. May see decrease in use of Marshall & Hveem
Material Property Relationships Soil classification • AASHTO • Unified • FAA Moisture and density	A discussion of material property relationships is provided in participant's manual (not covered in this presentation)

Correlations Strength vs. strength Stiffness vs. strength Stiffness vs. classification	Participant should refer to manual for information/discussion on correlation between items listed (not covered in this presentation)
Other Considerations Volume stability Stripping Concrete durability Seasonal variations	Present other types of laboratory tests that may need to be considered 1. Depending on nature of distress 2. Mode of failure
Summary States of stress Basic terminology Importance of lab testing Resilient modulus test Other test procedures Relationships and correlations	Review/Summarize key points

Module 2-5

Drainage Survey and Evaluation

Moisture is extremely detrimental to deterioration of pavement

Three important factors:

1. Drainage
2. Drainage
3. Drainage

Objectives

List distresses caused by moisture

Define drainage factors

Describe principle behind drainage time

List properties that influence drainability

Impact of moisture on pavement distress

Introduce the procedures used to assess the need for drainage improvements:

1. Four types of distresses caused by moisture
2. External & internal drainage factors
3. Drainage time
4. Drainability properties influence subgrade
5. Moisture influences

Definitions

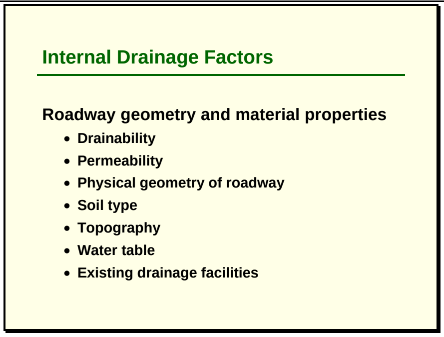
Moisture
- **Infiltration**
- **Lateral seepage through natural soils**
- **Capillary action from underlying water table**

Drainage
- **Removal of moisture from pavement**
- **Prevent entry of moisture into pavement**

Definitions:

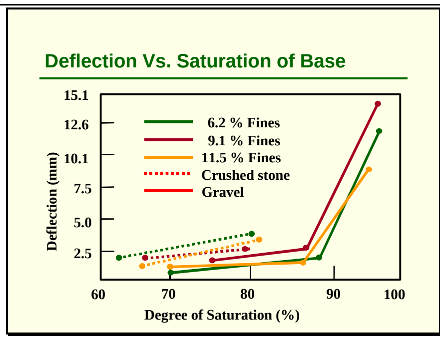
1. Moisture
   - Many sources
   - Impossible to completely eliminate or prevent
2. Drainage

Moisture Related Distress Survey Ditches clear of standing water ? Ditches and pavement edge clear of grass/weeds ? After a rain, is water flowing from joints or cracks ? Are typical signs of pumping evident ?	Discuss the need for a complete drainage evaluation: 1. Conduct a visual survey for signs of moisture 2. Tables 2.5-1 & 2.5-2 list moisture-related distresses
Visual Evaluation If sub-drainage is present, can the outlets be found and are they clear of debris ? Are inlets clear and functioning ? Are the joints or cracks sealed ? Is the sealant in good condition ?	Continue providing typical visual survey criteria
External and Internal Drainage Factors External drainage factors - climate • Local climatic information Precipitation used to estimate frequency that any granular layer at or near saturation Temperature used to estimate effects of freezing on base and subgrade soil layers	External drainage factors: 1. Definition- local climatic conditions that regulate the supply of moisture to the pavement Variables: 1. Precipitation 2. Temperature (freeze index)



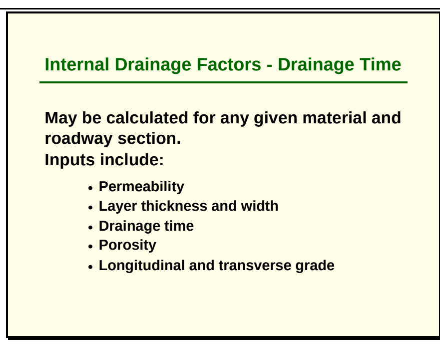
Present internal drainage factors:

1. Roadway geometry & material properties that affect drainage and pavement performance
   – List of factors are for each material in the pavement structure



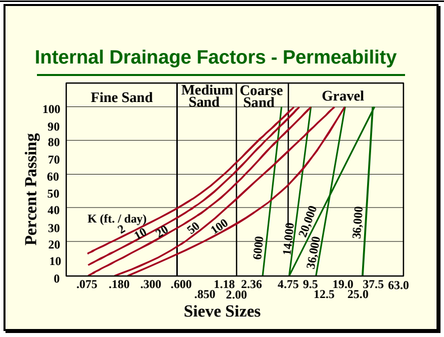
Effect of degree of saturation

1. Above 85%, total deflection increases rapidly
2. Can lead to accelerated development of fatigue damage
3. Deflection shows uniform change with increasing saturation level, permanent deformation will increase tremendously at higher saturation levels



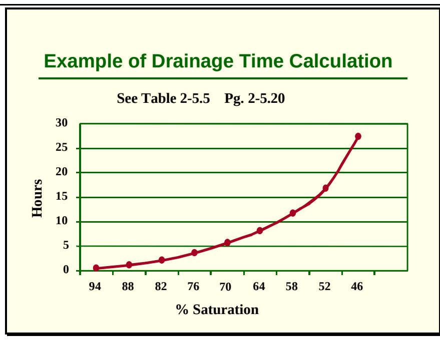
Discuss calculation of drainage time for granular layers:

1. Effective porosity
   – How strongly a material will hold water
   – Ration of volume of water that drains under gravity to total volume
2. Permeability
   – How fast water flows through a material
   – Function of % fines, effective grain size, specific gravity, dry density



Discuss typical permeabilities for a range of materials:

1. Permeability (k) measured as length per time (ft/day)
2. Coarse materials have more voids & thus greater permeability
3. Fines can clog granular layers and prevent drainage
4. Thus, use separator layers to prevent contamination of subgrade fines to permeable layers



Calculation of drainage time is complex

1. Work example on page 2-5.20 with participants

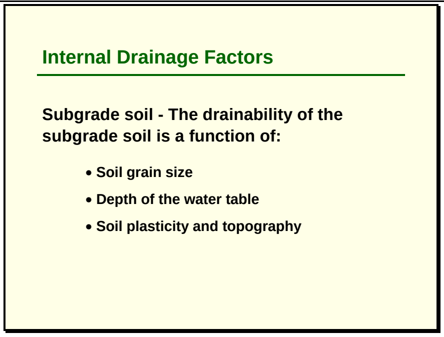
Internal Drainage Factors

Critical drainage time - Based on 85% saturation time related to the

- **Performance of jointed PCCP**
- **Less than 5 hr. to 85% considered acceptable**
- **5 hr. to 10 hr. marginal condition**
- **Greater than 10 hr. considered unacceptable**

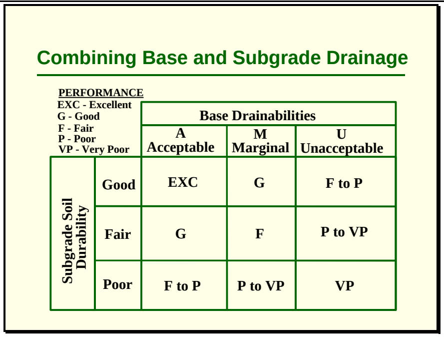
Critical Drainage Time for Granular Base Layer:

1. Based on 85% saturation level, a drainage time of:
   - 5 hrs = acceptable
   - 5-10 hrs = marginal
   - >10 hrs = unacceptable



Influence of subgrade soil must be considered in drainage evaluation:

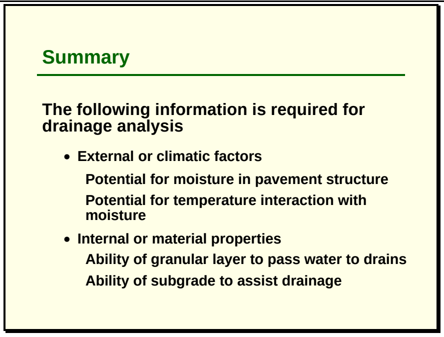
1. Can be classified into one of seven categories
   - Very poorly drained to excessively drained
   - Can also be given numerical rating based on potential for moisture-related damage
   - Called Natural Drainage Index (Figure 2.5-12)



Subgrade Soil Durability	Base Drainabilities: A Acceptable	M Marginal	U Unacceptable
Good	EXC	G	F to P
Fair	G	F	P to VP
Poor	F to P	P to VP	VP

Drainage Classification Table – Base & Subgrade

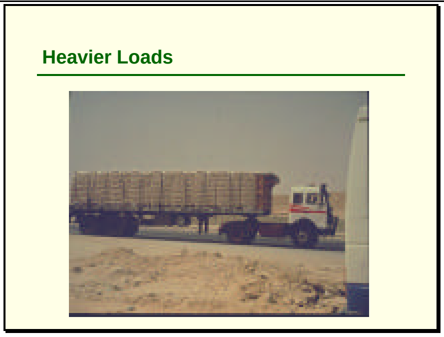
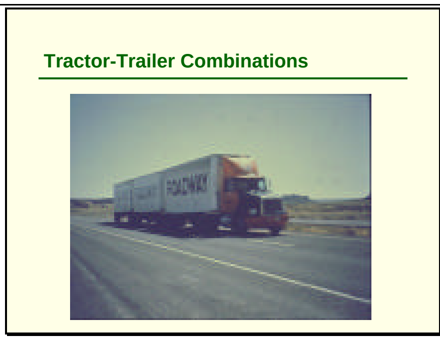
1. In AASHTO design procedure, drainability must be combined for overall drainability



Drainage Survey & Evaluation

1. Distresses caused by moisture
2. External & internal drainage factors
3. Drainage time
4. Drainability properties
5. Moisture influences

Module 2-6 ***Traffic Loading Evaluation***	Begin Module 2-6
Objectives **Recognize importance** **Describe relative damaging effects of axle load and configuration** **Describe forecasting procedures** **Appreciate WIM / AVC technology**	Objective: – Give participant a general understanding of how traffic loading (particularly ESALs) is evaluated
Introduction **Traffic - significant effect on design** **Historically poor forecasting practices** **Increased axle loads, higher tire pressures, and new axle configurations**	Describe how: 1. Traffic is significant in structural design 2. Forecasting practices have been poor 3. Difficulty with traffic forecasting is even greater due to increased loads, pressures, and new configurations

	Example of heavily loaded (150,000 lb) vehicle routinely found in Middle East 1. Maximum single axle load limit in US is 20,000 lb 2. What kind of damage is being done by single drive axle (or tandem axles)?
	Example of typical triple-trailer found in western US – Creates problem with: 1. Forecasting 2. Geometric design
	Example of another unusual axle configuration: 1. Maximized pay load – Axles loads controlled by weight per inch & tire width – 600 & 800 lb/inch are common – Washington State set new limit to 500 lb to reduce damage

Definitions

Load equivalency factor (LEF)
Truck factor
ESAL
Weigh-in-motion (WIM)
Automatic vehicle classification (AVC)

Instructor should define these terms

1. Although they seem self-explanatory, many participants are not familiar

Estimation Process

Traffic data collection (axle weights/counts)
Permanent weigh stations
Portable scales
WIM /AVC installations
Conversion to ESALs

Describe these key components to forecasting traffic:

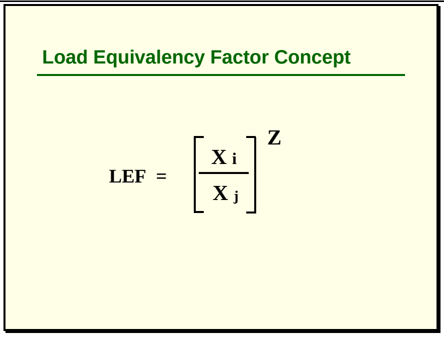
1. Weigh stations & portable scales
   - Do not operate year round or around the clock
   - Easy to by-pass
2. WIM-measures axle load while vehicle is in motion
3. AVC-classifies each vehicle without human intervention
4. Note that in state highway agencies, a small group has historically had responsibility for forecasting

WIM Pad

Example of a portable WIM:

1. Some devices that fall under WIM category:
   - Bridge weighing devices, capacitants pad, piezo-electric cables, strain gauge load cells, strain gauge bending plates, hydraulic load cells
   - Bending plates & piezozo-electric systems have been found to be more reliable

Estimation Process **WIM / AVC notes** • Calibration needed • Axle weights / counts • Vehicle classification	Notes about WIM/AVC: – LTTP has experienced many problems with WIMs because they were not calibrated – When properly calibrated, WIM axle weights will be on order of only 8% different than weights reported by static scales – AVC about 94-99% accurate
Conversion (for Design) **Rigorous** **Approximate** • Initial year ESAL • Growth rate	Design conversion: 1. AASHTO has rigorous method – Preferred method 2. Focus on – approximate procedure estimating ESALs in initial year – Apply growth rate to forecast ESALs
Initial Year ESAL $ESAL_1 = ADT \times 365 \times TKS \times DD \times LD \times TF$	Explain formula for calculating number of 80 kN equivalent axle loads (ESALs) that pavement experiences during year 1 of rehab



Explain LEF concept:

1. Relative damage caused by one load relative to another is dependent upon the ratio of those two loads taken to some power, Z

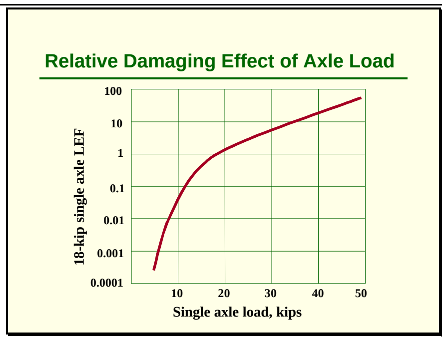
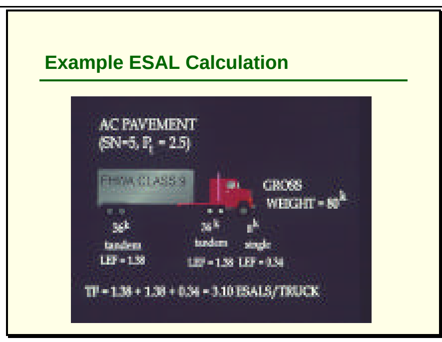


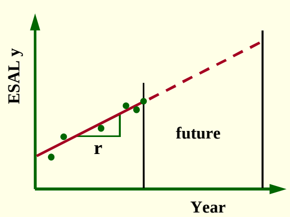
Illustration of relative damaging effect of axle load based on criteria & relationships in AASHTO Design Guide:

2. Area of interest is above the 10,000 lb line

(Note: At this time instructor should give examples of how LEFs can be extracted from this curve & used to demonstrate differences in relative damage for different axle load)



Example of an ESAL calculation

Key Points About LEF Axle weight and type are critical Truck weight is less critical	Explain how these key points are critical
Truck Factor TF = Mean ESAL per truck Tabular computation Increasing with time State vs. local	Discuss items shown
Growth Rate (r) 	Growth rate: 3. Information over the years makes it possible to project 4. Depending on similarity between traffic & truck growth rates, possible to assume truck growth rate is same as ADT growth rate

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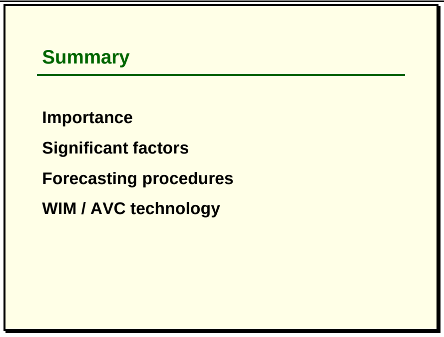
<td>
</td>
<td>Summarize key points in this module</td>
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Module 2-7 ***Overall Project Evaluation***	Begin Module 2-7
Objectives **Describe benefits of a thorough project evaluation** **Outline step-by-step procedure** **List key data** **Develop overall project evaluation checklist** **Describe approach to structural evaluation**	Overall objective is to demonstrate: 1. How previous modules are used to complete an overall evaluation
Introduction **Concept - Overall goal of rehabilitation design is to provide:** • **Cost-effective solution** • **Address deficiencies** • **Satisfy constraints** **Importance of thorough evaluation**	Purpose of rehabilitation: 1. Provide cost-effective solution to correct deficiencies & satisfy any constraints Importance of evaluation: 1. Rehab design is more complex than new pavement design 2. Costs are nominal compared to funds expended 3. Size of project justifies a complete evaluation (greater the investment, the greater the risk, the greater the need for a thorough evaluation)

Data Requirements Consider data categories Requirements also depend upon potential rehabilitation candidates Develop checklist Consider purposes • Qualitative • Quantitative Strive for balance	Data requirements: 1. Categories – Condition, original design, material properties, traffic, climate, drainage, geometric, safety, miscellaneous 2. Potential rehab candidates – The more there are, the more data is needed 3. Checklist – Helps carry out in a timely & orderly fashion 4. Purpose – How rigorously should it be collected 5. Balance – Use efficiently to choose best alternative
Project Evaluation Flowchart Office/Historical Data Collection ↓ Initial Site Visit ↓ Primary Field Survey ↓ Initial Data Analysis ↓ Secondary Field Survey ↓ Laboratory Materials Characterization ↓ Secondary Data Analysis ↓ Structural Capacity Analysis	Introduce the project evaluation process (Each step is explained below)
Step 1: Office / Historical Data Collection Office files Historical records	Collect as much data as possible 1. Plans & specs 2. Condition surveys 3. Traffic analyses 4. Maintenance operations, etc.

Step 2: Initial Site Visit

Design and maintenance engineers

- Scope of primary survey
- Assess potential mechanisms
- Identify candidate rehabilitation treatments
- Assess traffic control needs

Subjective information on distress, roughness, surface friction and drainage

"Windshield" or shoulder survey

Design & maintenance engineers should participate in the initial site visit

1. Define scope
2. Assess distress mechanisms
3. Identify candidate treatments
4. Identify traffic control needs
5. Develop their own ratings (distress, roughness, etc)
6. Can do this with informal survey

Step 3: Primary Field Survey

Condition (Module 2-2)

- Distress
- Roughness
- Friction

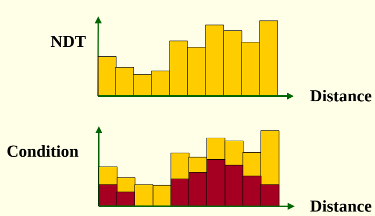
NDT (Module 2-3)

Drainage (Module 2-5)

Traffic (Module 2-6)

Data categories to collect during a field survey (discussed in previous modules)

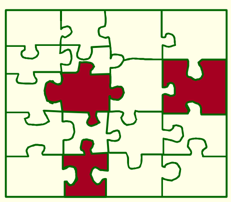
Step 4: Initial Data Analysis

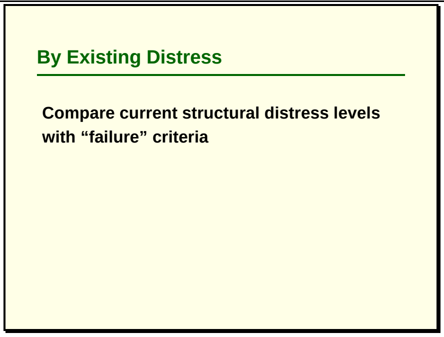


Example of what can be done to begin field data analysis:

1. Strip charts can be used to identify the location of cores for thickness verification and/or lab testing

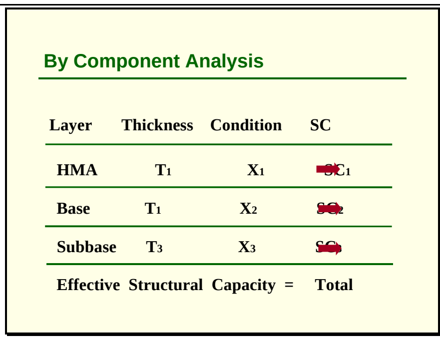
Step 4: Initial Data Analysis **NDT** • Max / Min deflection • Deflection indices • Layer moduli **Condition** • Distress • Roughness • Surface friction	Other data that can be plotted on strip charts characterize condition & behavior of the pavement (continues on next slide)
Step 4: Initial Data Analysis **Structure / Soils** • Layer thickness • Soil type or cut / fill **Moisture / drainage**	Continued from previous slide
Step 5: Second Field Survey **Destructive sampling** • NDT variability • Backcalculation problems • Stripping **Additional NDT** • Intensive deflection testing • Other NDT devices	Additional data that can be collected to address problems with analysis (if any)

Step 6: Laboratory Materials Characterization (if necessary) Indirect tensile strength Resilient modulus Permeability Existing mix properties Density / gradation Freeze-thaw durability Petrographic testing	This list provides examples of additional lab tests that might be needed 1. Should be established as a result of the first field survey data analysis
Step 7: Secondary Data Analysis (if necessary) 	Use data from the second field survey/lab tests to provide missing information 1. Refine analysis with additional data 2. Usually only when unusual distress or premature failure
Step 8: Structural Capacity Assessment Three basic methods are available	Structural capacity assessment: 1. How much life is left 2. Ability to support traffic Methods: 1. Existing Distress 2. Component Analysis 3. NDT



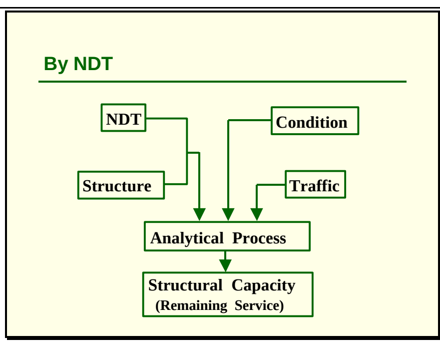
Subjective approach that is not a preferred method

1. Dependent upon past experience



Structural Capacity by Component Analysis (1993 AASHTO Design Guide):

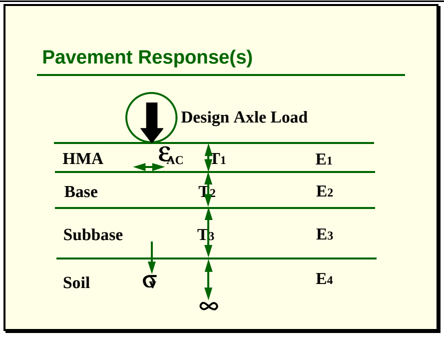
1. Calculates a Structural Number
2. Flexible pavements (rigid pavements if cracked & seated)
3. Subjective
4. Only used as a check on NDT approach in AASHTO Guide
5. Not preferred method



This is the preferred method for assessing structural capacity.

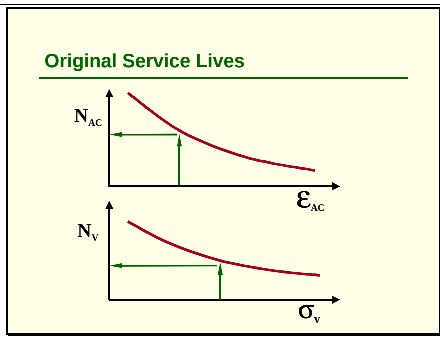
NDT in conjunction with data listed on slide provide analysis that is:

1. Reliable & complete
2. Measures remaining service
3. Or remaining life



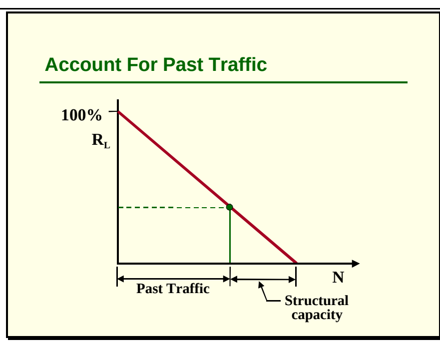
A key step in the analytical process is determination of critical pavement responses (HMA tensile strain, PCC tensile strain, Subgrade vertical compressive stress) as a function of:

1. layer thickness
2. effective modulus values



With known values of critical response
(e.g. tensile strain in HMA & compressive stress at top of subgrade):

1. Can use appropriate fatigue & rutting models
2. Can predict service lives of pavement based on models
3. Model with least life controls & is used for remaining design calculations

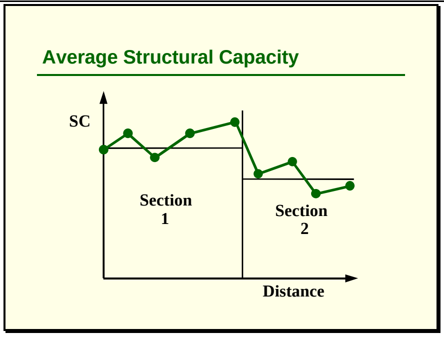


Note that previous life calculation does not represent remaining life or remaining structural capacity:

1. Some life has already been used by traffic

Structural capacity is determined by:

1. Calculating difference between original life & accumulated past traffic (since original construction)

	Determine structural capacity for every deflection point with NDT: 1. Plot profile & subdivide into subsections 2. Determine average structural capacity within each subsection
Summary Benefits / importance Data requirements Project evaluation flowchart	Review/summarize objective is to demonstrate: 1. How previous modules are used to complete an overall evaluation

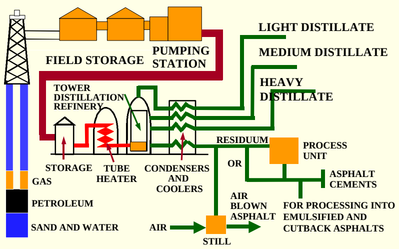
Module 3-1 ***Hot-Mix Asphalt Mixture Overview***	Begin Module 3-1
Objectives **Describe basic properties of asphalt cement** **Provide a brief introduction to SuperPave liquid asphalt cement specifications** **Describe basic aggregate gradations used to produce hot-mix asphalt**	Highlight Objectives: 1. Properties of asphalt cement 2. Superpave specs 3. Gradations
Introduction **This module describes the unique properties of asphalt cement and mineral aggregate and how they are affected by:** • **Construction** • **Traffic loading** • **Environment** • **Time**	Discuss: 1. AC as related to items 2. Aggregate as related to items

General Asphalt Cement Properties

- Adheres well to most rock
- Waterproof
- Fairly durable
- Resistant to reaction with most acids, alkalis, and salts
- Temperature sensitive

Describe general AC Properties

Source of Asphalt Cement



AC Production – Petroleum flowchart

Asphalt Composition

Corbett (Differential Absorption)	Rostler (Acid Separation)
asphaltenes	asphaltenes
petrolenes	maltenes
saturates	paraffins
napthene aromatics	second acidaffins first acidaffins
polar aromatics	nitrogen bases

Component analysis of HMA

Asphaltenes **Represent 5% to 25% of the asphalt** • **Insoluble** • **Black** • **Hard** • **Glassy**	Describe asphaltenes as a component of HMA
Maltenes **Saturates (paraffins)** **Nitrogen base resins** **Aromatics (acidaffins)**	Describe maltenes as a component of HMA
Asphalt Viscosity **High Temperature** **Intermediate Temperature** **Low Temperature**	Asphalt Viscosity: 1. High temp/slow load--more flow, plastic 2. Low temp/rapid load--stiff & elastic 3. Intermediate--combination of two

Polymer-Modified Asphalt The temperature viscosity properties of asphalt cement can be improved by the addition of polymers • High temperature properties determined by type and amount of polymer added • Low temperature properties largely determined by base asphalt cement grade	Explain how PMA works: 1. Improves temperature viscosity 2. Increasing in use
Polymer-Modified Asphalt Polymer classified as: • Elastomers for improvement of elastic properties of asphalt cements • Plastomers for improvement of stiffness of asphalt cements	Describe classifications of PMA: 1. Elastomers 2. Plastomers
Polymer-Modified Asphalt Asphalt properties that can be improved with modifiers • Temperature susceptibility • Adhesion to aggregates • Resistance to permanent deformation • Resistance to fatigue cracking • Elasticity, ductility, durability	Explain how PMA improves properties

New Superpave Binder Specifications

The Superpave binder specification is intended to improve performance by reducing the potential for the asphalt cement to contribute to permanent deformation, low temperature cracking, and early fatigue cracking in HMA pavements

Superpave Specs:

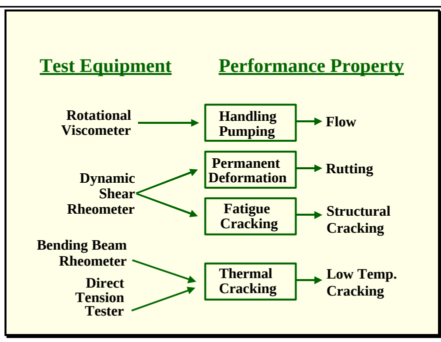
1. Measure physical properties related to field performance
2. Tests different temperatures for environmental regions
3. Simulate 3 critical stages of a binder's life
4. Used to develop mix design

Superpave Binder Specifications

Permanent deformation
Excessive aging from volatilization
Fatigue cracking
Low temperature cracking
Pumping and handling

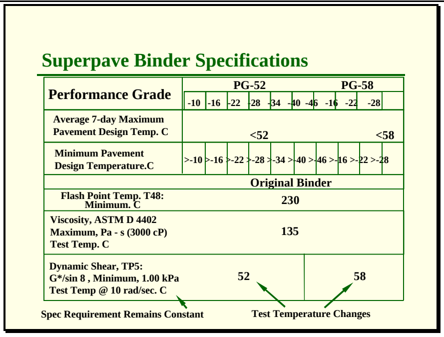
Explain how Superpave performs:

1. Improves performance
2. Limits potential of distress



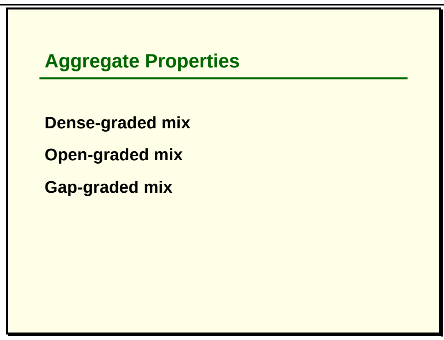
Describe Superpave lab tests:

- Relation to performance



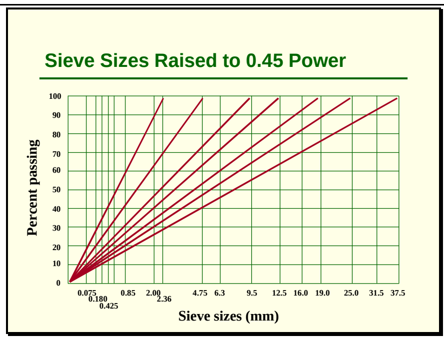
Introduce Superpave binder specs:

1. Test temperatures change
2. Spec requirement remains constant

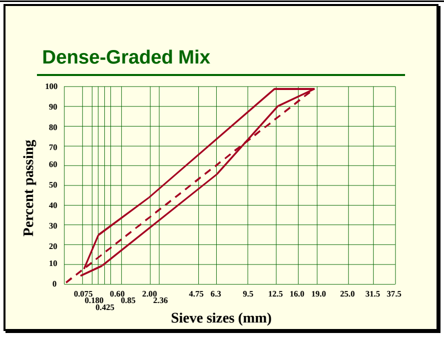


Discuss gradation properties:

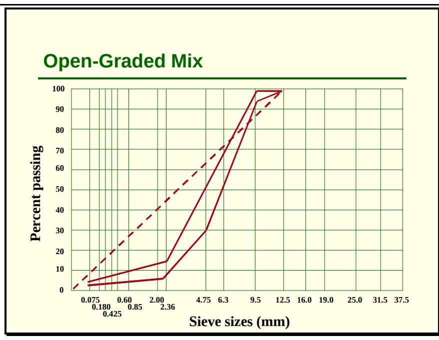
1. Variable property
2. Difficult to control
3. Effects pavement performance



Example of Sieve Analysis



Example of typical specification bands



Example of typical open-graded mix:

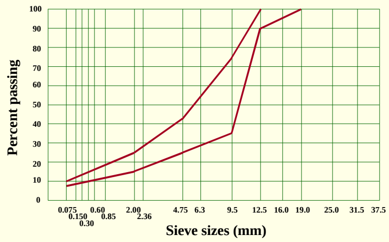
Open-Graded Mix

List of advantages from FHWA TA

- Provides good high speed friction qualities
- Reduces the potential for hydroplaning
- Reduces the amount of splash and spray
- Provides reduction in tire noise
- Improves visibility of pavement markings
- Conserves high quality aggregate

Discuss the list of advantages from FHWA technical advisory

Gap-Graded Mix



Example of typical gap graded mix

Gap-Graded Mix

Stone Matrix Asphalt (SMA) mixes developed and used in Europe are a form of gap-graded mix

SMA provide very stable high performance HMA using gap-graded aggregate to produce large stone contact stabilized with very thick asphalt films

SMA (aka split mastic asphalt):

1. Resistant to fatigue, rutting, & wear
2. Increased service life
3. More expensive

Summary

The properties of the asphalt binder depend on its chemical and mechanical properties which change with time, environment, and applied loading

The properties of the aggregate depend largely on the grading of the aggregate

The ultimate performance of the HMA depends on all aspects of both materials

Review key point covered in this module

Module 3-2 ***Crack Sealing***	Begin Module 3-2
Objectives **Describes recommended procedures for crack sealing operations in HMA pavements**	Identify: 1. Factors affecting sealant performance 2. Procedures for crack sealing 3. Sealant types, properties, specs
Introduction **Crack sealing is applied to** • **Extend the service life of the existing HMA** • **Prepare the existing pavement prior to construction of an HMA overlay**	Discuss purpose of crack sealing: – reduces moisture infiltration – extends life of existing HMA – prepares pavement prior to overlay

Thermoplastic Sealant Materials **Bitumen-based materials that typically soften upon heating and harden upon cooling** • **Hot Applied** • **Cold Applied**	Hot-Applied: 1. Asphalt cement-limited success 2. Asphalt rubber-widely used 3. Rubber asphalt-industry standard 4. Fiberized asphalt-no standards exist 5. PVC coal tar-health problems Cold Applied: 1. Asphalt cutbacks-poor 2. Asphalt emulsions-temperature sensitive & prone to tracking
Thermosetting Sealant Materials **Typically one or two-component materials that set by the release of solvents or cure through a chemical reaction** • **Chemically Cured** • **Solvent Release**	Chemically cured: 1. Polysulfides, polyurethanes – Two-part – Questionable adhesion 2. Silicones – One part – Self & non-self leveling Some sealants show potential for good performance but 4-10 times expense (material) as standard rubberized asphalt (but are placed thinner—lower labor & equipment costs) Solvent Release: 1. Not used on pavement
Purpose and Application **Cracks allow moisture and debris to enter the pavement** • **Contribute to stripping, spalling, cupping, lipping, delaminating, etc.** • **Reduce pavement and base stiffness which contributes to further load related cracking** **Purpose - seal cracks or joints** **Application - Flexible and rigid pavements**	The purpose of sealing cracks: 1. Prevent presence of excess water in base or subgrade which reduces the compressive & shear strengths of the supporting materials immediately below & adjacent to crack

Limitations and Effectiveness

There is a continuing debate regarding the cost effectiveness of crack sealing

SHRP experiments SPS-3 and SPS-4 are examining the effect of sealing activities on pavement performance

Most effective on pavements exhibiting little structural deterioration:

1. Effectiveness of sealing is questioned by some agencies
2. SPS-3 & SPS-4 (SHRP) experiments are examining effect of sealing on pavement performance

Limitations and Effectiveness

There is a general consensus among states that support sealing cracks as a cost effective rehabilitation or maintenance treatment

The overwhelming majority of states's experiences support contention that sealing cracks & resealing joints is meaningful rehab activity

- Within the constraints discussed in this module

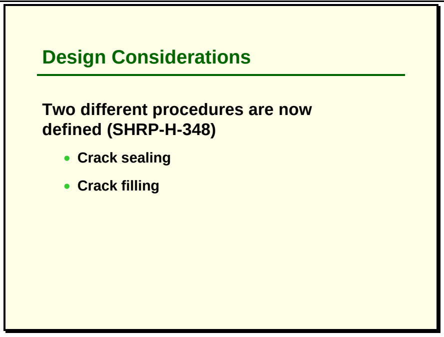
Design Considerations

Factors to be considered

- Climate conditions
- Highway classification
- Traffic level and % trucks
- Crack characteristics
- Materials and placement configuration
- Procedures, equipment, and safety

The planning process (based on existing & future road condition) should concentrate on:

- selecting optimum material & placement configuration
- determining procedures & equipment to be used



Definitions:

1. Placement of materials into working cracks
   – Working = horizontal and/or vertical movement equal to or greater than 2.5 mm (0.10 in)
2. Placement of materials into nonworking cracks
   – Nonworking = movement less than 2.5 mm either from load or annual temperature changes

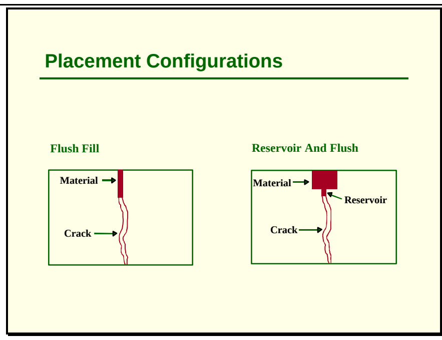


Diagram of different sealant configurations

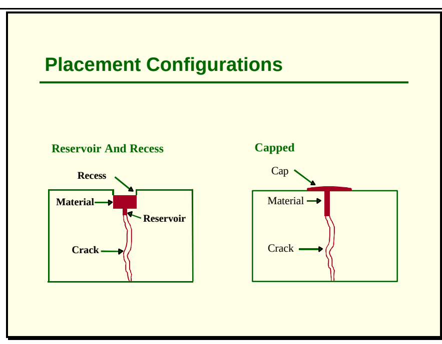
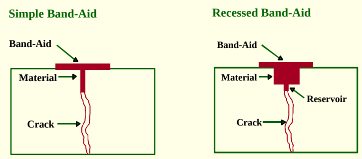
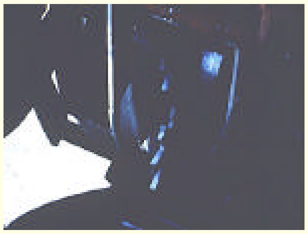
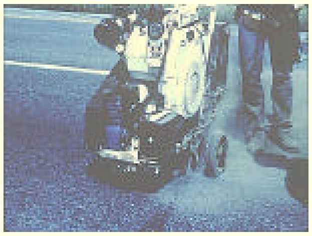
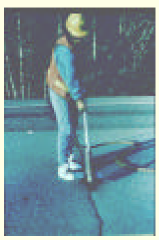


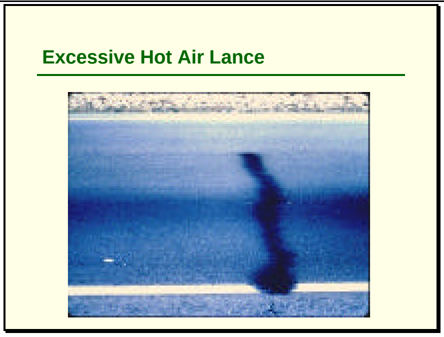
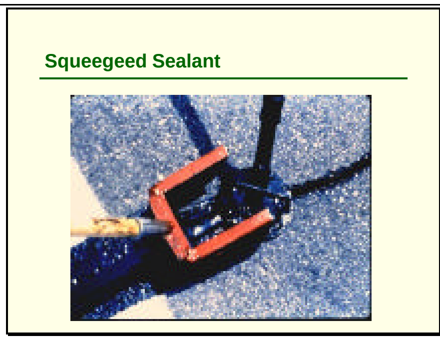
Diagram of different sealant configurations

Placement Configurations 	Diagram of different sealant configurations
Pavement Surveys **Information needed to determine crack sealing needs from survey** • Type of pavement • Overall pavement condition • Type and width of crack • Extent of cracking	To consider a pavement as candidate for crack sealing, bulleted items are needed as well as: 1. Are cracks reflective 2. Relative movement
Cost Considerations **Information needed to determine costs** • Amount of crack to be filled, sealed • Type of crack filler, sealer • Equipment and personnel required • Estimated performance of crack fill or seal	Table 3-6.1 in participant's manual shows typical sealant types & typical cost ranges (materials only) – For cost comparisons, total installation cost & anticipated life of sealant must be considered

Construction Sequence Crack sealing Crack filling	Successful sealing projects require close attention to detail: – Installation procedure is correct
Crack Sealing Crack refacing Crack cleaning Sealant installation	Describe procedure to follow prior to placing sealant in the crack
Vertical Spindle Router 	Example of a vertical spindle router used in crack sealant preparation

Rotary Impact Router 	Example of rotary impact router
Rotary Wheel 	Example of star wheel used in a rotary impact router
Rotary Impact Router 	Example of sawing operation with rotary impact router

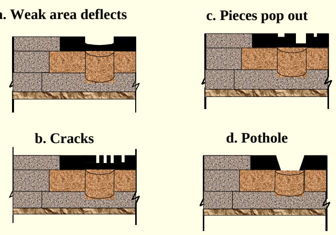
Airblasting 	Example of airblasting to clean cracks with compressed air
Hot Compressed Air Lance 	Example of hot lance equipment being used to clean & heat crack
Hot Compressed Air Lance 	Example of normal hot lance operation

	Example of excessive hot lance application: – Pavement was burned
	Example of sealant being squeegeed during crack sealing
	Example of finished crack seal with squeegeed overband

Crack Filling Crack cleaning Sealant Installation	Crack filling is intended to fill crack with low quality material to reduce/eliminate deterioration until rehab work can be done – Little if any crack preparation work is done (although cleaning with compressed air may occasionally be done)
Summary This section covered the basic aspects of crack sealing and filling which is used as a specific rehabilitation treatment, or as preparation for an HMA overlay Included were crack sealing materials, design, and construction procedures	Instructor should summarize key points in this module

Module 3-3 ***Patching With Bituminous Mixtures***	Begin Module 3-3
Objectives **Describe patching materials** **Review procedures**	Objectives of this module: 1. Describes properties needed in a bituminous patch 2. Techniques for construction of patches
Introduction **Patching the existing pavement with bituminous materials** • **Extends the service life of the existing HMA** • **Used in the preparation of existing pavement prior to construction of an HMA overlay**	Patching requires consideration be given to: 1. Pavement structure 2. Material used – Various materials available with range of results 3. Procedures used in construction

Introduction



Stages in the development of a pothole

Definitions

Bituminous patching materials

- Cold-mix
  - Used as temporary patches
  - Placed in stockpile and used over a period of time (Emulsion binders)
  - Special open-graded mixes
- Hot-mix asphalt (HMA)
  - Placed immediately while hot
  - Standard dense graded HMA

Definition for cold mix:

1. Combination of aggregate & either of two asphalt based binders
   – Cutbacks or emulsions
2. Chemical modifiers can be added to binder material
   – Enhance characteristics (notably stripping resistance)

Definition for HMAC:

1. Traditional material used to construct & do overlays
2. AC is heated & mixed into aggregate at central plant
3. No curing process

Purpose and Application

Patching of existing HMA to:

- Repair localized distress
- Improve motorist safety
- Reduce pavement roughness
- Reduce the rate of deterioration
- Repair pavement prior to overlay

Describe reasons why patching of HMA pavements is generally performed

Limitations and Effectiveness

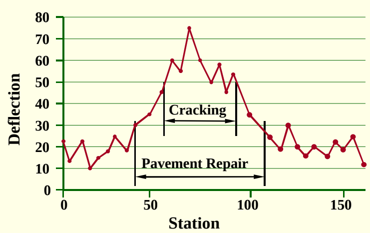
Patching is used to treat structurally or functionally deteriorated pavement

- **Application may not be appropriate**
- **Temporary patches are temporary**
- **Design may not be adequate**
- **Principal problem may not be corrected**

Potholes can be an indication that more extensive damage is present within structure:

1. If large areas of fatigue cracking are not patched, pavement will deteriorate
2. Waste of time & money

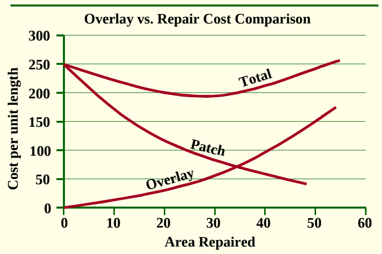
Pavement Survey and Marking



Example of relationship between surface deflection measured with NDT & areas with visible fatigue cracking:

1. Areas with visible fatigue should be patched
2. Plot shows areas with high deflections that do not show fatigue cracking
   – fatigue cracking begins at bottom of asphalt
   – cracks not showing yet

Cost Considerations



Optimum pavement management strategy favors projects as they start to fatigue crack but are not fully fatigue cracked:

1. Leads to need for some repair as part of most overlay design
2. When significant difference in overlay thickness, make comparisons between basic levels of repair for weakest sections & reduced overlay costs as shown here

Construction

Winter maintenance

- "Throw and Go" the most cost effective

Summer maintenance

- Semi-permanent patch the most cost effective
- Found to be three times more cost effective when considering full life cycle costs in a Pennsylvania study

Throw-and-go:

1. Shovel cold-mix into pothole & leave for traffic to compact
2. A life-cycle cost analysis of AC patching used in Pennsylvania found that throw-and-go cost approximately 3 times more than semi-permanent patching

Construction - Poor Conditions

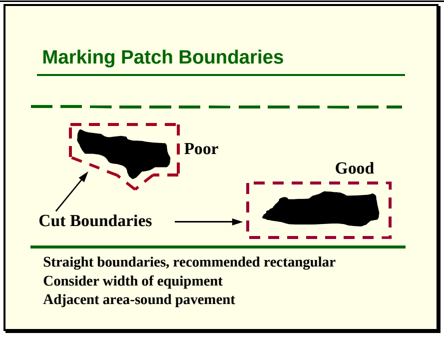
Example of situation where throw-and-go is appropriate

Construction

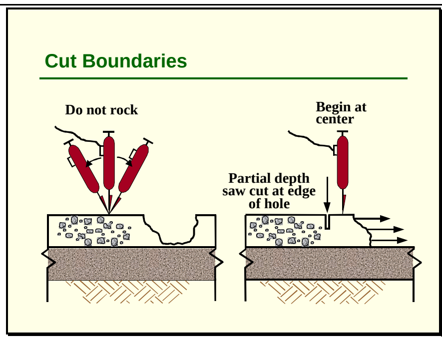
Procedures for construction of a semi-permanent patch

- Mark patch boundaries
- Cut boundaries
- Clean and repair foundation
- Apply tack coat
- Fill the hole with patching material
- Compact the patch
- Cleanup

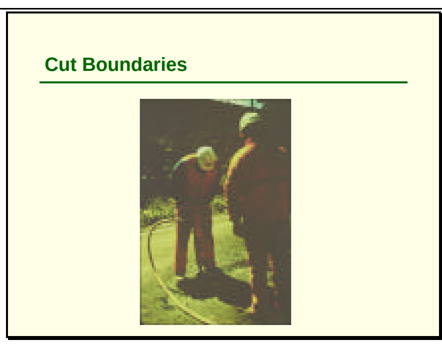
These area procedures identified by PennDOT for construction of a semi-permanent patch



Patching procedures:
1. Wide enough for equipment
2. Does not require a lot of hand work

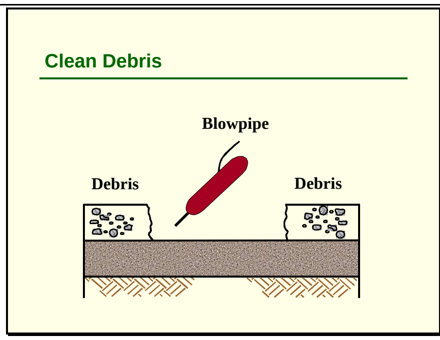


Discuss procedures for removal of deteriorated material for patch area:
1. should begin in center of marked area & work out toward patch boundaries
2. should be to depth where sound, dry material is found
3. full-depth saw cutting not recommended
   – produces too smooth of a face for good bonding
4. partial depth saw cuts & breaking out with jackhammers leaves rough face for bonding & interlock with patch material



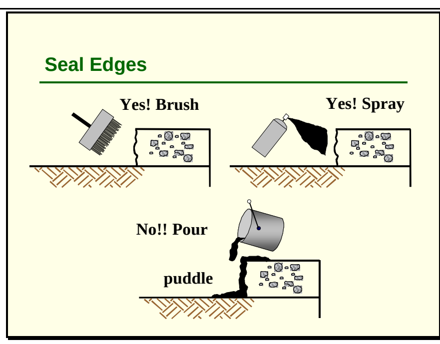
Example of material removal with a spade bit on a jackhammer

Example of removal with a small milling machine



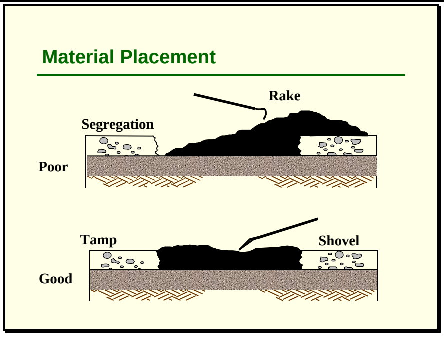
Explain importance of thorough cleaning :

1. provide surface for tack & patch material to bond
2. remove all loose particles with compressed air (emphasis corners)
3. if remaining material in bottom is wet, loose, soft, or disturbed must be reworked, dried out, recompacted or removed



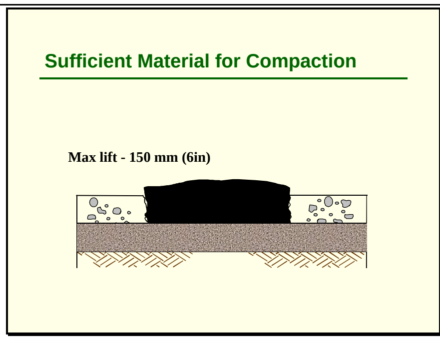
Discuss importance of tack coat to long-term performance of HMA patch:

1. tack coat wets existing material to promote bonding with patch mix
   – emulsions, cutbacks, synthetic resins provide suitable results when properly used
2. Should be low-pressure sprayed or brushed onto patch area
3. Obtain uniform thin coating along edges of prepared hole

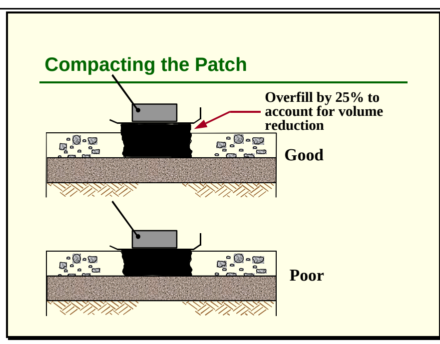


Patching material can be placed in 102 mm (4-in) lifts

1. Thicker patches placed in lifts determined by local experience & specs
2. Should be placed with shovel working from one side of patch to other
3. Material should never be thrown or raked into hole (could cause segregation)



Compaction is most critical procedure in obtaining a good patch



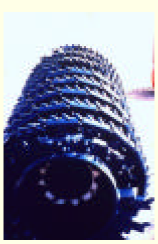
1. HMAC patch must be compacted before cools
2. Undercompacted mix will
   – Ravel, shove out of patch, compact excessively with traffic & leave a depression
3. Process & equipment should match size of hole being compacted
4. Material should first be pinched into hole by rolling edges of mix
5. Center of patch should be patched, moving outward toward edges with each pass
6. Roller must rest completely on patch & not on old pavement

Compacting the Patch 	Example of patch compaction with a pan vibrating compactor
Finished Patch 	Example of a completed patch
Automated Patching Equipment Rosco RA-200 Durapatcher Wildcat Roadpatcher	Recent development in pothole repair have produced a series of automated or semi-automated patching equipment: 1. Spray injection devices use a crushed aggregate & asphalt binder that are blow into pothole simultaneously to produce cold-mix 2. Three examples are listed

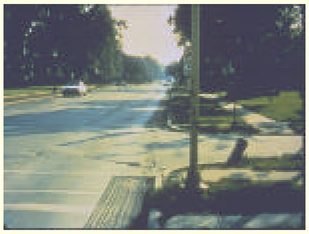
Automated Patching Equipment Spray injection procedures • Blow debris from hole • Spray hole with binder for tack coat • Blow aggregate and binder into hole • Top off with a layer of uncoated aggregate to prevent tracking • May be rolled to improve smoothness	All three use heated emulsified asphalt in most cases for improved coating & compaction: 1. Describe items listed on slide 2. Most manufacturer's do not require compaction of the material – Believe force of material as it is blown into hole provide compactive effort
Automated Patching Equipment 	Example of automated patching equipment
Automated Patching Equipment 	Example of the Wildcat Roadpatcher

Summary **This section covered the basic aspects of patching with bituminous materials which is used for maintenance, or as preparation for an HMA overlay** **Included were bituminous patching materials, design, and construction procedures**	Instructor should summarize what he/she feels are key point about module

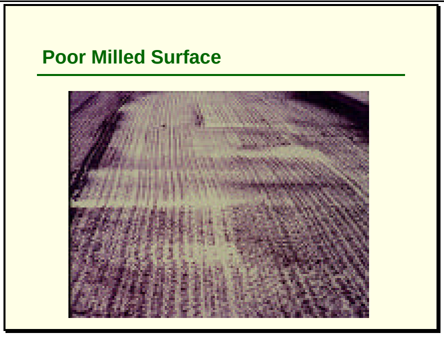
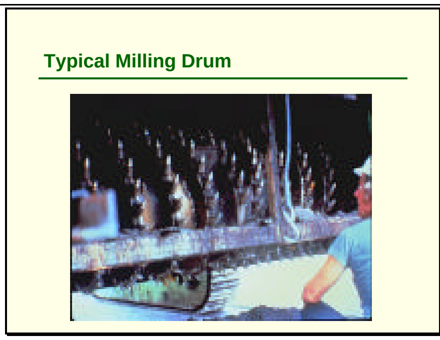
Module 3-4 ***Cold Milling***	Begin Module 3-4
Objectives **Application and uses of cold milling** **Describe equipment and construction procedures** **Differentiate between diamond grinding and cold milling**	This module describes basic techniques for pavement surface restoration: 1. Differentiate & describe objective – Diamond-grinding – Grooving – Cold-milling 2. Major reasons for cold milling HMA pavement surfaces 3. Describe equipment & construction problems
Cold Milling Equipment 	Example of typical cold milling operation removing HMA

Introduction Cold milling has evolved over the last 20 years such that its use has changed or modified many of the older processes for HMA removal, leveling and overlay preparation	Diamond-grinding & cold milling: 1. most basic forms of surface restoration 2. uses surface removal 3. corrects variety of surface distresses Each technique addresses specific distresses & may be used with other restoration techniques – Sometimes may use as only technique Only cold milling covered here
Definitions Cold milling - removal of pavement surface using drum-mounted carbide steel cutting bits	Define cold milling
Milling Drum - Triple Warp Head 	Example of typical carbide toothed milling head

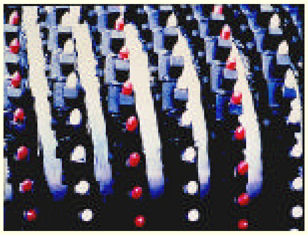
Purpose and Application **Cold milling has been used primarily on HMA, but there is some emerging use on PCC. Its use can range from full lane width removal to small areas of partial depth removal**	Generally performed on flexible pavements but increasingly on rigid pavements with HMA surface: 1. Mass removal of HMA surfaces 50 to 100 mm (2-4 in)
Purpose and Application **Major uses for cold milling:** • **Removal of rutting** • **Restoration of curb line** • **Restoration of cross slope** • **Restoration of surface friction** • **Mass removal of HMA** • **Roughened surface for improved bond between layers**	Can be used for: 1. Removing a layer of rutted or raveling ACP to recycle & replace 2. Preparation for new overlay 3. Level & profile existing surface to correct minor roughness or rutting – Requires a finer surface texture than mass removal
Mass Removal 	Example of mass removal of HMA over rigid pavement in preparation for a new overlay

Edge Milling to Maintain Curb Line 	Example of cold milling along curb where HMA has been removed to lower elevation at curb line before overlaying with new HMA
Rut Removal 	Example of pavement that has been milled to remove rutted pavement
Limitations and Effectiveness **Surface texture produced by milling is a function of:** • **Carbide bit spacing** • **Depth of cut** • **Rotational speed of head** • **Speed of travel**	Cold-milling provides a surface with: 1. Good frictional characteristics 2. Improved macrotexture 3. Better drainage profile

Potential Operation Problems 	Example of pavement texture resulting from excessive milling speeds
Design Considerations • Resulting surface profile • Skid resistance • Pavement removal and surface profiling	Quality of cold milling can be assessed through measurement of pavement roughness afterwards: – same ride quality standards as new construction – profile traces prior are compared to profiles after to determine improvements in ride quality
Construction Considerations Pavement to be resurfaced • Standard head with normal carbide bits • Standard line and grade requirements Pavement surface to be turned over to traffic • Special heads with more carbide bits • Smoothness and grade requirements in line with HMA wearing course	Technology is used on flexible & rigid pavements: 1. For flexible pavements, use of multi-head blocks may be cost-effective for – removing ruts – improving skid resistance – without producing excessive tire noise

	Example of poor surface texture left from cold milling
	Example of milling drum with standard tooth configuration
	Example of carbide tooth milling head with special tooth attachments (top down): – triple tooth – two rows of single tooth – double tooth

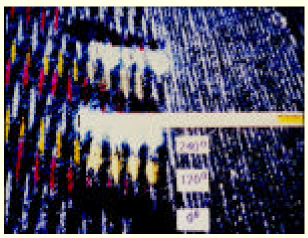
Special Multiple "Warp" Drum



Example of special milling head:

- with a triple warp milling head
- has three times the number of carbide teeth
- creates more contact at closer spacing
- produces a finer pavement texture after milling

Single Warp Vs. Triple Warp Drums



On the left of the side, example of pavement texture left after milling with a standard milling head with normal tooth configuration;

On right, texture left after milling with a special triple warp head:

- Tripling the teeth reduces the size & spacing of each divot removed by each tooth
- Results in finer surface texture

Milling Wheelpaths in Sweden

Example of special milling operation in Sweden:

- Southern Sweden experiences extensive studded tire wear
- Milling machine removes rutted pavement caused by stud wear

<table>
<tr><td>
</td><td>Milled areas are paved with new HMA</td></tr>
<tr><td>
</td><td>New HMA is compacted</td></tr>
<tr><td>
</td><td>Finished pavement is very smooth & uniform:
– Replaced wheelpath rutting can be seen but not felt</td></tr>
</table>

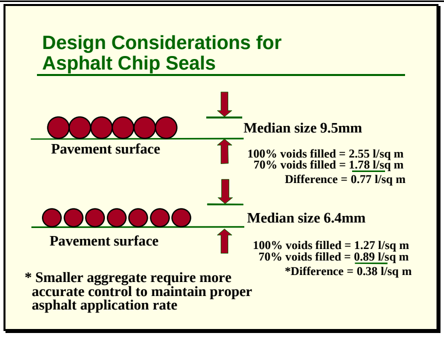
Summary **This section covered the basic aspects of cold milling which is used as a specific rehabilitation treatment, or as preparation for an HMA overlay** **Included were discussions on milling equipment, design, and construction procedures**	Summarize key point presented in this module

Module 3-5 ***Surface Rehabilitation Treatments***	Begin Module 3-5
Objectives **Describe the major types of surface rehabilitation techniques** **Discuss the basic design principles and characteristics of the various surface treatments** **Describe the construction techniques and equipment required for successful application of the surface treatments**	Introduce the various surface applied rehab techniques: 1. Chip seals, slurry seals, friction seals – Well-established methods – From low-volume roads to interstate highways
Introduction **Surface rehabilitation techniques** • **Have been historically used on low-volume roads in rural areas** • **With improved materials and processes are now being used on higher volume roads**	Discuss surface rehab techniques used for asphalt pavement maintenance & rehab: 1. Successfully extend pavement life at lower expense 2. Techniques with long-term performance may be considered for Federal 4R funding

Definitions **Surface application of asphaltic material with or without aggregate** • Fog seal • Sand seal • Asphalt chip seal • Slurry seal • Micro-surfacing • Cape seal	Introduce typical surface application treatments
Fog Seal 	Example of fog seal that has been used to seal a shoulder (application is either very fresh or very heavy)
Asphalt Chip Seal 	Example of an application of rubber asphalt as the binder for a single coat chip seal

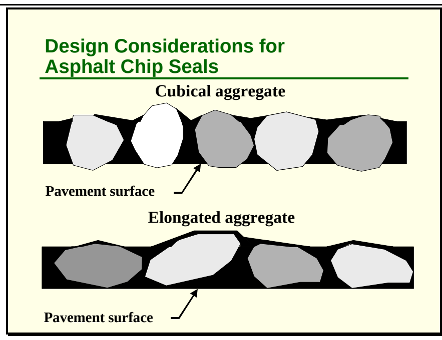
	Example of typical slurry seal
	Example of an application of microsurfacing
	Example of a cape seal being constructed (slurry over chip seal) – From Cape Province of South Africa

Functions of Surface Treatments Provide a new wearing surface Seal cracks in the surface Waterproof the surface Improve pavement surface friction and surface drainage	Describe the functions surface treatments
Functions of Surface Treatments Slow pavement weathering and aging Improve the surface appearance Provide visual delineation between the mainline pavement and the shoulder	Explain the functions of surface treatments
Design Considerations Asphalt chip seals • Existing pavement condition • Asphalt type • Aggregate • Quantity selections • Local conditions and experience • General environment	Two components to consider in design: 1. Asphalt material 2. Aggregate Variation in properties can result in complex design; local conditions must be taken into account



Voids in aggregate vary with gradation & maximum size:

1. Smaller aggregate--smaller void space
2. Finer gradations require lower asphalt application rate
3. Variation of +/- 0.23 L/m^2 (0.05 gal/yd^2)cause either bleeding or more rock loss



Shape of aggregate has effect on overall dimensions of:

1. Chip layer
2. Asphalt required for chip embedment
3. Cubical shaped chips preferred

Example of emulsion applied too heavily

Pavement Surveys

Performance of surface treatments highly dependent upon existing surface condition

- Amount of distress may restrict the choice of surface treatments
- More severe cracking require multiple lifts of asphalt chip seal
- Distorted pavement surface may require leveling up layers

If existing pavement is not structurally adequate to carry projected traffic for next 3-5 years, do not consider surface rehab techniques such as:

1. Open graded friction cores, slurry seals, & microsurfacing

Surface techniques that can be used (within limits) & provide reasonable service life:

2. Single & multiple chip seals

Cost Considerations

Typical surface treatment costs

Chip seal	$0.90 /m²
Db. chip seal	$1.35 /m²
Slurry seal	$0.84 to $1.14 /m²
Micro-surfacing	$1.05 to $2.00 /m²
Fog seal	$0.12 to $0.17 /m²
Sand seal	$0.30 to $0.48 /m²
Cape seal	$1.70 to $2.40 /m²

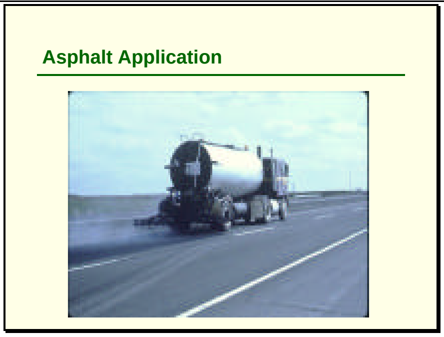
Illustrates average range of costs

Construction Procedures

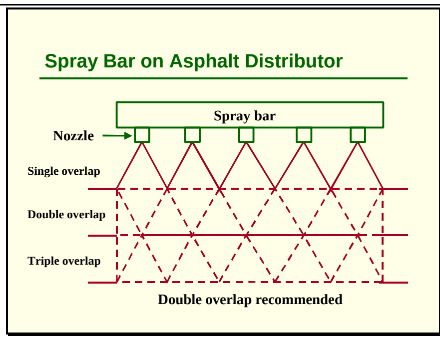
Chip seal construction issues:

- Equipment calibration
- Pavement surface preparation
- Application of asphalt
- Application of aggregate
- Rolling of aggregate
- Curing of binder
- Brooming of loose aggregate

Discuss each item in the slide in detail



Example of asphalt emulsion being applied for a chip seal

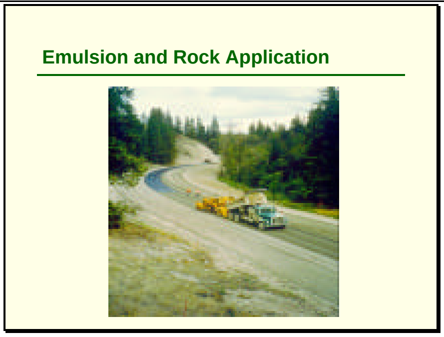
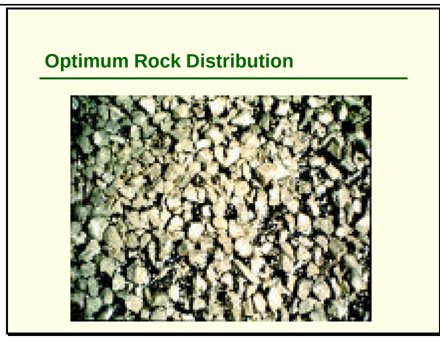


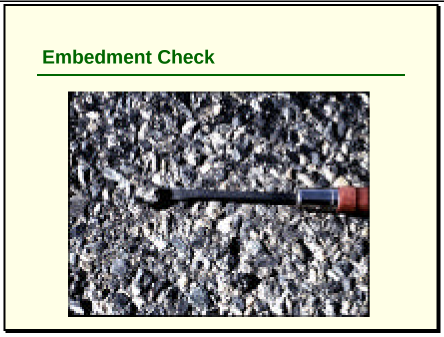
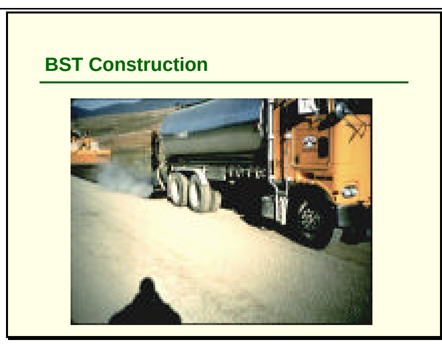
Example of spray fans from spray bar of asphalt distributor:

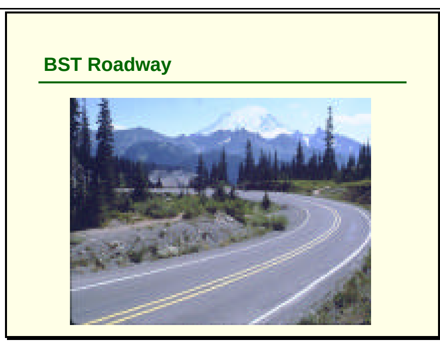
1. Double lap preferred
2. Spray bar has to be parallel to pavement surface & same height above surface throughout shot

Example of application of chips for chip seal:

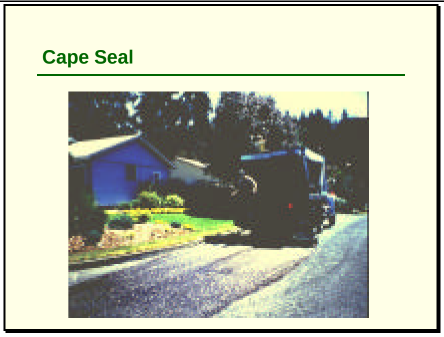
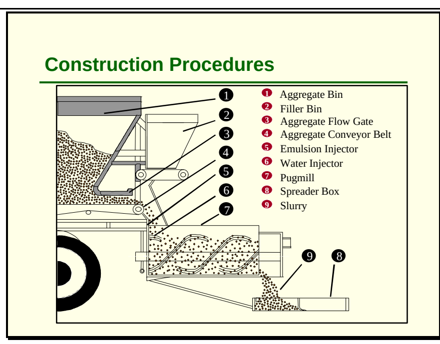
1. Note applications rate is a little heavy
2. Chips should be surface moist, not wet

	Chip application should closely follow an application of emulsion: – Separation should not be much greater than that shown in this photo
	Example of proper application of chips & asphalt emulsion
	Example of roller following application of chips: – Note rolling does not compact chip seal – Rolling embeds chips in emulsion & lays chips on flat side

	Example of chip removal to check embedment of chip in emulsion
	Top layer of BST with chip seal
	Second application of emulsion over 19mm chips

	Second layer of 12 mm chips for a two-layer BST
	Standard rolling of chips
	Example of BST roadway

Construction Procedures Fog seal Sand seal Slurry seal Cape seal Micro-surfacing	General discussion of construction procedures for the item listed
Slurry Seal 	Example of slurry sealing operation: – All cracks have been sealed before placing the slurry – Sealer should be squeegeed flush with pavement
Cape Seal 	Example of slurry seal being applied as the finish coat over a chip seal for a cape seal

	Example of slurry seal being applied as part of a cape seal
	Example of microsurfacing operations
	Illustrates the construction procedure for microsurfacing

	Example of rutted pavement that will be filled with microsurfacing
	Example of ruts filled with microsurfacing – Better to apply in several thin lifts than one thick lift
	Example of application of final layer across the full lane to finish project

Summary This section covered the use of various surface treatments which may be used for specific rehabilitation treatments Included were the various surface treatments, the materials used as well as a brief description of the types, design, and construction procedures	Summarize key point in this module

Module 3-6 ***Recycling Overview***	Begin Module 3-6, Pavement Recycling Operations: 1. Asphalt pavement recycling operations are discussed in modules 3-7, 3-8, & 3-9 2. PCC recycling is discussed in module 4-12
Objectives **Identify types of pavement recycling** **Describe recycling practices** **Describe recycling equipment** **Selection of recycling options** **Define recycled pavement mixture design techniques** **Describe benefits, costs, and performance of recycling operations**	Describe the following: 1. Types of pavement recycling operations 2. Equipment 3. Construction sequences 4. Mix design process 5. Recycling options for rehab & maintenance 6. Benefits, costs, and performance of recycling
Introduction **Recycling - A rehabilitation alternative** • **34 states using some form of recycling** • **$100 million in annual savings** • **Recycling is not a new concept**	Explain that recycling is a rehab & maintenance alternative: 1. Discuss bullets (self-explanatory) 2. Began in 1915 3. Amount recycled from 1915-1975 is small compared to amount after 1975 4. Due to equipment development and oil embargo in late 1973

Major benefits

- Reduced cost
- Preservation of existing pavement geometrics
- Conservation of aggregates and binders
- Preservation of the environment
- Energy conservation

Recycling has become increasingly important due to:

1. Bullet items (self-explanatory)
2. Recycling as rehab & maintenance alternative is expected to increase in future

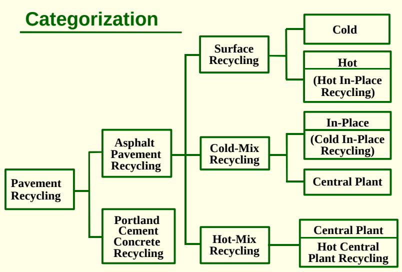
Types of pavement recycling

- Surface recycling
- Cold recycling
- Hot recycling
- Portland cement concrete recycling

Pavement recycling categories after research and development efforts:

1. Asphalt Recycling Types
   – Surface
   – Cold
   – Hot
2. PCC Recycling Types
   – Not same interest as asphalt
   – Supplied aggregate for PCC, base courses, asphalt stabilized materials, and chip seals

Categorization



Various forms of recycling are identified:

1. Recycling technology has continued to develop
2. Earlier types are discontinued
3. Three primary forms of asphalt pavement recycling are identified
   – Hot in-place--form of surface recycling
   – Cold in-place
   – Hot central plant--cold central plant is sometimes performed

Definitions Recycled asphalt pavement (RAP) Reclaimed aggregate material (RAM) Recycled hot-mix asphalt Asphalt recycling agent Asphalt modifier	Additional terms are sometimes used: 1. RAP- removed and/or processed pavement materials containing asphalt binder & aggregate 2. RAM-removed and/or processed pavement material containing no asphalt binder 3. Recycled HMA-final mixture of RAP, new asphalt binder, recycling agent, & new aggregate if required – Recycling agent – ASTM D4552, petroleum product with combination of chemical & physical properties designed to restore aged asphalt to a desired specification 4. Asphalt modifier-any compound or material used as an admixture to alter/improve properties of asphalt binder or HMA mixture
Selection of Recycling as a Rehabilitation Alternative Condition of existing pavement Traffic levels Expected life Costs Time required for rehabilitation	Explain that factors for selection of recycling as rehab or maintenance alternative are same as factors for other alternatives 1. Listed items are primary factors
Surface Recycling • Advantages • Disadvantages	Advantages & disadvantages are listed in table 3-6.1 of participant's manual

In-place Recycling • Advantages • Disadvantages	Advantages & disadvantages are listed in table 3-6.1 of participant's manual
Central Plant Recycling • Advantages • Disadvantages	Advantages & disadvantages are listed in table 3-6.1 of participant's manual
Module — **Title** 3-7 Hot in-place recycling 3-8 Cold in-place recycling 3-9 Hot central plant recycling 4-12 Rigid pavement recycling	This reference list contains key modules associated with recycling

Module 3-7

Hot In-Place Recycling

HIPR is most popular form of asphalt pavement surface recycling

1. Recycling with heat source is called cold planing or cold milling
   - Primarily used for remove & replace overlay operations
   - Materials removed can be used as base course for cold in-place, cold central plant & hot central plant recycling
2. Hot in-place uses heat source to raise temperature in pavement

Objectives

Types of hot in-place recycling
Equipment and operational sequence
Mixture design methods
Structural layer coefficients
Economics
Specifications
Quality control / Quality Assurance

Objectives:

1. Identify types of hot-in place recycling
2. Types of equipment
3. Sequence of operation of equipment

Introduction - History

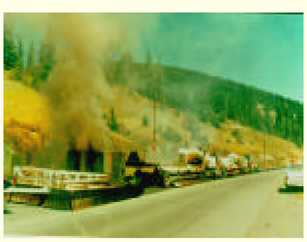
1930s - 1940s	Heater planer
1950s - 1960s	Heater scarification Heater repaving
1980s	Heater remixing
Late 1980s and 1990s	Increased depths Improved uniformity and air quality

Discuss information listed

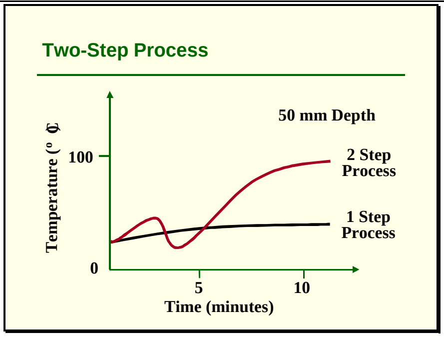
General Attributes Soften existing asphalt pavement with heat Mechanically removing the pavement Mixing with asphalt binder and/or new mixture Replacing recycled pavement on surface	Discuss the hot in-place recycling process as listed – May be performed in a single or multi-pass operation
Methods and Equipment Heater scarification Repaving Remixing	Discuss methods & equipment
Early Pavement Heater 	Example of early pavement heater

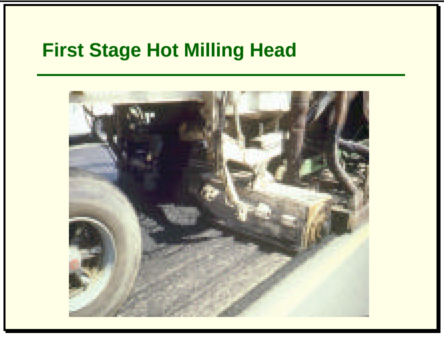
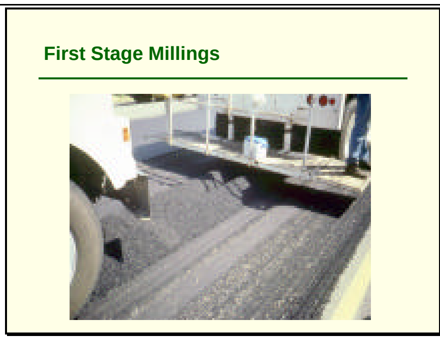
Early Propane Heater and Scarifier 	Example of early propane heater with scarifying teeth
Early Propane Heater and Scarifier 	Another view of early propane heater & scarifier
Small Heater for Patching 	Example of small heater used for patching pavements

Early Multi-Stage Heater 	Example of early multi-stage heater
Typical Heater Scarifying Operation 	Example of typical heater scarifying operation
Equipment Development and Typical Use **Early concerns** • In-place air voids • Overheating • Air quality • Safety • Depth • Production / cost • Vegetation	Discuss items of early concern

Equipment Development and Typical Use 	Example of early equipment
Problems with Heater 	Example of problems with early heater where direct flames have ignited pavement
Multiple Stage Heater with Milling Head 	Evolution of pavement heater to multiple stage heaters with hot milling heads to pick up heated pavement

Multiple Stage Milling Removal 	Example of multiple stage milling removal where two milling heads removed 25 mm each for a total removal of 50 mm
What Potential Problems Here? 	What potential problems here? – Heaters may kill plants next to curb
Equipment Development and Typical Use **Developments in the late 1980s, early 1990s** • Greater depths • Uniformity and control • Air quality • Production	Equipment developments have concentrated on these items listed

	Example of a two step heating & milling operation
	Temperature/time relationship for single & two-step process at 50 mm (2- inch) level: – One step process, heat is applied only to surface – Temperature rise at 2-inch depth is slow and at a low level
	Example of a project with a two-step process

	Example of first stage hot milling head & pavement removal
	Millings are placed in a windrow then picked up & conveyed over second stage heater & milling head
	Example of new mix being introduced

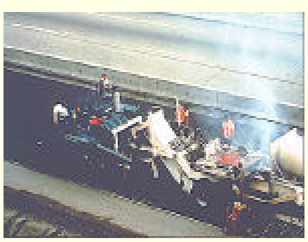
Added HMA

Example of added HMA:
- HMA grading is a little coarser than normal to account for finer materials produced in the milling operation

Pavement After Second Milling

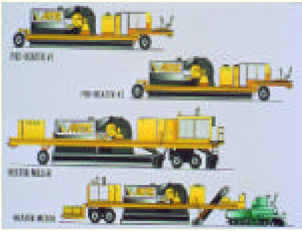
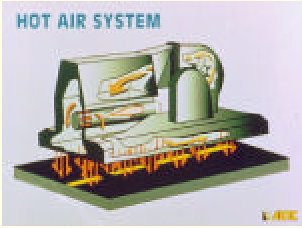
Example of pavement surface after removal of pavement by second hot milling head

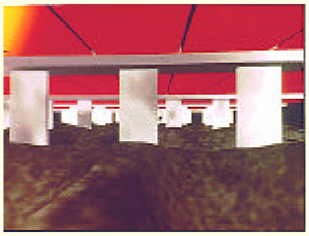
RAM and New Mix Passed to Paver



Example of RAM & new mix as it comes from pug mill & is placed in paver

RAM and New Mix Behind Paver 	Example of RAM blended with new mix placed with paver – Mix is over raked
Needs (1994) Higher mixture temperatures Greater depths Improved air quality Variable widths Reduced noise Larger amounts of new material Climb steep grades Better uniformity QC/QA guidelines	In 1994, a workshop on HIPR recognized that additional equipment developments were needed to maximize potential of this type of recycling
Operating Characteristics Hot air and low level infrared for heating Diesel and other fuels Recirculating hot-air system air quality Heating, stirring, drying of RAP on road surface	Equipment has beneficial operating characteristics: 1. Heating accomplished by hot air produced in combustion chamber & low level infrared 2. Diesel & other fuels produce hot gases 3. Hot gases are recirculated to improve air quality 4. Heating, stirring & drying of RAP is done on pavement surface 5. Mixing of materials is performed in high capacity pugmill

Five-Step Process **Preheating (units 1 and 2)** **Heater / Miller (unit 3)** **Heater / Mixer (unit 4)** **Addition of new material and mixing** **Laydown and compaction**	Describe the five step-process that is performed on four units of equipment
Five-Step Process 	Example of the newly developed equipment
Five-Step Process 	Heater system consists of a combustion chamber to produce the hot gases – Gases are distributed onto the pavement through a manifold & then recirculated

Mixing Paddles and Hot Air 	The heater & stirring process is performed on old pavement – Very efficient as heat does not have to penetrate from the surface to heat the pavement at depth
Five-Step Equipment 	Five step equipment working on a project
Use of Hot In-Place Recycling Experimental basis - 28 states Somewhat regular basis - 10 states Heater scarification - 13 states Repaving - 15 states Remixing - 16 states	Discuss use of HIPR by states

Economics

Hot-In Place Recycling Operation	Approximate Cost (Dollars / sq.m.)
Heater-scarification (25 mm + recycling agent)	1.20
Heater-scarification (+ 25 mm overlay)	3.17
Repaving (recycle 25 mm + 25 mm hot-mix asphalt mixed together)	3.50
Remixing (recycle 25 mm + 10-20 percent new hot-mix asphalt)	2.75
Remixing (recycle 50 mm + 10-20 percent new hot-mix asphalt)	3.25

Typical cost information for HIPR

- Dependent upon required depth, use of recycling agent & environmental conditions

Guidelines For Use

Uniformity of old pavement
Depth of old HMA
Presence of chip seal
Asphalt content
Aggregate gradation
Asphalt properties
Traffic
Types of distress

The selection of HIPR should consider the factor shown:

- Properties of HIPR are dependent upon many of these factors
- Typically HIPR projects are covered with a chip seal or HMA

Specifications

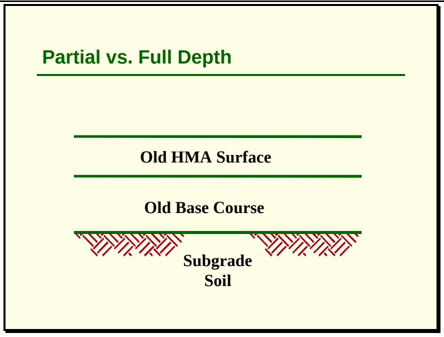
Description
Materials
Mixture design
Equipment
Construction operation
Acceptance
Measurement
Payment

Key sections of HIPR specs should include factors shown:

- Depth of recycling & quality control/quality assurance sections of specs are extremely important

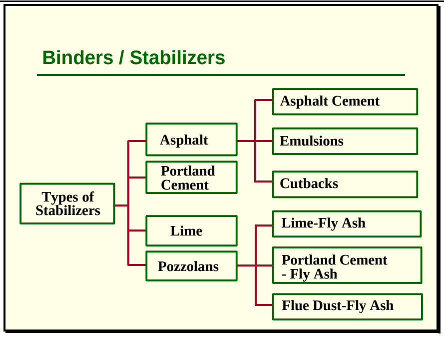
Quality Control / Quality Assurance Adjustments for condition of old pavement Asphalt binder content In-place density Laboratory molded density Smoothness Depth of recycling	Typically QC/QA specs with pay factors are not utilized with HIPR: – Key items to include are those listed
Summary HIPR types Equipment Mix design Economics Specifications QC /QA	Summarize key points from this module

Module 3-8 ***Cold In-Place Recycling***	CIPR is one of most popular forms of pavement recycling – Used by cities, counties & state agencies for rehab – Primarily on low volume roads – Substantial savings possible when using CIPR compared to other rehab techniques
Objectives **Types of cold in-place recycling** **Types of equipment and operational sequence** **Mixture design methods** **Structural layer coefficients** **Economics** **Specifications** **Problem Areas**	Objectives is to identify: 1. Types of CIPR 2. Equipment & sequence of operation
Cold In-Place Recycling **Partial depth** **Full depth**	Discuss the two CIPR operations: 1. Partial depth – Usually recycling top 50- 100 mm of depth – Does not penetrate into the unbound pavement layers 2. Full-depth – Recycles existing asphalt bound materials & a portion of unbound materials beneath surface layer – Depths usually 100- to 300 mm



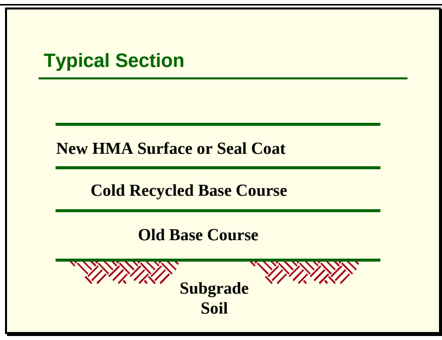
Depth of recycling determines:

1. Type & sequence of equipment
2. Speed of operation
   – typically more uniform operation when partial-depth CIPR is performed



Variety of stabilizers can be used with CIPR:

1. Asphalt most common
2. PCC, lime & pozzolans have been used
3. CIPR without stabilizers is common



Typical surface courses used on CIPR materials:

1. Chip seals
   – Low volume roads
2. HMA
   – Common on numerous projects

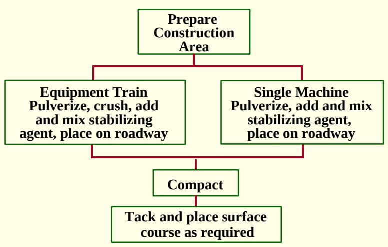
Recycling Methods and Equipment

- Pavement sizing
- Addition of new aggregate
- Addition of new asphalt / recycling agent
- Mixing
- Laydown
- Aeration
- Compaction
- Curing
- Application of wearing surface

CIPR operations consist of some or all listed:

1. Equipment & sequence of operation dictated by specs, contractor experience & type of CIPR (partial- or full-depth)

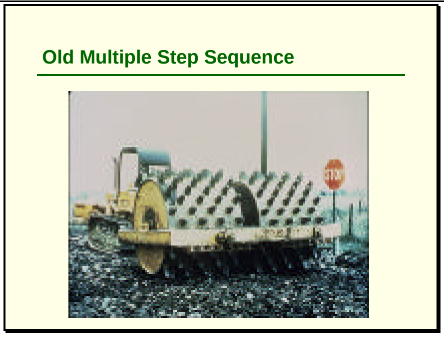
Recycling Methods and Equipment

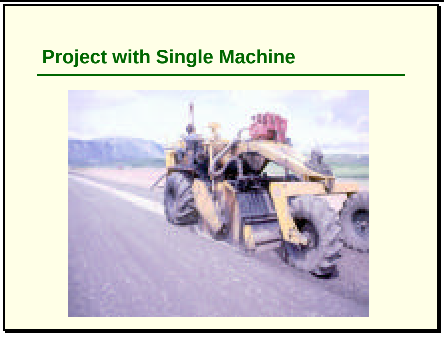
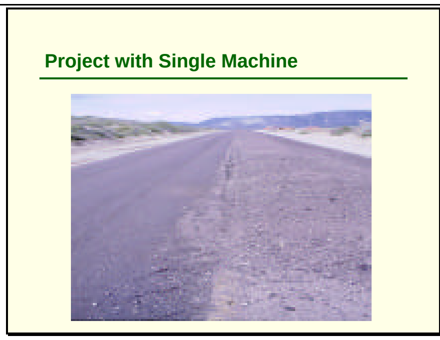


Example of typical operations for partial-depth CIPR

Old Multiple Step Sequence

Example of ripping of HMA as final stage of old multiple step cold recycling sequence

	After ripping, the HMA was broken down in place with a sheepsfoot roller
	Same process is now accomplished much more efficiently by milling & sizing with a single machine
	Single machine can also be used to mix emulsion in place after milling & sizing

	Example of project in Eastern Washington: – First milling pass
	Example of second sizing pass on left side
	Example of single machine used to mix emulsion with RAM & some of the underlying base rock

Project with Single Machine 	Another example of mixing emulsion with RAM & base rock to produce emulsion bound base
Project with Single Machine 	Example showing a problem with uneven emulsion application
Project with Single Machine 	Example of cold recycled material re-laid with a paver to get proper line and grade: – After emulsion treated base cured for 3 weeks, a 75 mm HMA wearing course was placed over the base

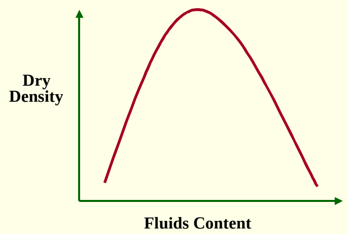
	Example of cold recycling equipment train in action: – Milling machine, small crusher, pugmill
	Example of cold recycled material picked up & placed in a paver
	Example of cold recycling project

	Example of equipment train: – Screen deck & crusher in the middle of the photo – Pugmill on right side of photo
	Example of windrow of cold recycled material after mixing with asphalt emulsion in pugmill
	Example of cold mix material after it is picked up from windrow & re-laid with paver

	Example of finished cold recycled material after compaction: – Material was cured for 3 weeks – Overlayed with 75mm HMA
	Example of mixing operations
	Example of laydown, aeration, & compaction

Recycled Mix Design **Available methods** • No standard procedure • The Asphalt Institute • Chevron USA	Mix design is similar to method for hot in-place & hot central plant recycling design (summary of these designs is found in module 3-9)
Recycled Mix Design **Basic design steps** • Field samples • Laboratory analysis • Field adjustments	Basic steps in mix design process include: 1. Sampling of RAP 2. Lab mix design process 3. Adjustment of job mix formula in field – Due to construction differences 4. Pavement may have areas of low or high asphalt content & modifier may have to account for this 5. Field mixing, compaction & curing may require changes in mixing water content
Mix Constituents Air Voids New Asphalt Old Asphalt New Aggregate Old Aggregate (RAP)	Mix design procedure for CIPR more difficult due to more materials used: – New asphalt – Old binder – New aggregate – Old aggregate

Typical Design Criteria



Lab mix design process should establish fluids content (asphalt plus volatiles) associated with producing maximum density for a given compactive effort:

– Moisture content starting point for achieving max density
– Density of CIPR materials is low compared to HIPR materials

Design methods

AASHTO

The Asphalt Institute

State DOT

Discuss methods that can be used to design pavements with CIPR:

– Problem with these methods is determination of load carrying ability of CIPR material

AASHTO Structural Layer Coefficients

Stabilizer	Range	Average	Typical
Asphalt	0.22- 0.49	0.36	0.35
Portland Cement	0.23- 0.42	0.31	0.15- 0.23

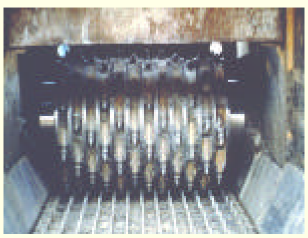
Summary of AASHTO structural layer coefficients for CIPR

AASHTO Structural Layer Coefficients Performance Economics Guidelines for use Specifications	These topics are discussed in the participant's manual
Material Specifications Aggregate sizes Asphalt modifier	Specifications usually defined: 1. Size of RAP 2. Type of acceptable binder and/or modifiers – ASTM spec is available
Equipment Specifications General description End result	Most specs contain some description of the type of equipment and end result desired (RAP size, density, etc.

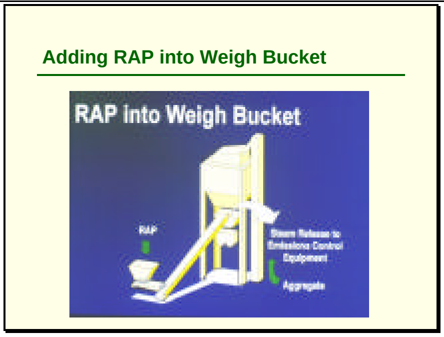
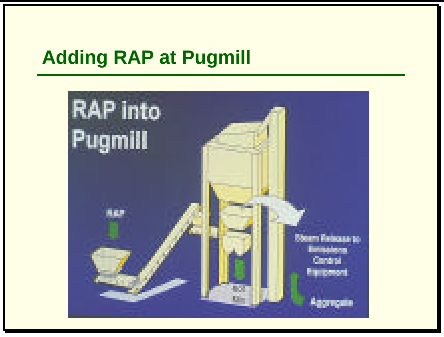
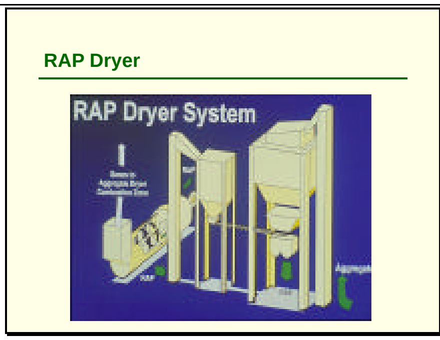
In-Place Density Low densities Limited amount of data	A typical problem with CIPR is in-place density: 1. Proper amount of fluids is needed – Even with proper amount of fluids & compactive effort, air voids could be 12-15 % (typical 8% for hotmix operations)
Problem Areas Depth of removal Degree of pulverization Uniformity of mixing In-place density Curing Protection from traffic	The construction process should be controlled to ensure that these problems are not an issue in performance of CIPR
Summary Types of procedures Equipment Mix design Economics Specifications Problem areas	Summarize key points discussed in this module

Module 3-9 ***Hot Central Plant Recycling***	Hot central plant recycling is most popular form of asphalt pavement recycling in U.S. and expected to increase in the future
Objectives **Types of hot central plant recycling** **Types of equipment and operational sequences** **Structural layer coefficients** **Economics** **Specifications** **Quality control**	Discuss objectives as shown
Introduction **RAP use** • **Tens of millions of tons used** • **Everyday occurrence** • **45 million tons generated / year** • **1/3 of all HMA removed is recycled into HMA** • **Severe limitations in some areas**	Discuss RAP as a commonly used pavement material

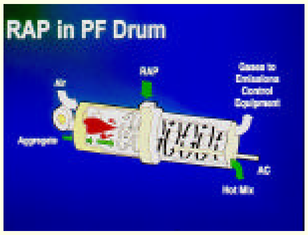
Recycling Methods and Equipment **Construction sequence** • Pavement removal • Crushing and stockpiling • Mixing in central plant • Laydown and compactions	Describe the recycling operation as shown: – Traffic can use pavement after mix has cooled
Generating RAP 	Example of normal milling operation generating RAP
Milled RAP **Little additional processing required** **Uniform properties in layer** • Gradation • Asphalt content • Asphalt properties **Usually stored in separate stockpile**	Milled RAP can be used directly in a hot central plant operation: – Some states have requirement on maximum particle size for RAP – Additional processing after milling may be necessary

RAP from Full-Depth Removal Pavement broken into slabs Material must be processed Often stored for later processing Material from different sources Blending / crushing mixed RAP can produce consistent material	Additional processing is required when RAP is full-depth removal: – Control crushing, sizing & stockpiling operations to produce uniform RAP product
RAP Sizing 	Example of cracking equipment to reduce sized RAP
Stockpiling 	Example of typical RAP stockpile: – Standard stockpiling operations are followed to minimize segregation

Stockpiling RAP Large, conical stockpiles preferred RAP does not re-compact Forms “crust” (200-250 mm) 8-10 inches Crust sheds water and easily broken RAP under crust easy to manage	Discuss items shown
How to Recycle Equipment Methods	Equipment & methods for hot central plant recycling are presented
RAP in Plant Facility Plant type • Batch • Drum	RAP can be added to a HMA plant or facility depending upon plant type

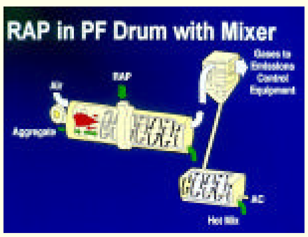
	A typical plant which adds RAP to the weight bucket
	A typical plant which adds RAP to the pug mill
	A typical RAP dryer system for a pugmill operation

RAP Feed to Parallel Flow Drum Mixer



A typical RAP parallel flow drum mix process

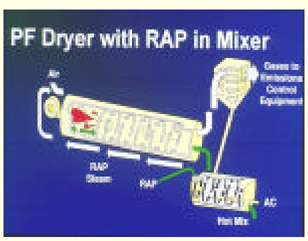
RAP Feed to Drum Drier



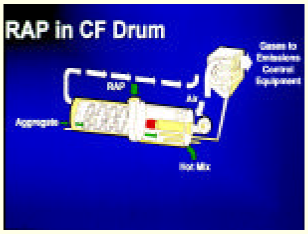
Parallel flow drum mixers with separate continuous mixer units have been used:

- A typical plant operation
- New asphalt binder is usually added into the continuous mixing unit

RAP Added to Continuous Mixer



A typical parallel flow drum mixer with RAP collar and isolated or extended mixing chamber

RAP Feed to Counter Flow Drum Mixer 	A parallel flow dryer with separate mixture unit is shown with the RAP added to the separate mixer rather than the collar in the central portion of the drum
Laydown and Compaction 	Example of typical laydown operation with recycled HMA
Design Methods **AASHTO** **The Asphalt Institute** **National Crushed Stone Association** **State DOTs**	The AASHTO structural design method is most popular in U.S.

AASHTO Structural Coefficients

Layer	Range	Average	Typical
Surface	0.37- 0.59	0.48	0.44
Base	0.37- 0.49	0.42	0.35

Each of the structural design methods use some measure of load carrying ability of various materials in the structure:

- Little information is available for hot central plant recycled materials

RAP Performance

FHWA survey of 17 states

RAP mixes comparable to virgin mixes

- Proper design
- Process control

Louisiana study

- No significant differences in RAP mix and control

Survey shows that hot central plant mixes have similar performance to conventional HMA provided:

- Good mix design was used
- Proper construction was performed

(Other studies have suggested similar relative performance)

Quality Control

Similar tests as for virgin asphalt cement

Additional tests required

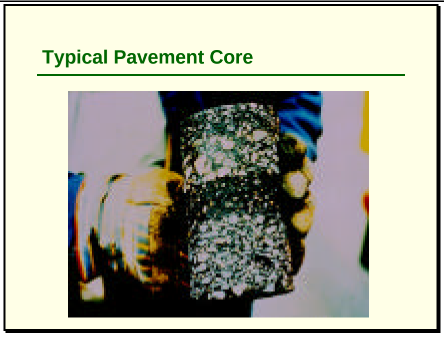
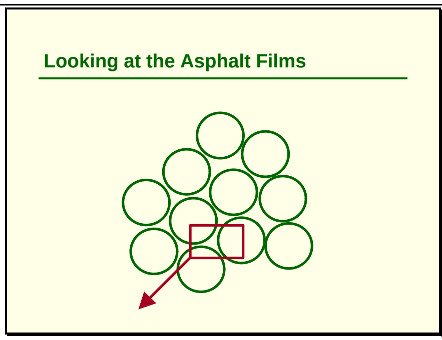
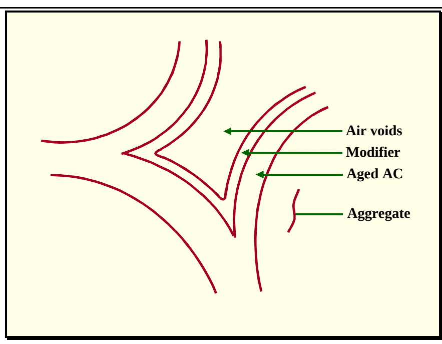
More frequent testing

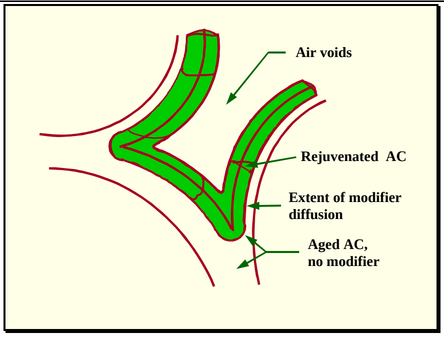
Greater variation in test results

More variability when using recycled materials:

- More frequent sampling & testing may be required
- Tests for QC/QA are typically same as those for conventional HMA

Quality Control Tests Composition and properties of RAP Tests on RAP / RAM / aggregate stockpiles Tests during construction • Gradations of aggregate / RAM • Extraction / recovery tests on RAP and recycled mix • Density of compacted mix	Discuss typical tests that should be taken as part of quality control
Summary Improved processing equipment enhances use Emission considerations addressed Processing and handling techniques established Use of RAP is cost-effective Quality control	Summarize the key points of hot central plant recycling
Recycled Mixture Design Project considerations • Uniformity • Depth of HMA • Presence of chip seals • Asphalt content (bleeding) • Aggregate gradation • Asphalt properties • Traffic • Types of pavement distress	Introduce the recycled mix design process: 1. Must be done for each project 2. Performed under direction of an engineer

	Core samples or processed samples from the pavement to be recycled should be obtained: – For a pavement section of like properties, a sampling program from each of five locations is often used – Project uniformity can be determined by analyzing cores
	Example of a cross section of a typical HMA: – Mix contains aggregate, binder & air voids
	Close-up of cross section shows a recycled mixture immediately after application of recycling agent or modifier (initially coats the aged asphalt binder)

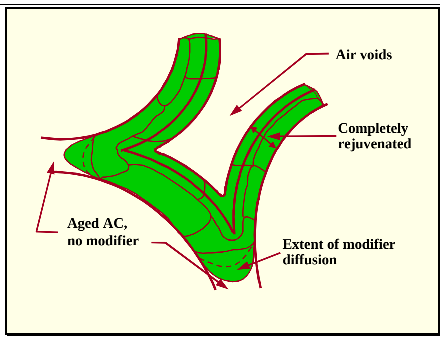


Recycling agent will penetrate the aged asphalt as a function of :

1. Time
2. Temperature

Extent of diffusion will (to a degree) determine mix

- If agent remains on surface of aged asphalt, stability of recycled mix will be low



When diffusion is complete:

1. Binder is alternated or rejuvenated (complete diffusion is assumed when agent is selected by engineer)

Mixture Design

Evaluated salvaged material
- **Asphalt properties**
- **Aggregate properties**

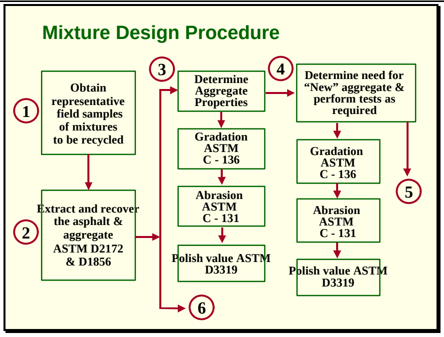
Need for additional aggregate

Selection of recycling agent
- **Type**
- **Amount**

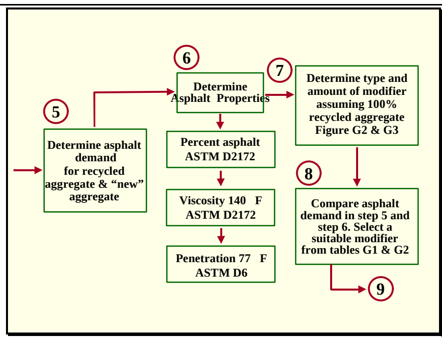
Preparation and testing of mixtures

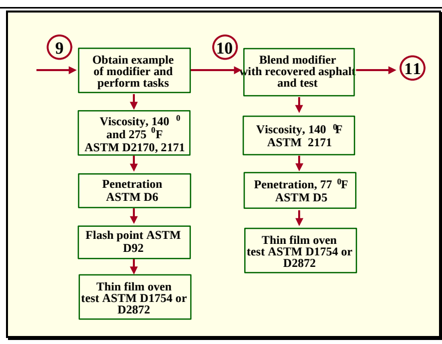
Select optimum for design

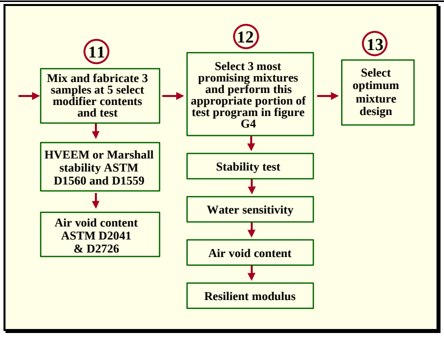
Discuss the mix design process



A flow diagram describing this process & individual tests that should be performed indicates that information for both aggregate & asphalt binder must be utilized to establish amount & type of recycling agent







Other Tests

- Resilient modulus
- Creep (permanent deformation)
- Indirect tensile strength
- Water susceptibility

Additional non-standard tests should be performed on projects with high volumes of truck traffic:

2. Resilient modulus for load carrying capability
3. Creep (rutting)
4. Strength for thermal cracking
5. Water sensitivity for raveling & stripping

Summary

Summarize key points in mix design process

Slide	Notes
Module 3-10 ***Hot Mix Asphalt Overlays***	Begin Module 3-10
Objectives List deficiencies which can be corrected Identify conditions that are best suited and most cost-effective Determine if need is functional or structural Determine feasibility and extent of pre-overlay repair Describe thickness design approaches	Describe objectives shown
Introduction Most popular method Relatively fast and cost-effective means for: • Correcting deficiencies • Restoring user satisfaction • Adding structural capacity Poor performance is NOT uncommon	There are a number of design & construction factors that need to be considered by design engineer to achieve maximum performance (discussed in Module 2)

Definitions Functional performance - Ability to provide a safe, smooth riding surface Structural performance - Ability to carry traffic without distress Empirical - Design based on past experience or observation Mechanistic - Design based upon engineering mechanics	Explain definitions
Purpose and Applications General (HMA and PCC) • Improve functional and/or structural characteristics • Factors to consider in comparing HMA and PCC overlays	Overlays address: 1. Existing surface deficiencies 2. Increasing load-carrying capacity HMA & PCC differences: 1. Initial cost 2. Traffic control requirements 3. Potential life, etc.
Purpose and Applications Specific (HMA) • Wide range of applications Road surface categories Climate and support conditions • Typical characteristics Dense graded HMA Flexible or rigid surface 25 to 200 mm thickness • Mill and Fill	Discuss specific purpose & application of HMA overlay

Limitations and Effectiveness

General - Recognize why many overlays fail prematurely

- Improper selection
- Wrong type
- Inadequate design
- Insufficient preoverlay repair
- Lack of consideration of reflection cracking

Once the need for an overlay is accurately identified:

1. Determine type of preoverlay repair required

The overlay design is critical:

1. To correct surface deficiencies
2. To increase structural capacity

Limitations and Effectiveness

Specific are defined by:

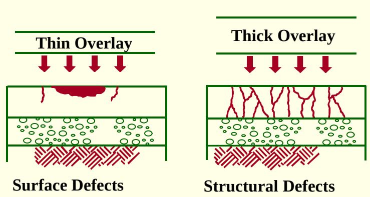
- Distress exhibited
- Intended design life
- Availability of quality materials

Ways to improve effectiveness

- Pre-overlay treatments
- Better materials and practices
- Sound engineering judgement

Discuss items shown

Selection of an Overlay to Correct Deficiencies



Using a thin or thick overlay based on functional & structural adequacy of pavement:

1. Functional (thin overlay)
   - Polishing in wheelpaths
   - Roughness from non-load distress (joint spalling, raveling)
   - Inadequate cross slope
2. Structural (thick overlay)
   - Fatigue, rutting, patches, reflection cracks, corner breaks (detailed in Module 2)

Considerations in Overlay Selection

Construction feasibility

- Traffic control
- Constructibility
- Vertical clearances

Performance period

Funding

Factors to consider for determining feasibility of overlay as an alternative

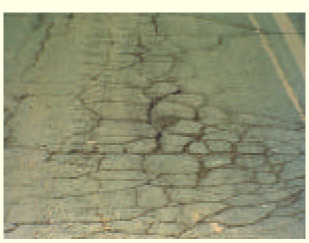
Preoverlay Treatment and Repair

Dependent upon:

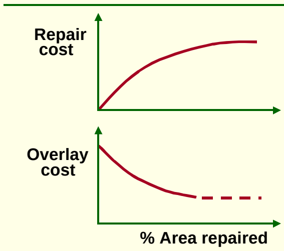
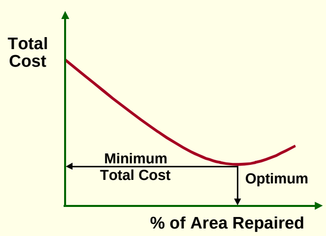
- Type of overlay
- Structural adequacy of existing pavement
- Existing types of distress
- Future traffic
- Physical constraints
- Cost

The amount & type of repair that is done prior to overlay is single most important factor that affects future performance

To Repair or Not to Repair



Example of a highly distressed pavement

Types of Preoverlay Treatments Localized repair (patching) Surface leveling Controlling reflection cracking Drainage improvements	Describe types of preoverlay treatments listed
1. Localized Repair 	Example of repair & overlay versus percent area repaired
1. Localized Repair 	Example of total cost versus percent of area repaired

2. Surface Leveling Cold milling Leveling course to fill ruts Leveling course to improve longitudinal profile	It has been found that permanent deformation will reappear in an overlaid pavement & can be corrected by methods listed
3. Controlling Reflection Cracking Geotextiles or fabrics Stress relieving or stress absorbing membrane interlayers “Band aid” type crack sealants	Reflection cracking usually problem with overlay on rigid but can be problem with HMA overlay on flexible with transverse cracks (Module 4-14 provides more on reflection cracking)
4. Drainage Corrections Drainage survey Identify moisture / drainage related distresses Develop solutions that address moisture problems	If poor drainage conditions are contributing to deterioration, overlay will not correct problem

Two Aspects of Overlay Design

Asphalt mixture

- Fatigue cracking
- Permanent deformation
- Thermal cracking
- Moisture susceptibility

Two aspects of overlay design are asphalt mix design & thickness design:

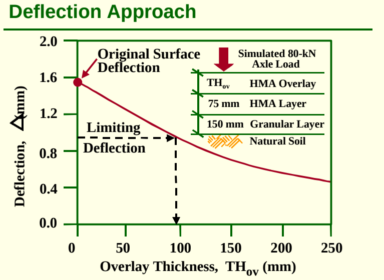
- Module 3-1 provides information on asphalt design

Overlay Thickness

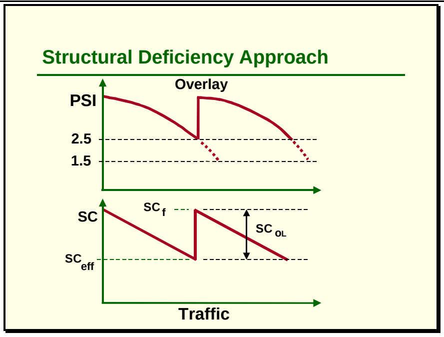
- Engineering judgement
- Deflection approach
- Structural deficiency
- Mechanistic approach

There is no universal thickness design procedure

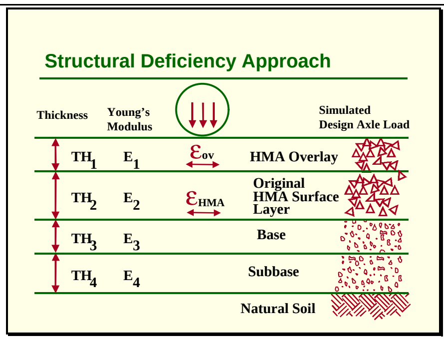
Deflection Approach



The larger the deflection is, the weaker the pavement & subgrade soil must be

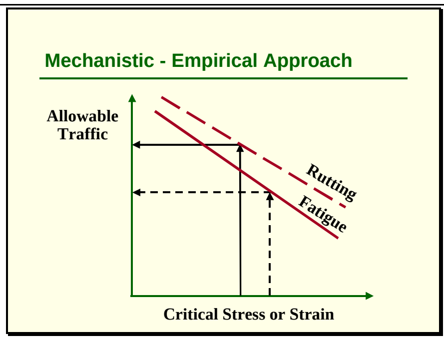


An overlay is required that is equal to difference between structural capacity of a new pavement design & the structural capacity of existing pavement

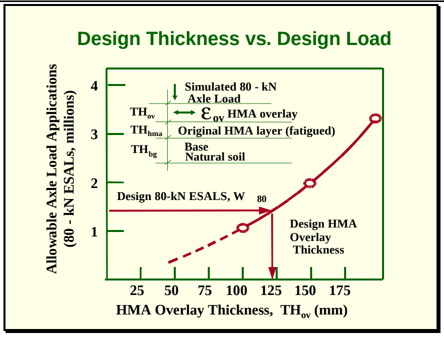


The effective structural capacity of the pavement is done by:

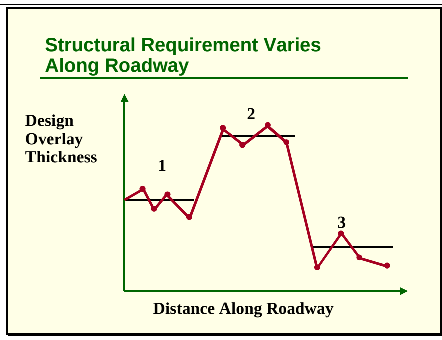
1. Measurement of structural deflection
2. Observations of pavement condition
3. Predictions of past load applications



The design overlay thickness is one that limits fatigue damage in the pavement to an acceptable level over the design period



Graphical method for determining design HMA overlay thickness using the mechanistic (fatigue damage) approach



Example of a profile showing differing structural requirements along a roadway

Summary

- Functional vs. structural
- Applications, limitations and effectiveness
- Preoverlay repair issues
- Approaches to overlay thickness design

Review/summarize key points in this module

Module 3-11 ***Identification of Feasible Alternatives***	Begin Module 3-11
Objectives **Describes what a decision tree or chart is, and how it's developed** **Describe how to analyze a specific project and develop a list of treatments that best fit the needs of that project** **Discusses some limitations associated with the strict use of decision trees**	Explain Objectives: 1. Combines information covered in this class for basic design processes – Necessary data collection – Determine distress mechanisms – Use decision charts to develop best rehab treatment Solutions limited to demands of project: 1. Expected traffic load, existing structural conditions 2. Should provide longest service life given funding constraints
Introduction **Decision trees are developed as an aid to help the engineer sort through the many items that should be considered in treatment selection** **They help account for the specific distress encountered and the basic mechanisms that are at work within a pavement section**	In addition to items listed, decision trees: 1. Account for project specific field conditions 2. Constraints 3. Available funding

Pavement Condition

Pavement condition is usually the single most important piece of information to be considered when assessing a pavement and it's rehabilitation needs

For project planning & design, a pavement is considered in good condition when:

1. There is little or no surface distress
   - that would lead to roughness
   - that would lead to pavement failure resulting in cracks & potholes making pavement unsafe

Pavement Condition

- **Fatigue cracking**
- **Transverse cracking**
- **Rutting**
- **Raveling or wearing**

These common distresses found in flexible pavements were covered in Module 2-2.5

Use of Decision Trees

Example estimating distress mechanism from table of distress groups

- **Distress group - Fracture**
- **Distress Mode - Flexible Pavement cracking**
- **Distress Mechanisms**
  - **Excessive loading**
  - **Repeated loading (i.e. Fatigue)**
  - **Thermal changes/Moisture changes**
  - **Slippage/Shrinkage**

Discuss use of decision trees

Use of Decision Trees **Example estimating cause and treatment from table of pavement distress and possible causes and treatments** • <u>Distress</u> Rutting • <u>Possible Causes</u> HMA mix design Structural deficiency Stability of pavement layers Compaction	Continue discussion of use of decision trees
Use of Decision Trees **Example estimating cause and treatment from table of pavement distress and possible causes and treatments** • <u>Distress</u> Rutting • <u>Rehabilitation Alternatives</u> Cold milling with profile requirements, with or without overlay Heater scarification or milling with overlay Replacement	Continue discussion
Use of Decision Trees **Example estimating cause and treatment from table of pavement distress and possible causes and treatments** • <u>Distress</u> Raveling • <u>Possible Causes</u> Low asphalt content Excessive air voids Water susceptibility Aggregate characteristics Hardness and durability of aggregate	Continue discussion

Slide	Notes
Use of Decision Trees **Example estimating cause and treatment from table of pavement distress and possible causes and treatments** • <u>Distress</u> Raveling • <u>Rehabilitation Alternatives</u> Dilute emulsion fog seal Sand seal Slurry seal Thin HMA overlay	Continue discussion
Use of Decision Trees **Example estimating cause and treatment from table of pavement distress and possible causes and treatments** • <u>Distress</u> Alligator cracking • <u>Possible Causes</u> Structural deficiency Excessive air voids in HMA Asphalt cement properties Stripping of asphalt from aggregate	Continue discussion
Use of Decision Trees **Example estimating cause and treatment from table of pavement distress and possible causes and treatments** • <u>Distress</u> Alligator cracking • <u>Rehabilitation Alternatives</u> Seal coat Replacement (full depth patching with HMA) Structural HMA overlay Recycle Reconstruction	Continue discussion

Limitation of Decision Trees **Decision trees should be treated as an analysis aid, helping the engineer sort through a large amount of project related information to provide conformation of possible cause for the distress, and the possible treatments that could be used** **Decision trees should not be used as mandatory requirements**	Continue discussion

Module 4-1 ***Rigid Pavement Overview***	This overview of PCC pavements is not comprehensive but a general background on the composition, behavior & performance of rigid pavements
Objectives **Identify rigid pavement layers** **Describe the rigid pavement responses** **Describe fundamental materials** • **New construction** • **Rehabilitation**	Objectives: 1. Identify layers & types of rigid pavements 2. How PCC responds under traffic & environmental loading (how it differs from flexible pavement) 3. Aware of fundamental materials
PCC Composition **Coarse aggregate** } **Separated by 4.75 mm sieve** **Fine aggregate** **Portland cement** } **Control water-cement ratio** **Water** **Admixtures**	PCC is a mixture of portland cement, aggregate & water: – Different cement types are available – Variety of admixtures to obtain certain properties Important to limit water-cement ratio

Types of Rigid Pavement

Jointed plain concrete pavement (JPCP)
- No reinforcement
- Short joint spacing (4 to 6 meters)

Jointed reinforced concrete pavement (JRCP)
- Wire or mesh reinforcement (0.1 to 0.3%)
- Long joint spacing (7 to 30 m)

Continuously reinforced concrete pavement (CRCP)
- Continuous reinforcement (0.6 to 0.8%)
- No contraction joints

Discuss types of rigid pavement in use today

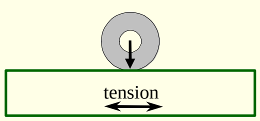
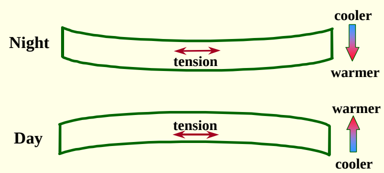
Transverse (Mid-panel) Crack

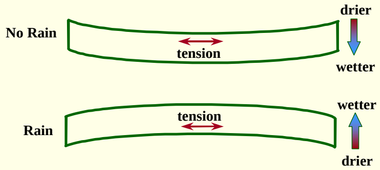
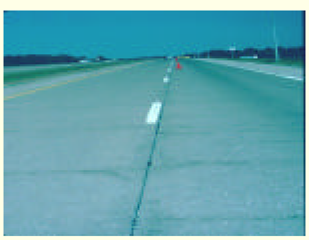
Example of a transverse crack on jointed concrete that has opened up & begun to deteriorate
- If on JPCP, no steel across crack to hold it together
- If on JRCP, this would indicate steel reinforcement failure, due to either inadequate steel content or corrosion of the steel

Faulting

Example of faulting of transverse joint
- Could be inadequate dowel bar design or absence of dowel bars

Pumping 	Example of pumping which can lead to loss of support beneath slab corners & edges: – Can lead to transverse joint faulting & corner breaks
Joint Spalling 	Example of joint spalling
Punchout 	Example of a major structural distress for CRCP

Rigid Pavement Responses Rigid structures (high modulus) Distribute applied loads over wide area About 10 times stronger in compression than in tension Most concerned with tensile strength	Discuss rigid pavement responses under traffic loading
Traffic Related Stress Most critical at mid-panel edge and corner If tensile stress > tensile strength, a crack occurs  	Example of traffic related stress in rigid pavement
Thermal-Gradient Related Stresses Temperature differential between the top and bottom of the slab  	Stresses can also develop in slab due to environmental conditions: 1. Thermal curling – Daytime – Nighttime

Moisture-Gradient Related Stresses Variations in moisture content between top and bottom of slab 	Stresses can also develop due to differences in moisture contents of the top & bottom of the slab: 1. More seasonal in nature – Wetter moisture contents causing expansion of slab
Other Stresses Shrinkage stresses Internal stresses • Durability cracking • Alkali-silica reactivity	Shrinkage stresses occur when slab undergoes change in volume Internal stresses occur due to result of aggregate component of PCC mix
D-Cracking 	Example of a pavement exhibiting D-cracking: – Occurs primarily at joints & cracks – Associated with freeze/thaw of susceptible aggregates

D-Cracking 	Another example of severe D-cracking at transverse joint: – Performance of many rigid pavements has been limited by materials problems such as this
Concrete Pavement Materials Type I (a)…….Normal Type II (a)…….Moderate heat of hydration Moderate sulfate resistance Type III (a)……High early strength Type IV……….Low heat of hydration Low strength gain Type V………..High sulfate resistance a = air entraining agent	Describe different cement types available: 1. Type I most common 2. Type III becoming more frequent particularly in rehab
Summary PCC is a rigid, durable material Composition of aggregates (coarse and fine), cement, water, and admixtures Tensile stresses are most critical Stresses caused by several mechanisms	Review/summarize key points presented in this module

Module 4-2

Joint Sealing

This module will present not only best practices but also a discussion on recent debate on need for joint sealing & resealing

Objectives

Identify factors affecting sealant performance

Describe the steps for resealing joints

Identify sealant types, properties, and specifications

Describe factors to consider for design

Objective here is to explain joint sealing process, not whether or not it is effective

Introduction

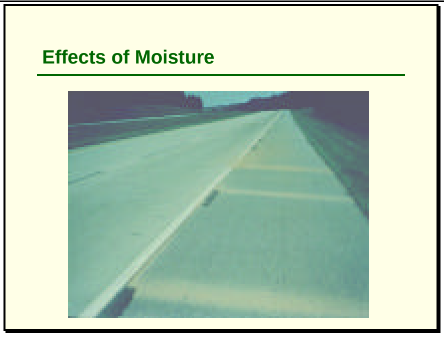
Purpose of joint sealing

- **Reduce moisture infiltration**
- **Prevent intrusion of incompressible materials**

Transverse contraction joints are generally most critical

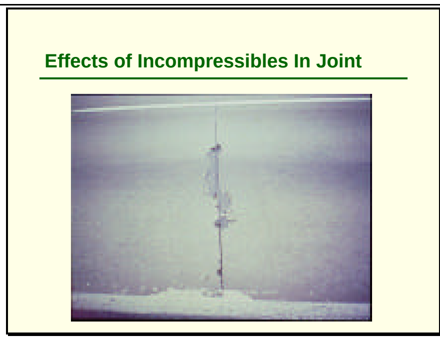
Longitudinal joints are sometimes sealed

Discuss information shown on slide



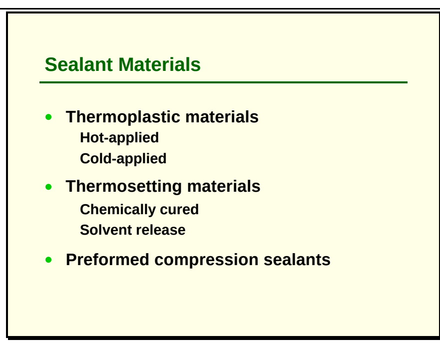
What are the 3 conditions necessary for pumping to occur?

1. Load
2. Water
3. Pumpable material



Example of spalling at transverse joint due to incompressible:

- Effective sealing/resealing will eliminate this problem



Introduce the three categories of sealant materials (listed in order of increasing costs & expected life of material)

Preformed Compression Seals

An in-place compression sealant (also called neoprene sealants):

- Highly effective in keeping incompressibles out of the joint

Guidelines for Resealing

Reseal when no longer functional
- Missing or damaged sealant
- Poor bonding to joint face
- Incompressibles in joint

Resealing most effective when:
- Pavement is not severely deteriorated
- Performed with other restoration activities

Moderate installation temperatures

Proper joint preparation is essential

Resealing requires significant effort that may not be economically justified

Sealant Material Performance

Performance life varies by material type

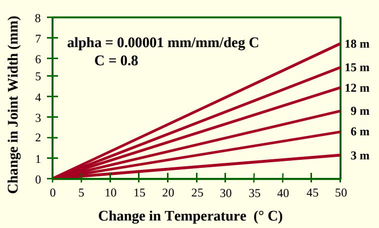
Recent studies suggest silicone sealants are the most cost effective

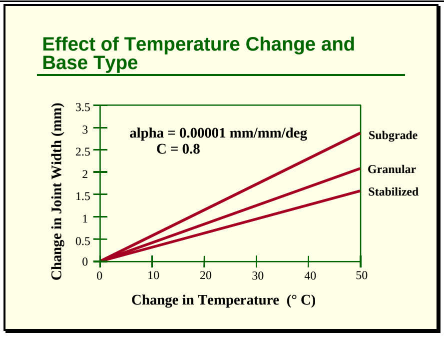
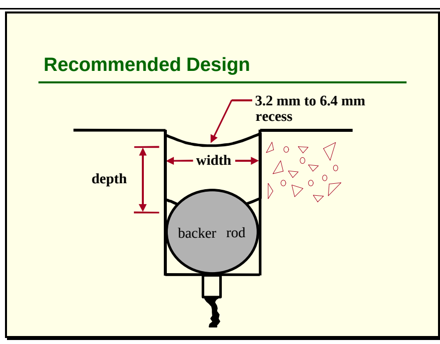
Several on-going studies
- SHRP H-106
- SPS-4 studies
- United Kingdom

Cost-effectiveness assessed:

1. Cost of material
2. Cost of installation
3. Projected life of material

Cost-effective is one that lasts considerably longer than other for a relatively low installation cost

Effect on Pavement Performance Some debate as to the effectiveness of joint resealing Most states continue to reseal joints Some believe the benefits do not offset the costs, especially under certain conditions	Discuss elements of debate (started by Wisconsin): 1. If sealing is not needed, initial construction costs & rehab costs can be reduced 2. Conditions where not needed could be combination of well-draining materials & minimum moisture 3. If joint does not require sealant, needs to be sawed sufficiently wide to initiate transverse crack
Design Considerations Transverse joint movement Shape factor Sealant configuration Sealant properties	Sealant projects require design effort (introduce steps to be covered)
Effect of Temperature Change and Joint Spacing  	For different temperature changes and slab lengths (right side) there is a considerable variation in joint opening

	The base type also has an effect: – It is thought that stabilized & granular layers will resist slab sliding or horizontal movement more than a slab placed directly on the subgrade
Shape Factor Ratio of sealant width to depth (W/D) Stresses based on shape of sealant Design should consider strain and deformation Recommended shape factors • 1:1 to 1:2 for hot-poured sealants • 2:1 for silicone sealants Backer rod is highly recommended	Different sealants require different shape factors: – Less material is actually better for long-tem performance – Backer rod placed to proper depth control amount of sealant used
	Note that the depth is the thickness of the sealant & not the distance from the pavement surface: – Backer rod does not have to rest on the bottom of the reservoir

Sealant Properties

- Durability
- Extensibility
- Resilience
- Adhesiveness
- Cohesiveness

Define the desirable properties from a typical sealant

Typical Material Costs ($/kg)

Asphalt cement	0.11 - 0.33
Fiberized asphalt	0.33 - 0.55
Rubberized asphalt	0.44 - 1.10
Polysulfide	2.21 - 2.76
Polyurethane	6.08 - 7.18
Silicone	5.52 - 7.73

* Cost comparisons should consider total installation cost and anticipated life

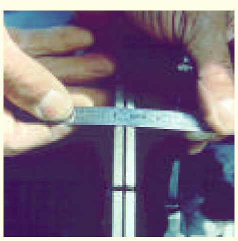
Emphasis should not be placed on initial cost of material:

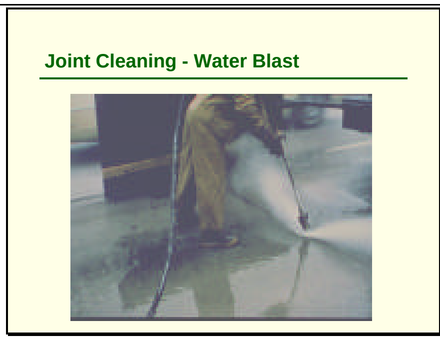
1. Costs vary considerably
2. More expensive are expected to last longer
3. Less material is used with silicones & poly products

Transverse Joint Resealing Steps

- Remove old sealant
- Reface joint sidewalls
- Clean joint reservoir
- Install backer rod
- Install new sealant

Introduce the steps for resealing joints that will be discussed in this module

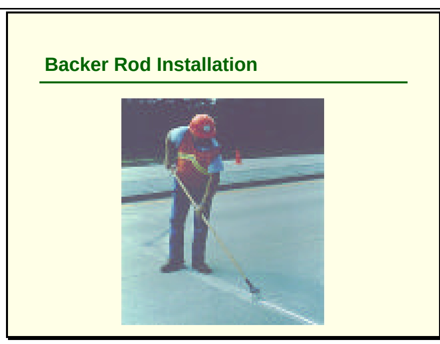
Sealant Removal Using V-Plow 	Using a plow attached to a tractor to remove old sealant
Sealant Reservoir Refacing 	Example of a sawing operation—note that this also refaces the reservoir walls (before resealing the concrete must be completely dry)
Refacing Blades 	In the refacing operation, diamond saws are spaced so that they cut into both sides of the joint reservoir

	Many failures have been attributed to inadequate joint cleaning. In the background is the sawing operation. This is followed in the foreground by high pressure water blasting to remove all loose debris & concrete slurry
	A close-up of the water-blasting operation
	Prior to resealing, all debris, dust, and other deleterious materials are blown out of the reservoir

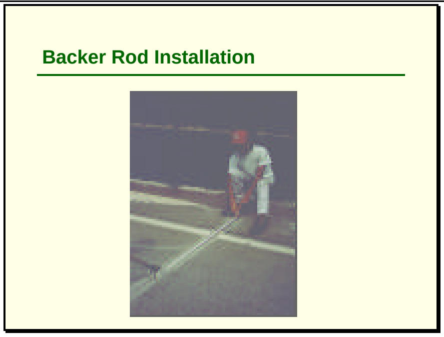
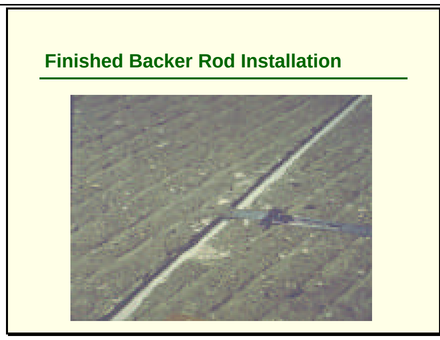
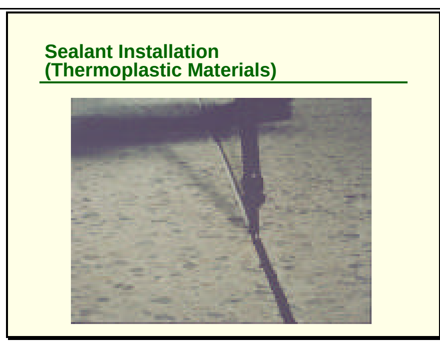
Sandblasting can also be used as part of the preparation process. To be effective, both faces of the reservoir must be hit. Sandblasting is effective in removing any remaining sealant or sawing slurry that remains in the reservoir.

Backer rod is used to obtain the desired shape factor. Also prevents 3-sided bonding that will increase the internal stresses in the sealant.

Example of backer rod ready for installation. Different sizes to fill range of openings.



Roller depth is adjusted so that backer rod is pushed down to exactly the desired depth for the designed shape factor

	Stretching the backer rod slightly helps to ensure that there are no gaps or twists
	This backer rod installation is now ready for sealant (note how small the actual sealant reservoir is). This installation will perform better than filling up the entire joint with sealant.
	A hot-pour installation on top of the backer rod (note that overheating & burning can be one of the biggest problems).

Sealant Installation (Thermosetting Materials)

Silicone sealant applied in foreground. Cleaning in background.

Sealant Installation (Compression Seals)

Installation of the neoprene (compression) sealant requires the use of an adhesive/lubricant and a device to compress the seal.

Longitudinal Joint Sealing

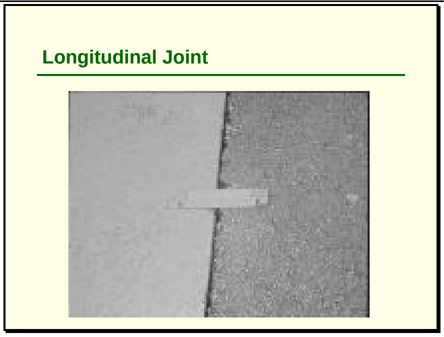
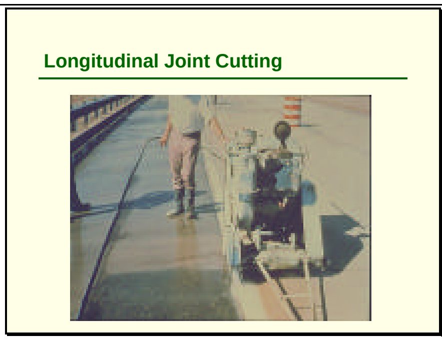
PCC/PCC joints

- Limited movements (typically tied)
- Hot-poured thermoplastic materials used
- No reservoir is formed or needed

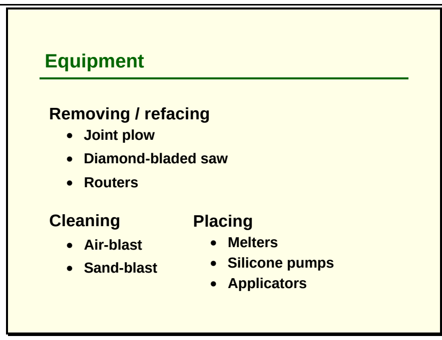
PCC/HMA joints

- Large vertical and horizontal movements
- 25-mm width (minimum) and depth
- No backer rod required
- Hot-pour and silicone sealants used

Potentially the greatest source of moisture to an existing pavement

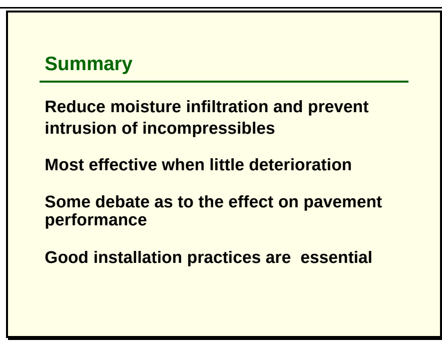
	Lane-shoulder joint showing large opportunity for moisture entry.
	As with transverse joint operation, the first step is to saw the reservoir
	The finished product

The final product



Summarize the equipment used in the process:

- Depends upon materials
- Depends on steps required



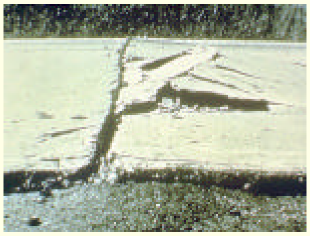
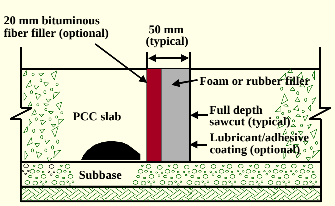
Review/summarize the key points in this module

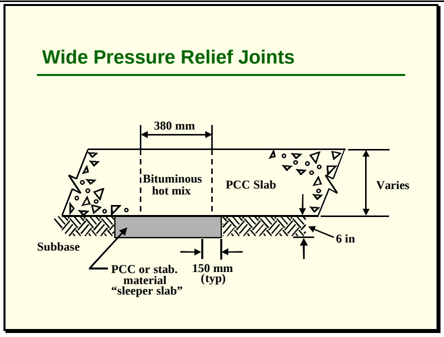
Objectives for resealing project are shown on this slide.

While there is debate on the effectiveness of sealing joints:

- More research done on sealing new pavements
- Little on effect of resealing on pavement performance

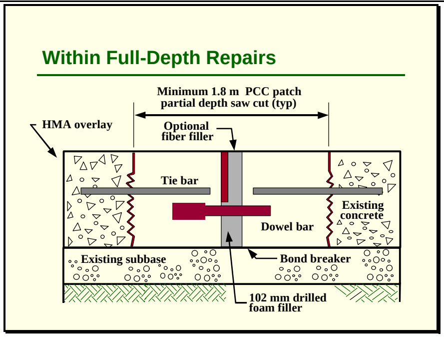
Module 4-3 ***Pressure Relief Joints***	Ask participants about experience with relief joints: 1. Has anyone used? 2. For what purpose? 3. Were they effective?
Objectives **Identify causes of expansive pressures** **Identify pressure-related distresses** **Describe the applications of pressure relief joints** **Describe proper construction techniques** **Recognize potential problems of pressure relief joints**	Objectives: Discuss items shown
Introduction **Expansive pressures can build up in rigid pavements** • **Incompressibles in joint** • **Expansion of reactive aggregates** • **Thermal and moisture conditions** **Severe distresses often result** **Pressure relief joints relieve internal expansive pressures**	Most common distresses from expansive pressures: 1. Joint spalling 2. Blowups 3. Damage to adjacent structures

Slide	Notes
Blow-up 	Example of pavement that has experienced a blowup
Types of Pressure Relief Joints Narrow pressure relief joints Wide pressure relief joints Within full - depth repairs	This list provides a few of the more common designs of pressure relief joints
Narrow Pressure Relief Joints 	Narrow pressure relief joints: 1. Installed using two cuts of diamond blade saw or single pass of a carbide tooth wheel saw 2. Joints are less 100 mm wide (typical 50 mm) 3. Filler material (styrofoam or sponge rubber) place in joint to prevent incompressible (preformed sealants have also been used) 4. Sealant is place on top of filler



Wide pressure relief joints:

1. Full-depth HMA patches
2. Typically 0.9 to 1.2 m wide
3. Extend full width of traffic lane
4. Sleeper slab is recommended under bituminous patch to prevent settlement of patch
5. Slab should be PCC (or stabilized material) & extend 150 mm on either side



Pressure relief joints within full-depth PCC repairs:

1. Part of full-depth repair
2. Typically 25 to 50 mm wide
3. Places relief joint in center of repair
4. Repair tied to original slab on both sides
5. Special heavy-duty expansion joints with dowels are recommended (especially for AC overlays)
6. Design effective but expensive

Causes of Pavement Expansion

Incompressibles in joints and cracks

Expansion of reactive aggregates

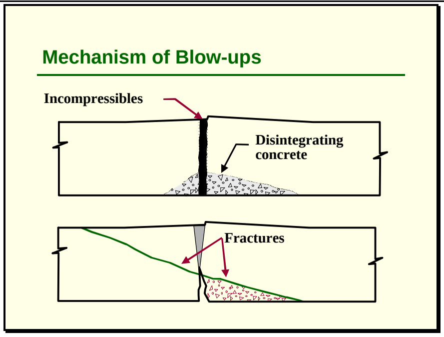
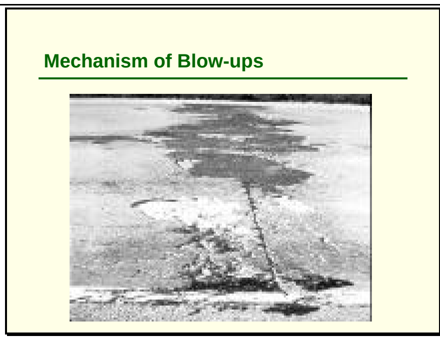
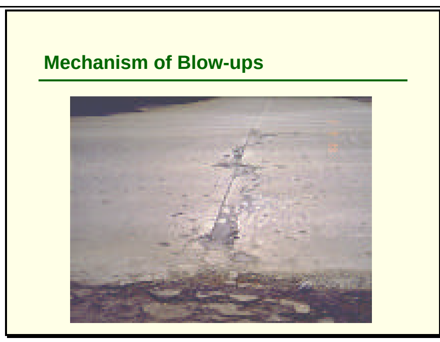
- Alkali - silica reaction (ASR)
- Alkali - carbonate reaction (ACR)

High pavement temperatures (α)

High moisture contents

During winter months, slab contracts, joint & cracks are open widest:

1. Allows compressibles into openings
2. Slab expands during summer & can result in expansive pressures at joint & cracks because not able to move freely (refer table 4-1)
3. Expansion can also be from reactive aggregates

	Discuss theory of blow-ups (participant's manual)
	Example of pavement that experienced severe cracking & spalling at transverse joint which may lead to blowup: – Good candidate for pressure relief joint
	Another example of a severely spalled & deteriorated transverse joint caused by expansive pressure

Limitations Poor load transfer Joints may close completely over time (temporary fix) Widening of nearby joints and cracks, causing intrusion of incompressibles, faulting, and damage to joint sealants "Humping" of asphalt patches Accelerated pavement deterioration	Pressure relief joints are often constructed without load transfer devices: 1. Not a permanent fix 2. Milling of asphalt patch often required during hot weather (humping); not recommended
Applications Recommended only on pavements with severe blow-ups or bridge pushing problems Most effective on long-jointed rigid pavements and near bridges Not recommended on CRCP or non-doweled JPCP Not required near other pressure-relieving features	Proper maintenance (resealing joints) is best preventive measure for reducing expansive pressures
Design Recommendations Install 300 m from other pressure relief joints or pressure-relieving features Install at mid-slab locations Limit widths to 25 to 50 mm Continued use is recommended to protect bridges and other structures Existing drainage conditions and improvements should be considered	Only use on PCC pavements: 1. history of blowups or bridge pushing 2. with reactive aggregates Blowups typically occur within 6 to 12 years after construction

Construction Considerations Joint created with a carbide-tipped wheel saw or a diamond-bladed saw Filler is generally compressed Filler is capped with sealant On multi-lane pavements, joint should be installed full width within 48 hours Moderate installation temperatures (4 to 21 ºC) are recommended	Cost dependent upon whether joint is installed: 1. Part of planned rehab 2. Response to blowup 3. Part of full-depth repair Costs should include labor, materials & equipment
Summary Reduce expansive pressures and distresses Only recommended on pavements exhibiting blow-ups or bridge pushing Unwarranted use can lead to problems Bituminous patches are not recommended Not recommended on CRCP or non-doweled JPCP	Review/summarize key points presented in this module – Effectiveness is questionable – Only use where pressure-related problem is known to exist

Slide	Notes
Module 4-4 ***Partial-Depth Repairs***	This module addresses partial depth repair of spalling on concrete pavements: – Widely used to restore rideability (not a structural repair)
Objectives **Identify distress types suitable for partial-depth repairs** **Identify various materials for repairs** **Describe successful construction procedures**	Identify when it is appropriate to use to use PDR: 1. What materials work 2. Range of construction procedures that have been used
Partial-Depth Repairs **Removal of shallow areas of deterioration and replacement with a suitable repair material** **Alternative to full-depth repairs when:** • **Deterioration is limited to upper one-third of the slab** • **Load transfer devices are still functional** **Most commonly used to repair shallow joint spalling**	Explain definition of PDR

Applications

Deterioration must be confined to upper one-third of the slab

Good candidate with joint resealing

Preparation for HMA or bonded PCC overlay

Conduct before undersealing and slab jacking

Conduct before diamond grinding and joint sealing

Guidance for PDR projects

1. When it has worked
2. When it is cost-effective
3. When it contributes to pavement performance

Limitations

Not candidate for:

- Cracks and spalls due to compressive stress buildup
- Spalls due to dowel bar misalignment or lockup
- Cracks caused by improper joint construction
- Working cracks
- Spalls caused by durability problems
- Joints with ineffective load transfer

These are all indications of ongoing problems

Typical Spalling

This spall may have been caused by an incompressible in the joint. It is shallow & does not appear to be part of a continuing problem of deterioration:

– A good candidate for PDR

Questionable Spall Repair 	This does not appear to have been a good candidate: – Either the crack went all the way through the area that is now repaired – Or the pavement continued to crack after the patch was placed
Candidate for Partial-Depth Repair? 	Occasionally the preparation for a PDR will reveal that the deterioration seen on the surface extends much further in to the pavement: – What's the typical depth of a dowel? – What are the limitations on the depth of spall to repair with PDR? – Is this a good candidate? – What should be done when this is encountered?
Effectiveness **Performance has been acceptable at many sites after 5 to 10 years** **Failures often attributed to poor practices** **Stringent quality control and inspection** **Good construction techniques** **Must achieve strong bond between concrete and repair material**	The more expensive/exotic the material, the more dependent performance is on strict QC/QA procedures.

Repair Locations and Size

Typically placed along transverse and longitudinal joints

Coring is recommended to determine the extent of deterioration

More economical to conduct one large repair than several small repairs

Areas less than 150 mm long or 40 mm wide are not good candidates

Identifying repair areas

Repair Materials

Factors to consider
- Available curing time
- Ambient temperature
- Cost
- Size of repair

Types of materials
- Cementitious
- Polymeric
- Bituminous

There really isn't any one "correct" or "best" material:
- Appropriate candidates can be identified based on the factors shown

Another factor to consider is performance:
- How well have previous materials worked?

Bonding Agents

Required with some materials to enhance bond with existing pavement

Sand-cements grouts have been successful with PCC repair materials

Epoxy bonding agents have been successful with PCC and proprietary repair materials

Bonding agents:
- No good guidelines
- Important to follow manufacturer’s recommendations

Material Properties and Costs

Product	Opening Time, hr	Moisture Sensitive	Cost, $/m^3
Type III PCC	5.0	No	375
Duracal	1.5	No	280
Set 45	1.5	Yes	1300
Five Star HP	1.5	No	1100
MC 64	2.0	Yes	8500
Percol FL	0.2	No	3550
UPM	0	No	185

This is comparative data from a SHRP study of spall repair materials:

– Note the purported claims for moisture insensitivity

Construction Steps

- Locate repair boundaries
- Remove deteriorated concrete
- Prepare joint
- Clean repair area
- Apply bonding agent
- Mix and place repair material

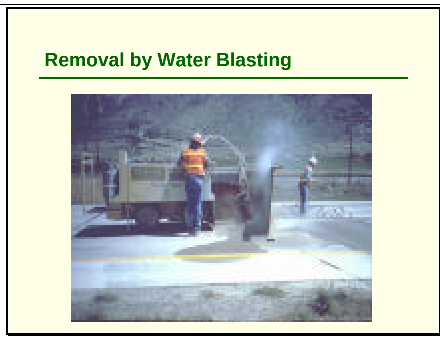
Introduce steps for construction that will be covered in this module

Detection of Deteriorated Concrete

This is an example of sounding:

– Sound concrete will produce a higher pitched ping than deteriorated concrete (thud)

	Once the area is identified, the boundaries for sawing are marked on the pavement
	The initial sawcut may be either at those marked boundaries (about 50 mm deep) or at the boundaries and in a criss-cross pattern throughout the area to be removed
	The traditional method of breakout is with a jackhammer: – Major concern is not causing additional damage to the pavement

	Example of milling operation using a different piece of equipment: – A spall is being repaired on both sides of the joint
	Example of hydrodemolition is widely used in concrete removal & bridges & other structures: – Being tried here for spall repair – Trials of this technology were not successful – Problems included slow production & frequent breakdowns of the equipment
	Following removal of the broken up spall, the pavement must be clean of any materials that might prevent bonding of the repair material: – Here sandblasting is being used to clean the pavement

This is the result of the breakup and removal process:

- Note the coarse surface (good for promoting bond)

Incompressible material has been forced into the transverse joint:

- This prevents any of the patch material from entering the joint & preventing movement of the joint
- This insert is normally removed before the joint is sealed

A bonding agent is applied by hand:

- Note that it is being worked into the corners & along the patch sidewalls

Material Placement Use small quantities (short curing time) Follow temperature recommendations Some epoxy concretes must be placed in lifts Consolidation • Internal vibrators • Vibrating screeds • Rodding or tamping Screed and hand trowel	Handling patch materials is no different from handling the same materials in other applications: – Repair represents small percentage of the pavement volume – Movement is restricted on at least 4 sides – Will cure differently
Grout Mixer 	Example of a portable mixing operation that is set up in the field
Adding Admixture 	Some materials have a very rapid set time: – Here a specialized repair material is being mixed in the field to precise proportions

Preparation of Epoxy Patching Material 	MC-64, a two-part epoxy with rubber aggregate, is mixed on site using a jiffy mixer
Material Placement 	Consolidation is an important step in the placement of cementitious materials
Curing Shrinkage cracks can develop if not cured properly Hot-weather curing methods include a curing compound, moist burlap, or polyethylene Cold-weather curing methods include an insulating blanket or tarp Follow recommendations for proprietary materials	If shrinkage is too severe: – Repair materials will lose bond immediately – Once lost, the repair will not last very long

Crack Sealing after Patching

Joint sealing helps to ensure that incompressibles don’t cause additional spalls to occur

Finished Patch

Example of a finished patch

Summary

Good candidate for deterioration limited to upper one-third of the slab

Weak areas must be thoroughly removed

Good bond with existing concrete is required (may require bonding agent)

Special joint preparation and forming methods are required

Review/summarize key points:

- proper project selection is key
- bituminous material may be best for temporary repair
- most cost-effective repair matches materials & placement methods to desired life
- it is not the cheapest materials or one that can be tossed from back of a truck

Module 4-5 ***Full-Depth Repairs***	Module presents the procedure for cast-in-place full-depth repair of concrete pavements
Objectives **Describe alternative methods** **Identify repair areas** **Design acceptable repairs** **Describe proper construction procedures** **List specific materials and procedures**	Describe objectives
Introduction **Full-depth concrete repairs** • **JPCP** • **JRCP** • **CRCP** **Full-depth bituminous patches are not recommended**	Different concrete pavement types require variations in design & construction procedures: 1. Only concrete repairs discussed here 2. Full-depth PCC repairs should always extend across the entire width of a traffic lane 3. Commonly placed across two or more traffic lanes

Purpose

- Restore rideability
- Prevent further deterioration of distressed areas
- Prepare for an overlay

Explain purpose of full-depth repairs:

1. Extend life in a cost-effective manner

Candidate Distresses (JCP)

- Blowup (L, M, H)
- Corner break (L, M, H)
- D-cracking (M, H)
- Deterioration of or near repairs (M, H)
- Longitudinal cracking (M, H)
- Spalling (M, H)
- Transverse cracking (M, H)

Describe the candidate distresses listed for JCP:

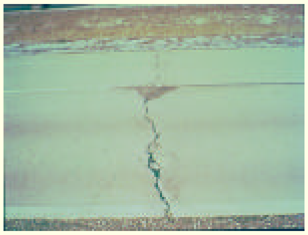
1. If joint spalling is limited to upper 1/3 of slab, partial-depth repairs are feasible & may be more cost effective
2. Durability problems, full-depth repairs used cautiously as deterioration can be more extensive at bottom of slab
3. Coring near deteriorated joint & cracks is recommended to determine extent of subsurface deterioration

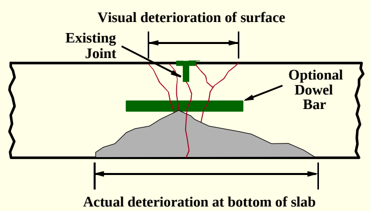
Candidate Distresses (CRCP)

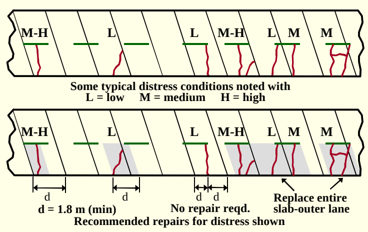
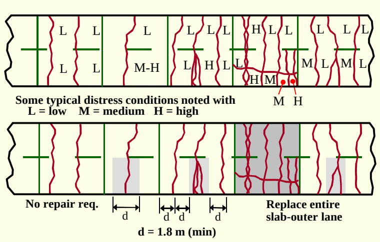
- Blowup (L, M, H)
- D-cracking (M, H)
- Deterioration of or near repair (M, H)
- Localized distress (M, H)
- Longitudinal cracking (M, H)
- Punchout (L, M, H)
- Transverse cracking (M, H)

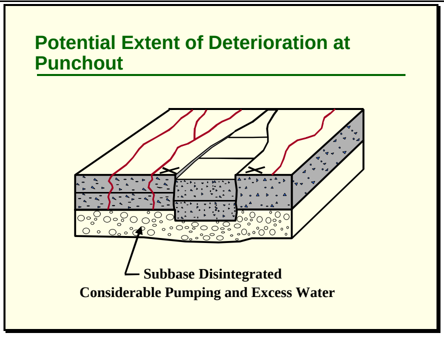
Explain candidate distresses for CRCP:

1. Similar to JCP
2. Major difference is punchouts (structural failure of CRCP)
3. Low severity punchouts should be repaired as they deteriorate rapidly

Candidate Distresses (JCP) 	Example of a working transverse crack in JPCP: – Width indicates significant movement – Deteriorated & spalled – Ideal candidate for full-depth repair
Candidate Distresses (JCP) 	Example of a transverse joint badly deteriorated & spalled due to D-cracking: – Full-depth patch already in adjacent lane – Patch extends about 1 meter either side of joint, much wider than extent of visible deterioration at surface – Patch must cover full extend of deterioration
Effectiveness Can provide good long-term performance (>10 years) Critical factors • Timing of repairs • Proper load transfer design • Quality of construction	Discuss effectiveness: 1. Study in Pennsylvania found pavements with less than 5% patching demonstrated much better performance

Design Considerations Selecting repair boundaries Multiple-lane repairs Repair materials Load transfer design Curing and opening to traffic Cost considerations	Emphasize importance of proper design
Potential Extent of Deterioration at Joint  	Deterioration at bottom of slab can extend beyond the visible deterioration at the surface (often as much as 1.0 m): – Coring is recommended at representative joints & cracks to determine actual deterioration at bottom
Minimum Repair Dimensions (JCP) Doweled or tied repairs • Length ≥ 1.8 m (6 ft) • Width ≥ 3.6 m (12 ft) Non-doweled or non-tied repairs • Length ≥ 1.8 m (6 ft) for low traffic ≥ 2.4 m (8 ft) for med-high traffic • Width ≥ 3.6 m (12 ft)	Discuss minimum repair dimensions for JCP

Guidelines for Selecting Repair Boundaries (JCP) Repairs longer than 4.6 m (15 ft) require an intermediate joint Repairs should be 1.8 m (6 ft) from transverse joints and cracks Extend repairs 0.3 m (1 ft) beyond joints Cracks located 3 m (10 ft) or more from a joint can be repaired alone	Isolated cracks can be repaired individually but cracks near other joints & cracks should be combined into one patch
Repair Recommendations (JPCP) 	Top illustrates cracks & severities; bottom illustrates recommended patch dimensions: 1. Note that where a crack near a joint is to be repaired, patch extends beyond the joint 2. Multiple joints & cracks are combined into a single, larger patch
Repair Recommendations (JRCP) 	Similar illustration for JRCP: 1. Main difference is that low severity cracks do not represent a failure & do not require repair (only medium- & high-severity cracks require full-depth patches)



Punchouts represent a structural failure on CRCP, which result from breakdown of transverse cracks:

1. Vertical movements cause pumping & loss of support
2. Repair boundaries need to address extent of deterioration
3. Coring & deflection testing can help assess underlying deterioration

Guidelines for Selecting Repair Boundaries (CRCP)

Minimum repair length

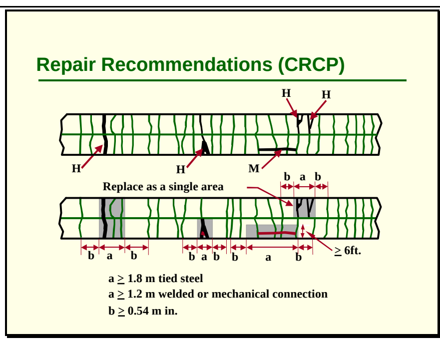
- **1.8 m (6 ft) if steel is tied**
- **1.2 m (4 ft) if steel is mechanically connected or welded**

Repairs should not be closer than 460 mm (18 in)

Minimum repair width is 1.8 m (6 ft)

Full width patches are recommended

Patches that extend full width of traffic lane are recommended



Guidelines for selection repair boundaries for CRCP:

1. Low-severity cracks do not require repair
2. Difficult because repair should cover extent of deterioration but not be too close to cracks

	Example of a full-depth patch across traffic lane
	Example of distress that requires a full-depth patch across both traffic lanes
	Example repair (What's Wrong?)

Curing Times for Repair Materials

Blended cements	2- 4 hours
Sulfo-aluminate cements	2- 4 hours
Type III with accelerator	4- 6 hours
Type I with accelerator	6- 8 hours
Type III with water reducer	12-24 hours
Type I	24-72 hours

Discuss available repair materials & typical curing times required before sufficient strength is obtained for opening to traffic:

- Depends on available lane closure time
- To ensure durability, concrete mix should have between 4.5 & 7.5 percent entrained air

Curing and Opening to Traffic

Curing methods
- Curing compound
- Insulation blankets

Opening criteria
- Minimum strength
- Minimum time

Describe curing time and opening to traffic requirements:

1. Moisture retention & temperature during curing period are critical to ultimate strength of concrete
2. Recommended minimum compressive strength is 13.8 MPa (2 ksi) and minimum modulus of rupture is 2.1 MPa (300 psi)

Load Transfer Methods

Dowel bars

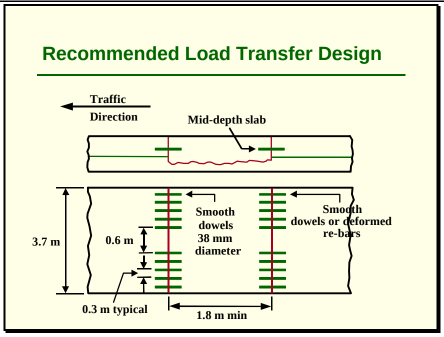
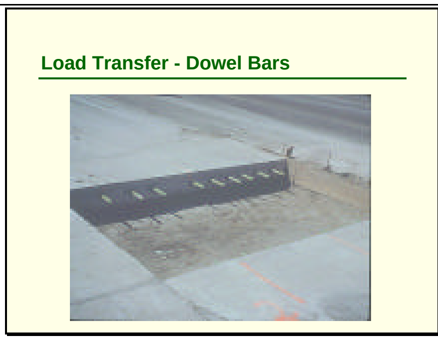
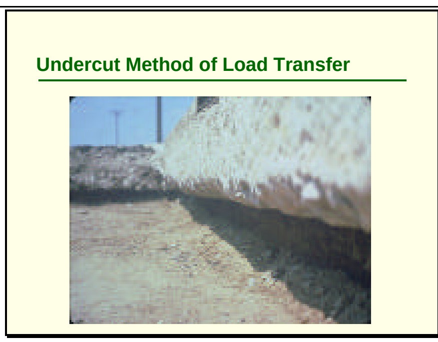
Tie bars

Undercutting

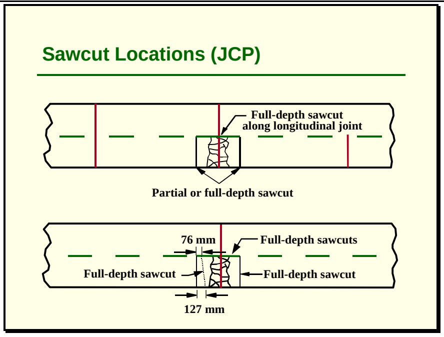
Aggregate interlock

Discuss load transfer methods:

1. Dowel bars most common
   - Allow horizontal movement of joint
2. Tie bars used where no horizontal movement is desired
   - Not for load transfer but to maintain intimate contact for effective aggregate interlock
3. Undercutting & aggregate interlock are not typically recommended

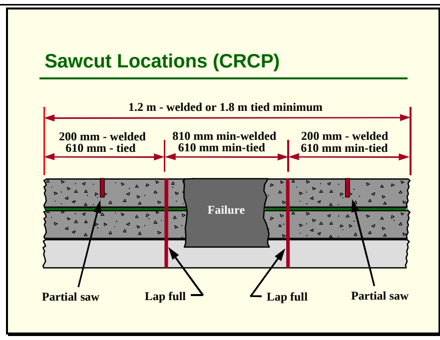
	This design by Illinois Department of Transportation: 1. One example of effective design 2. Four dowels in each wheelpath – 38 mm (1.5 in) for most interstate pavement – 32 mm (1.25 in) used only for light traffic or pavements less than 250 mm (10 in) thick
	Example of dowel bars in a full-depth repair: smooth dowel bars recommended to allow free horizontal movement
	An important consideration for full-depth repairs is the underlying support: – removal of concrete can leave void underneath – area should be cleaned so that concrete is allowed to fill these voids

Tie-bar Load Transfer (plus Undercut) 	Example of deformed tie bars in a full-depth repair: 1. If tied joint is used, should be placed at approach joint because it tends to become very tight due to action of truck wheels pushing repair backwards 2. Tied joints not recommended on JRCP due to greater horizontal movement
Cost Considerations Average cost about $80/m^2$ ($95/yd^2$) Slab replacement is preferred over several full-depth patches • Lower cost • More reliable repair	Discuss cost considerations: 1. CRCP are significantly higher due to material & labor costs associated with restoring continuity of the reinforcing steel 2. Highest cost items are full-depth sawing & jointing, unit cost is lower for larger repair areas
Construction Steps Layout repair locations Saw concrete Remove concrete Prepare area Provide load transfer Prepare joint Place and finish concrete Cure Seal joints	Describe the nine construction steps for full-depth repairs



Discuss sawcut locations JCP:

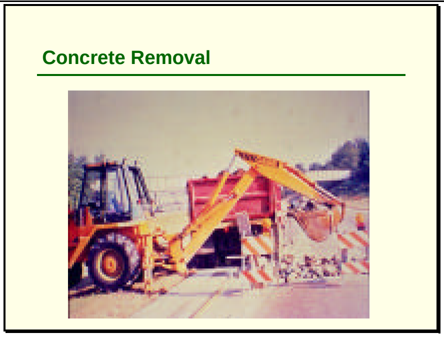
1. Boundaries must be sawed full-depth on all sides with diamond-bladed saw
2. Preliminary relief cut may be required on extremely hot days (carbide-tipped saw)
3. Traffic loading should be limited at sawcuts (no load transfer)
4. Traffic should not be allowed for more than 2 days to avoid pumping & erosion beneath slab



Sawcut locations for CRCP:

1. Saw partial-depth cuts at outer boundaries
   - Reinforcing steel should not be cut
   - If accidentally cut, length of repair must be increased by required lap length
2. Two full-depth sawcuts are made at specified distance (length required for lapping the reinforcement) in from partial-depth sawcuts
   - Recommended distance is 610 mm (24 in) for tied laps, and 200 mm (8 in) for mechanical connections or welded laps

Example of sawing operation for a full-depth repair

	Example of a drop hammer: – One method to breakup concrete – Others--jackhammers, hydraulic rams – Breakup should always begin at center of repair & extend outward in both directions – Use of large jackhammer near sawed joints should be avoided
	Example of broken up concrete: – Remove with backhoe or hand tools – Avoid damage to sound concrete adjacent to repair area
	Example of break up & clean out method: – Efficient – Pavement breakers break up concrete & rapidly remove with backhoe – Disadvantage is it disturbs underlying layers – Requires either replacement of the layers or additional concrete

Example of lift-out method:

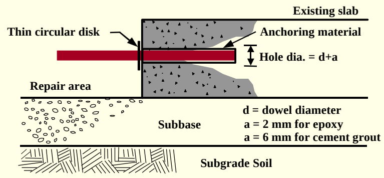
- Lift pins are placed in drilled holes with repair area
- Lift pins are hooked with chains to a front-end loader or other equipment capable of vertically lifting the slab

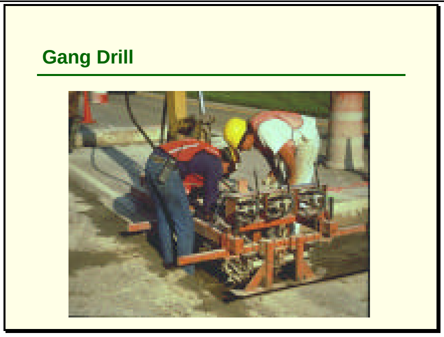
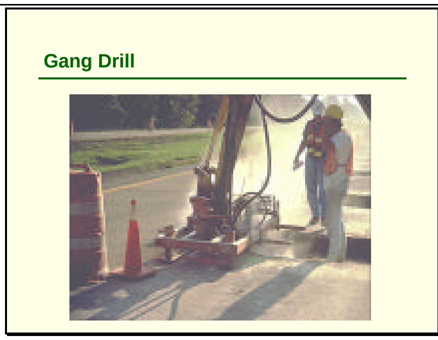
Example of lift-out method:

- Reduces potential for damage to underlying layers & adjacent sound concrete
- Permits more rapid removal than break up and clean out method

Example of concrete being lifted out of repair area

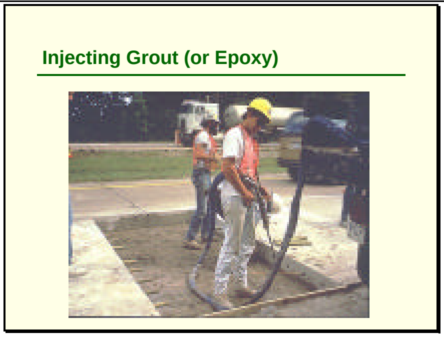
Problem with Lift Out Method 	The use of heavy lifting equipment & disposal of large pieces of concrete present the biggest obstacle for the lift-out method
Prepare Area 	All subbase & subgrade material that has been disturbed or that is loose should be removed & replaced with either similar material or concrete: – Any excessive moisture in repair area must be dried out before placing concrete – Placement of lateral drain may be necessary – Trench must be cut through shoulder & a lateral pipe or open-graded crushed stone placed
Prepare Area - Add/Recompact Base 	Compacting granular material within such a confined area is extremely difficult: – Hand vibrators generally do not produce adequate compaction to prevent settlement of repair – Replacement of subbase or subgrade with concrete will provide best performance

Dowel Bar Placement  	Discuss steps required in placement of dowel bars
Reinforcing Steel Placement (CRCP) Match existing steel Connect to existing steel • Tied splice • Welded splice • Mechanical connection Provide support (chairs) to prevent bending of steel Provide minimum 60mm (2.5 in) cover	Describe steps for reinforcing steel placement (CRCP): – Match existing steel in grade, quality & number
Gang Drill Dowel Holes 	Example of tractor-mounted gang drill to drill holes in existing slab: – Several drills mounted in parallel on a rigid frame – Equipment drills several holes simultaneously while maintaining proper horizontal & vertical alignment – At mid-depth of exposed concrete face

	Example of a tractor-mounted gang drill
	Example of a tractor-mounted gang drill: – Hand-held drills that drill single hole are available but not recommended because of likelihood for misalignment – Proper hole alignment crucial to guard against premature deterioration of repair
	Example of holes after drilling: – Holes drilled slightly larger than dowel diameter to allow room for anchoring material – If cement grout used, hole diameter should be 6 mm larger than dowel diameter – If epoxy mortar used, hole diameter should only be 2 mm larger than dowel diameter as material can ooze out through small gaps

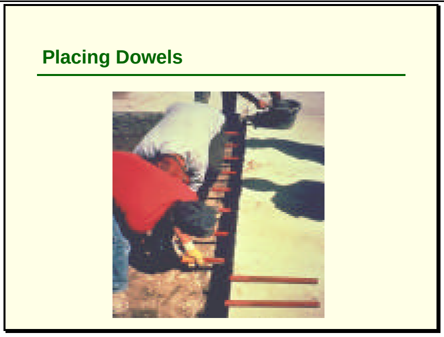
After drilling the holes, debris & dust should be removed from the holes by blowing them out with air

- Holes should be allowed to dry before installing the dowels



Example of application of an epoxy mortar into holes:

- Nozzle should extend to the back of the hole



Example of insertion of dowel bars into holes:

- Insert using a twisting motion so that material in back of hole is forced up & around the dowel bar
- Ensures uniform coating of the anchoring material over the dowel bar

Dowels in Place with Grout Retaining Washers 	Before inserting the dowel, a grout retention disk should be placed over dowel & against the slab face: – Disk prevent anchoring material from flowing out of the hole & help create an effective face at the entrance of the dowel hole
Area Prepared with Dowels in Place 	Final step is to lightly grease the protruding end of the dowels to facilitate movement: – Bond-breaking material should be placed along the existing longitudinal joint to ensure independent action between the lanes
Concrete Placement and Finishing Avoid use of additional water for workability Ensure adequate vibration near edges of repair Best results with vibratory screed Avoid over-finishing Match surface level and texture	Discuss concrete placement & finishing: – Concrete placement may need to be limited to late afternoons – On some projects in which concrete was placed in morning, expansion of adjacent slab in afternoon resulted in crushing of repair (especially where failure extends across all traffic lanes)

Curing

Methods

- **Curing compound**
- **Wet burlap**
- **Polyethylene sheeting**

Insulation blankets can accelerate curing and provide higher strengths

Describe curing procedure

Concrete Placement

Repair should be struck off to ensure that its finish is flush with the adjacent concrete:

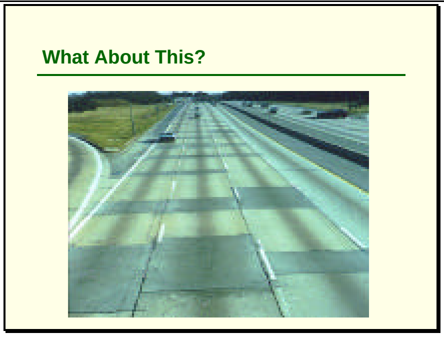
- A vibratory screed can provide better results than this manual method

Concrete Finishing

Finally, surface should be textured to match that of the surrounding concrete as closely as possible

Application of Curing Compound 	Example of application of a white-pigmented curing compound: – Currently most common method
Curing - Use of Insulation Blanket 	Insulation blankets are sometimes placed over repair area: – By not allowing heat to escape, insulation blankets accelerate hydration, which results in higher early strengths – Method can be used where early opening to traffic is a priority
Joint Sealing Transverse and longitudinal joints Saw and seal as soon as possible after concrete placement Reduces spalling and moisture infiltration Follow procedures for joint sealing (Module 4-2)	Discuss joint sealing along the repair (procedures are same as normal joint sealing which have been discussed in previous module)

	What's wrong here? – Damage to adjacent slab – Damage to reinforcing steel – Damage to underlying material
	And here? – Dowels or tiebars have not been used in this patch – Patch does not meet minimum length requirement of 1.8 m (6 ft) – Patch will be prone to rocking & faulting
	Have participants discuss bad practices shown here

	Have participants discuss bad practices shown here
Summary Bituminous patches not recommended Repairs should address the extent of the deterioration Slab replacement is more economical than multiple full-depth repairs Provide load transfer (dowels) on JPCP Restore continuity of steel on CRCP	Review/summarize key points discussed in this module

Module 4-6

Accelerated Rigid Paving Techniques

Traditional view of concrete pavement rehab is:

1. It involves use of cementious materials which cause long closures & large user cost

This module presents information on different construction techniques & mix designs that speed up different types of rigid pavement rehab projects

Objectives

- Identify conditions for use
- Select appropriate materials
- Discuss special construction procedures
- Describe field testing procedures for monitoring concrete strength
- Determine criteria for opening to traffic

Primary purpose of module is to get agencies to look at rigid pavement rehab with new set of tools:

1. Materials & paving techniques are available to repair & overlay with cementitious material
2. Understanding when techniques are appropriate
3. How to use them

Accelerated Rigid Paving Techniques

- Fast track paving
- Addresses major limitation of concrete rehabilitation
- Not all projects are suitable candidates
- Reduces
  - Time of lane closure
  - Number of lanes closed
  - Overall time of delay

Discuss accelerated rigid paving techniques

Identification of Appropriate Projects Must result in savings • Reduced direct agency costs • Reduced user delay costs Candidate projects • Urban intersections • Commercial areas • Single access roads • Urban highways	ARPT may not result in direct project cost but tends to reduce user delay costs: 1. Look at list of candidate projects – Reducing closure time is benefit to agency & user 2. Discuss benefits of ARPT in each of project types
Rehabilitation Applications Partial-depth repairs Full-depth repairs Slab replacement Concrete overlays Reconstruction	ARPT can be used on these rehab techniques (not all covered yet): 1. Emphasis is use of appropriate materials to accelerate job 2. Increased demand on agencies to work during less congestive times (between am & pm rush hour & overnight) 3. First three applications can be done within these constraints 4. Last two, within limitations, over slightly longer periods
Material Selection Scope of project Job site conditions Climatic conditions Opening time requirements Available equipment Cost Faster setting materials are typically more expensive	Discuss material selection: 1. Proprietary & non-proprietary materials available (set up within an hour) 2. Range of products with set & cure times that can match specific needs 3. More rapid a material sets, more likely to crack

Material Types

Portland cement (Type I, II, and III)
- **Higher cement content**
- **More finely ground cement**
- **Water reducers / superplasticizers**
- **Accelerators**

Rapid set cement

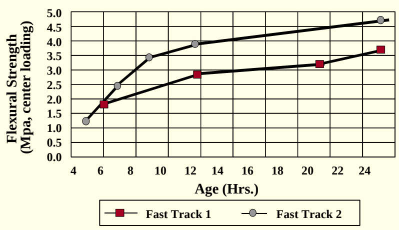
Regulated set portland cement

Proprietary materials

Most common material type:

1. PCC
   – High early strength properties are listed
2. Rapid set & regulated set cements are done by changing combination of constituent elements to add rapid setting characteristics
3. Proprietary materials
   – Achieve high early strength through many ways (including using completely different materials: magnesium phosphate or polymers)
   – More expensive

Strength Development of Fast Track Mixes



Mix designs should be developed & evaluated in lab before use in field:

1. Different materials offer different advantages
2. Many fast track mixes provide a high early strength but lower ultimate strength
3. Which is more important?

Construction Procedures

Concrete removal

Concrete placement

Curing

Joint sawing and sealing

Compressed construction schedule requires careful planning and coordination of activities

Construction process is good opportunity to accelerate a job:

1. Explain items in list

NDT Methods

Surface hardness (ASTM C 805)

Penetration (ASTM C 803)

Pull-out (ASTM C 900)

Break-off (ASTM C 1150)

Maturity (ASTM C 1074)

Pulse velocity (ASTM C 597)

NDT methods are attractive:

1. Require minimal or no coring
2. List in table 4-6.3 includes relationship between test results & cylinder strengths
3. These correlations must be developed for each specific mix

Maturity Approach

Accumulated product of time and temperature

Nurse - Saul method:

$$M(t) = \Sigma (T_a - T_o) \Delta t$$

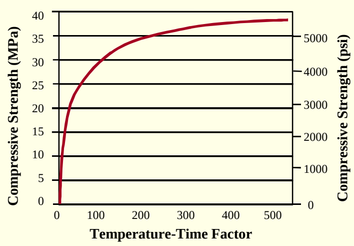
Laboratory testing is required to develop a relationship

Temperature is monitored using temperature probes or thermocouples

Concrete strength gain is function of time since placement at given temperatures:

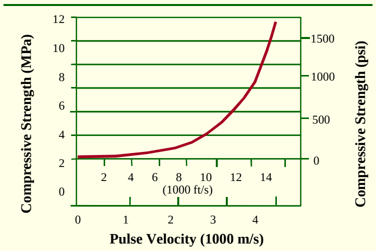
1. Develop maturity curve for a given mix in lab
2. Temperature is then monitored in field
3. Concrete can be opened at desired strength when required temperature-time is reached

Maturity Curve



Example of a maturity curve:

1. If 24 Mpa is desired opening strength, what temperature-time factor must be achieved?
2. This approach better reflects actual field conditions, but requires significant work be completed in the lab prior to its use

Pulse Velocity Approach Device sends short pulse sound waves Transducers receive the signals Velocity of the wave correlates to concrete strength Relationships developed through laboratory testing	This is another NDT technique increasing in use: 1. By knowing rate at which sound travels through a concrete mixture in different stages of curing & by establishing lab relationships between those stages & strength, field strength can be monitored 2. This requires that an exposed corner be available
Pulse Velocity Curve  	Specific curves are developed for a given mix & cannot be used for other mixes: 1. Once developed, measured pulse velocity can be related to cured strengths
Summary Faster setting materials are typically more expensive Careful planning and coordination are required High early strength development • Increase cement content • Reduce water / cement ratio Opening based on in-place strength	This module assembles information that is available in literature but may not be easy to find: 1. Techniques & materials available that can accelerate PCC rehab jobs 2. Shortens user delays 3. Makes potential projects more feasible

Module 4-7

Slab Stabilization and Slab Jacking

This module reviews two rehabilitation techniques that use similar technology but serve different purposes

Objectives

Discuss purpose and importance of slab stabilization

Describe available materials

Describe evaluation and construction procedures

Estimate amount of material required

Objective is slab stabilization:

- Has agency used?
- Did it work?
- Performance information not available (in fact, quite variable)
- When not done properly, many projects are worse than if nothing had been done

Slab Stabilization

Purpose is to fill existing voids and to restore support

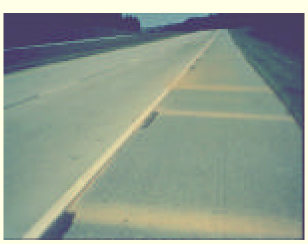
Performed mainly to address pumping and/or voids detected by NDT

Other common names

- **Pressure grouting**
- **Undersealing**
- **Subsealing**

Definition - Slab stabilization is to fill voids caused by pumping:

- Before voids become too large
- Before faulting develops
- Filling voids reduces deflections
- Results are temporary

Slab Jacking Purpose is to raise the slab and to restore rideability Addresses localized areas of settlement and depression Should not be performed to correct faulting	Slab jacking is a localized repair technique: – Uses similar equipment & materials as slab stabilization (are covered together in this module)
Selection of Projects for Slab Stabilization Joints and working cracks exhibiting loss of support Prior to onset of pavement damage Determining loss of support • Visual survey • Deflection testing • Ground penetrating radar? • Infrared thermography?	Selection of projects: 1. Timing is critical 2. Not an effective technique if signs of diminished structural capacity 3. Best applied where voids identified but not yet poor performance
Selection of Projects for Slab Stabilization 	Signs of pumping are good indication of loss of support: – What are contributing factors for pumping? – If pavement shows signs of pumping but does not yet have any faulting, good candidate

Selection of Projects for Slab Stabilization

Another good indication of loss of support is presence of corner breaks:

- If only corner breaks & no other structural deterioration, may be good stabilization candidate

Large Void Beneath Slab

This shows the extent of the void that can develop beneath a slab:

- This results from some very serious pumping
- Incidentally, if the void is this large, it may be visible using GPR or IR technology

Effectiveness of Slab Stabilization

- Comparison of deflections before and after grouting
- Effective at filling voids
- Overgrouting can be more detrimental than doing nothing
- Long-term effect on pavement performance is not well established

Methods for measuring effectiveness of slab stabilization:

1. Compare deflections of leave slab before & after undersealing
   - What are the expected results?
2. Look beneath the leave slab
   - Not cost-effective if done frequently
3. More of a good thing is bad
   - Projects fail because of overgrouting (void is overfilled & slab is raised a little)

Selection of Projects for Slab Jacking Localized areas of settlement due to loss of support • Fill areas • Culverts • Bridge approaches Not to be used to repair faulted joints	Selection of projects: 1. Simpler method 2. Any localized depression that affects rideability – Drive over project (not obvious from walking survey)
Effectiveness of Slab Jacking Effectiveness depends on amount of lifting required at a location Do not lift more than 6 mm (0.25 in.) at a time Effective when closely monitored	Measures of effectiveness: 1. Depends on rate at which lifting was done & how job was sequenced 2. Likely to have good long-term performance when properly done – Localized repair – Not for progressive condition
Limitations / Design Considerations Grout material • Ability to fill voids • Time before opening to traffic Effect on subsurface drainage Potential to develop new voids	Most common material used: 1. Cement grout – slightly stiffer for slab jacking

Grout Materials

Cement grout mixtures

- **Slab stabilization**
  - **Pozzolanic - cement grout**
  - **Limestone - cement grout**
- **Slab jacking**
  - **Stiffer cement grout mixtures required**

Asphalt cements

Proprietary materials

Today's products are all higher quality materials, and even polymers & silicone foam have been tried:

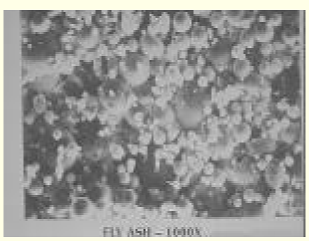
- How effective are they?

Materials - Limestone Dust

Limestone grout has been used:

- Problem with limestone can be seen when comparing it to the next photograph of fly ash grout

Materials - Fly Ash



The fly ash consists of multi-sized round particles:

- Grout made out of this material pumps and flows very well
- Makes it an ideal material for forcing into small openings

Flow Cone Test 	Flow cone test is standard measure of flowability: – Typical flow times for grout materials are from 9-16 seconds (compare this with water's flow cone time of 8 seconds) – Incidentally, the stiffer grout used for slab jacking has a time in the range of 16-26 seconds.
Void Detection Approaches Maximum corner deflection Corner deflection profile plots Plot of corner deflections at varying load levels (x-intercept) Epoxy / core test method	Discuss methods for confirming presence of voids
Void Detection Using NDT 	Example of void testing: – FWD measuring deflections at a joint – Available methods either focus on the maximum corner deflection, the relationship between the approach & leave slab deflections, – or looking at corner deflections at different load levels

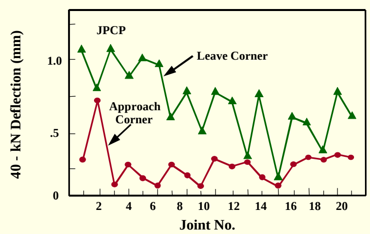
Maximum Corner Deflection Criteria

South Dakota	0.25 mm
Florida	0.38 mm
Pennsylvania	0.50 mm
Texas	0.50 mm
Oregon	0.64 mm
Georgia	0.76 mm
Washington	0.89 mm

Discuss limiting (maximum corner) criteria shown:

1. Maximum deflection alone does not indicate presence of void
   – At lower levels many factors will affect maximum deflections (load transfer, support conditions)

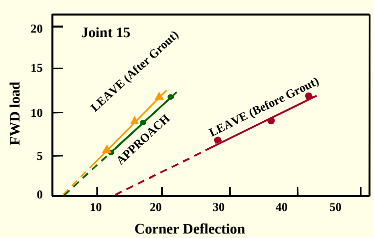
Corner Deflection Profile Plot



Difference between deflections at the approach & leave corners for each joint:

1. If significant difference between two, then a void may exist
2. What is a reasonable value?
   – 0.50 mm (other factors affect this value)

Load-Deflection Plot



Use load versus deflection plot for three different load levels:

1. Resultant line passes through or near origin, less likely to be a void

Discuss graph showing before & after grouting response

Cement Grout Slab Stabilization

Procedure for estimating quantity
- Measure corner deflections
- Plot load vs. deflection data
- Compute estimated quantity

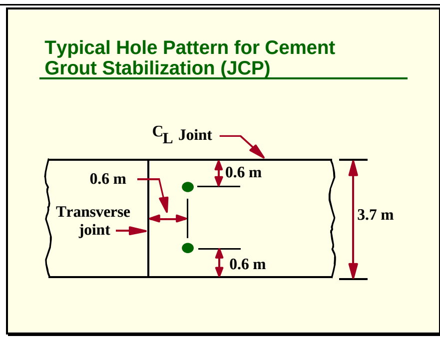
GROUT = PJG • AGT • TNJ

Average cost = $1.15 / m²

Discuss method for estimating quantity of joints needing stabilization:

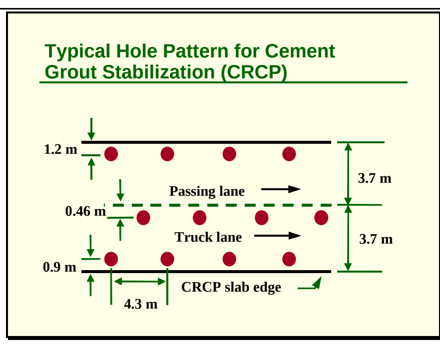
1. Percent of joints needing grout
2. Average grout take per joint
   – 0.031 to 0.093 cubic meters
3. Total number of joints

Cost varies based on the number & size of voids



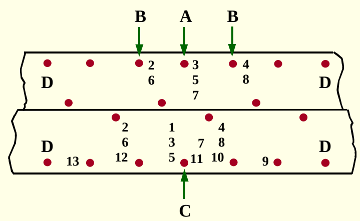
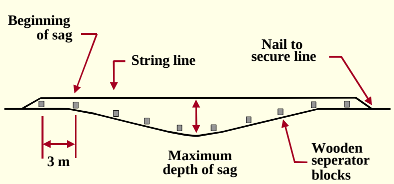
Describe construction sequence:

1. Locate grout holes
   – In JCP, in leave slab, inner & outer wheelpaths (locations where voids expected to develop



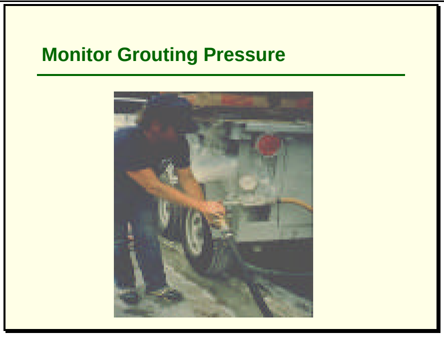
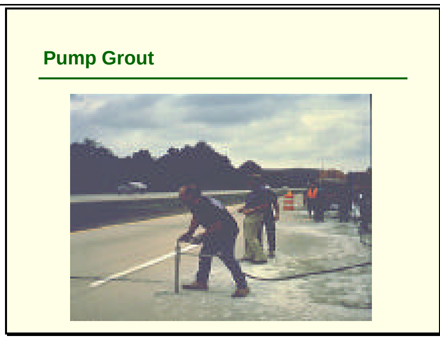
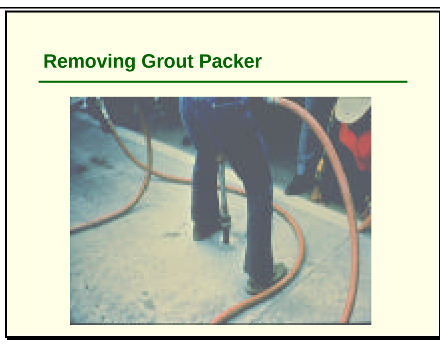
Locations where voids are expected to develop in CRCP (no transverse joint)

– Requires adjustment in field as needed

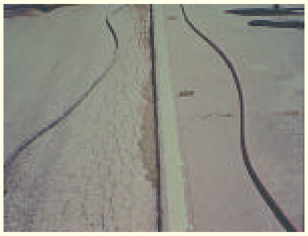
Recommended Mix Design for Pozzolanic-Cement Grout One part portland cement (Type I or II) Three parts pozzolan Water to achieve fluidity Accelerator (temperatures below 10° C) Water reducers, superplasticizers, and other additives as needed	Perform a mix design & verify: 1. Compatibility of cement & pozzolan 2. Compressive strengths desired 3. Flow cone results 4. Initial set time – No traffic for at least 3 hours
Hole Pattern for Slab Jacking 	Describe hole pattern for slab jacking: 1. Raise slab evenly without cracking intact concrete 2. Sequence is important 3. Two lanes are involved – should both be brought up slowly – leave outer edges for last
Stringline Method to Control Slab Jacking 	Monitoring slab jacking: 1. Use a stringline – stretch line from one end of depression to the other – each end is located in a slab outside the sag – distance between string & blocks is monitored to track rate of lifting & final elevation

Stringline Method of Control 	This is an overview of the slab jacking operation: – Holes with the peg have already been filled
Stringline Method of Control 	The distance between the block & stringline is the amount that the slab needs to be raised: – This is done to monitor the rate of jacking
Drill Hole ? 	The first construction step is to make the holes in the pavement: – Pneumatic drill is effective, especially if it is hooked up to a compressor

	Drills can also be used & will create less spalling at the top & bottom of the slab
	Once the holes are drilled & blown out, the grout is packed into the holes: – A grout plant on site is used to mix the material
	Shown here are the pozzolan & the cement being mixed in the grout plant

 	The pump must be capable of a discharge of about 1700 kPa: – This is a fairly high pressure, & is needed to inject the material into narrow voids
 	The grout packer is connected to the grout plant: – The grout hole must be sealed immediately after the grout is injected – It must also be capable of recycling the grout so it doesn't harden in the hose
 	The most important consideration in slab stabilization is protection against overfilling

Checking Slab Lift 	One of the best ways to guard against overfilling is to monitor movement of the slab: – Unlike slab jacking, the intent is not to raise the slab – As soon as this modified Benkelman beam detects movement the stabilization should stop
Grouting Hole and Plug 	Example of a grout hole & plug
Grout Layer 	A final way to document that the stabilization process is working is to remove the slab & look at the void: – In this cutaway, the thin layer of grout is clearly visible between the slab & the base

Grout Extruding from Joints at Slab Edge 	Example of cement grout that has flowed up along the pavement edge: – Grout in transverse joints & locking up is not major concern, (the material should break down against a slab's compressive force) – Concern with filling drainage or permeable layers with grout – One reason why office data collection is important for rehab project
Summary **Slab Stabilization** • Fills voids and restore support • Corrects faulting **Slab Jacking** • Lifts the slab and restores rideability • Corrects localized areas of settlement **Both require experienced contractors** **Do not overfill**	Review/summarize key points in this module

Slide	Notes
Module 4-8 ***Diamond Grinding and Grooving***	Begin module 4-8: Two similar methods for treating surface problems (cold milling is also included as it is very similar to grinding)
Objectives **Describe diamond grinding and grooving** **Describe conditions under which the methods will be beneficial** **Describe equipment and construction problems** **Distinguish from cold milling**	Discuss the objectives shown: – Grooving is more of a safety matter than a pavement rehab technique
Diamond Grinding **Uses closely-spaced, diamond saw blades mounted on a rotating drum** **Removes weathered concrete** **Corrects surface irregularities** **Provides smooth riding surface**	Diamond grinding: 1. Used in initial construction for smoothness specs 2. Commonly used in rehab at transverse joints to remove faulting

Diamond Grooving Uses diamond saw blades spaced 19 mm (0.75 in) apart Cuts grooves into the concrete Reduces incidence of hydroplaning Used on flexible and rigid pavements	Diamond grooving: 1. Equipment is similar to grinding – Blades are spaced further apart 2. Grooves provide channel for water to get off pavement
Cold Milling Uses drum-mounted carbide steel cutting bits Chips off the pavement surface Removes deteriorated areas Prepares surface for an overlay More common on HMA pavements	Cold milling: 1. Primarily a preparation technique – Has been used instead of grinding 2. Where it’s a surface prep technique, pavements left open to traffic for several years without adverse effects
Benefits of Diamond Grinding Removes faulting Removes wheel path wear Removes joint warping Provides texture to polished surface Improves slope and drainage	Discuss benefits of diamond grinding as shown on slide

Selection of Projects for Diamond Grinding IGGA / ACPA Criteria • PSI between 3.8 and 4.0 • Before faulting reaches critical levels Does not address structural problems Need to address the cause of distress Not effective for durability problems Hardness of aggregate affects costs	Selection of projects: 1. Important - recommended for pavements in fairly good condition – Means less material will be milled off – Primary causes may be more readily addressed – Cost of rehab will be less
Selection of Projects for Diamond Grooving Potential locations for wet weather accidents • Horizontal curves • Interchanges • Entire project Pavements should otherwise be structurally and functionally sound	Selection of projects: 1. Similar to grinding operation 2. Does not address case of roughness 3. Sole purpose is to reduce wet weather accidents
Selection of Projects for Diamond Grooving 	Example of what grooving is intended to correct

Selection of Projects for Cold Milling

Not recommended for final texturing
- Produces a rough surface
- Creates spalls at transverse joints

Uses on concrete pavements
- Restore surface friction (modified)
- Provide surface for bonding overlays
- Remove material for partial-depth repairs

Selection of projects:

1. Previously used to remove contaminated surface material
   – Prior to placing a bonded overlay
   – To remove surface before flexible overlay where clearance is a problem
2. With development of more closely spaced bits, now used instead of grinding in some applications

Cold Milling

This is a milled interstate pavement that was going to receive a flexible overlay but was instead left open to traffic for several years while funding was arranged:

– Motorists complained about higher road noise, but the ride was satisfactory

Cold Milling

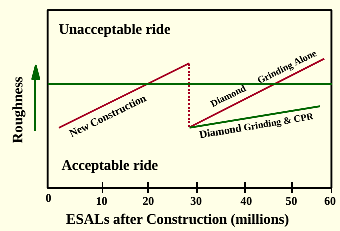
Another view of a milled concrete surface

Effect of Diamond Grinding on Roughness

Location	Before	After 2 Years
AL	1.86	0.92
AZ	1.99	0.58
GA	1.55	0.63
NY	2.35	0.60
SD	1.45	0.58
Average	1.85	0.66

This table illustrates the effect of diamond grinding on roughness in 5 states

Effect of Diamond Grinding on Roughness



Effect of diamond grinding:

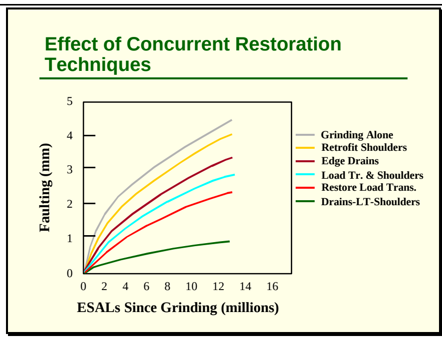
– Does not address roughness (this case faulting)
– Slope of recurring roughness after grinding is same as slope before grinding
– Slope changes if grinding is done with other rehab techniques

Effect of Diamond Grinding on Friction

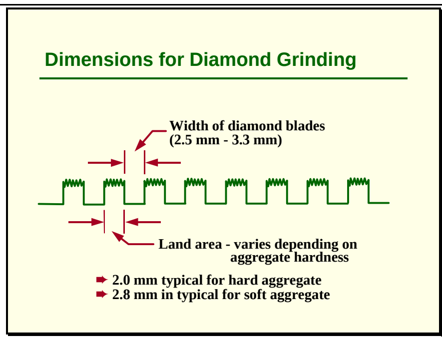
Year	NB Lane	SB Lane
0 (before)	31	29
0 (after)	40	44
1	49	45
2	40	42
3	34	34
4	34	33
5	33	33

What is a critical number?

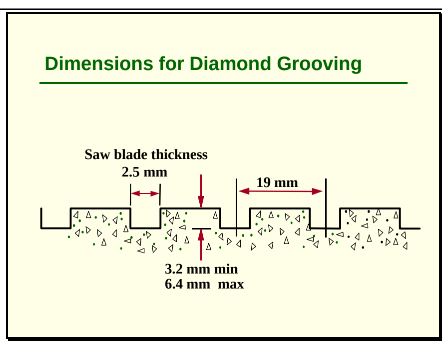
1. Most agencies reluctant to define
2. 35 is typical
3. Grinding restored friction
4. Note project with highest friction before showed least improvement



This illustrates concurrent techniques & their effect on the return of faulting



This spacing is such that the pavement surface texture after grinding will be quite smooth

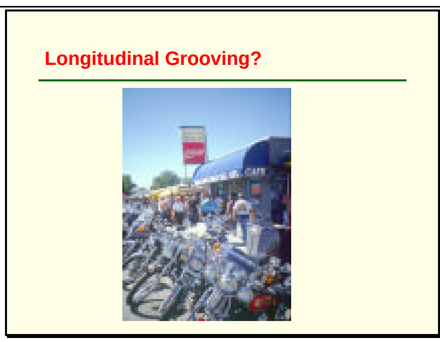


Illustrates difference between grinding & grooving:

- Sawcut is about the same
- Spacing much different

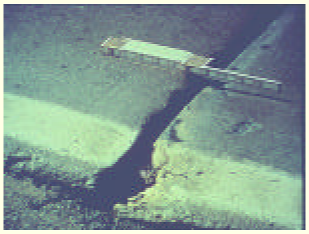
Review purpose of differences

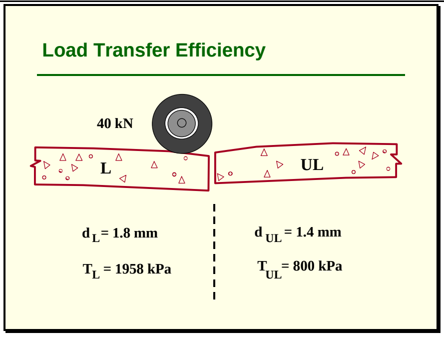
Acceptance Criteria for Diamond Grinding **Similar criteria as for new construction** **Profile measurements** • California profilograph • K.J. Law Profilometer • Mays Ridemeter **Skid resistance** • Ribbed tire (ASTM E 501) • Smooth tire (ASTM E 524)	Different ways to assess result of diamond grinding: – Similar to new construction – Absolute measure with devices for roughness or faulting – Measure skid number
Cost Considerations **Diamond grinding** • Soft aggregate $2.40-3.60 /m² • Med. aggregate $3.60-6.00 /m² • Hard aggregate $6.00-9.60 /m² **Diamond grooving** • Depends on hardness of aggregate • Range from $1.80-3.00 /m²	Note that these costs have held steady for many years
Construction Considerations for Diamond Grinding Disposal of slurry (vacuum) New equipment produces smooth surface Continuous operation for best results Begin and end perpendicular to centerline Maximum overlap of 50 mm (2 in)	Construction Considerations: 1. Critical - disposal of slurry – Some areas just pump off road – Most agencies restrict

	Self-explanatory
	Self-explanatory
	Self-explanatory

Slide	Notes
Construction Considerations for Diamond Grooving Disposal of slurry (no vacuum) Groove dimensions • Width = 2.5-3.3 mm • Depth = 3.2-6.4 mm • Spacing > 19 mm Conducted in longitudinal direction Most often performed only in localized areas	Grooves not only easier to apply longitudinally, but also work better: – Contrast to airport runways where grooves are transverse to centerline & enhance stopping ability
Construction Considerations for Cold Milling Should use micro-milling specifications Spalling of transverse joints Carbide bits require frequent maintenance and replacement Conducted in longitudinal direction Requires close monitoring of equipment	Construction considerations: 1. Past concerns were spalling – No concern if overlay 2. Equipment was designed for milling asphalt – Not powerful enough for concrete – Modifications have been made – Closer spacing of carbide bits
Summary Diamond grinding and grooving correct surface deficiencies Do not address structural problems Most effective with other restoration techniques Cold milling is not widely used on concrete pavements	Review/summarize key points presented in this module

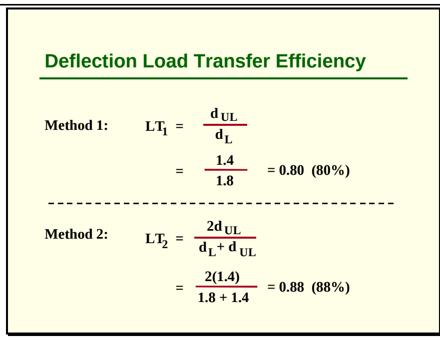
Module 4-9 ***Load Transfer Restoration***	Load transfer restoration is a strategy for providing load transfer on pavements that were constructed without it
Objectives **Identify problems that can be addressed by load transfer restoration** **Understand the available techniques for assessing need for load transfer** **Describe the installation procedures** **Identify the performance capabilities of load transfer devices**	Introduce objectives for LTR: 1. Used more frequently – What happens when there is poor load transfer?
Pumping 	Easily recognizable result of poor load transfer: 1. What is the distress? 2. What factors contribute to its occurrence? (heavy loads, water, pumpable material)

Faulting 	After pavement has pumped for awhile, faulting can be expected: 1. What are critical levels of faulting? 2. At what point does it become noticeable? 3. At what point is it an indicator for rehabilitation? 4. Does the pavement look like it's at a critical point?
Corner Cracking 	As pumping progresses, corner breaks are another outcome: 1. This double corner break is unusual & may be explained by some additional factors. For example, consider the presence of the edge drain. – What impact might this have had?
Load Transfer Restoration Increasingly popular method Installation of devices to transfer load Transverse joints and cracks Reduces further deterioration • Pumping and faulting • Spalling • Corner breaks	LTR is used to forestall development of distresses: 1. Discuss LTR items listed



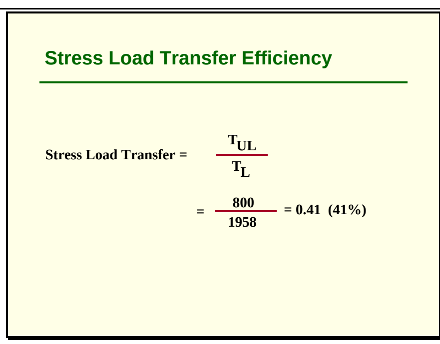
Measuring LTE:

1. Look at deflections on loaded & unloaded side of a joint
2. Use an FWD with load plate on approach slab, & first sensor on leave slab



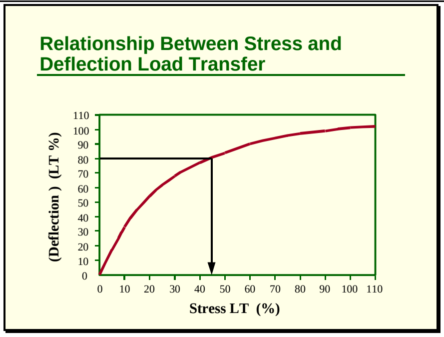
Deflection load transfer is the ratio of deflection measured on the unloaded side to the deflection of the loaded side:

- – Perfect load transfer ration is 1.00 (100%)



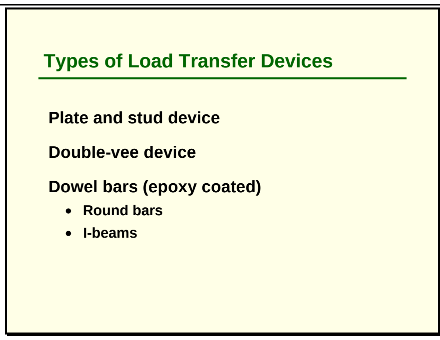
Stress Load Transfer Efficiency:

1. More important than deflection load transfer
   - – Deflections alone do not cause pavement deterioration

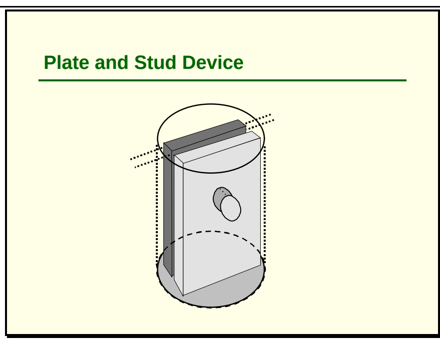


Illustrates there is not a linear proportion between stress & deflection load transfer:

- Deflection load transfer is better than none
- Recent research reports on use of shear transfer as most meaningful indicator of joint's structural capacity



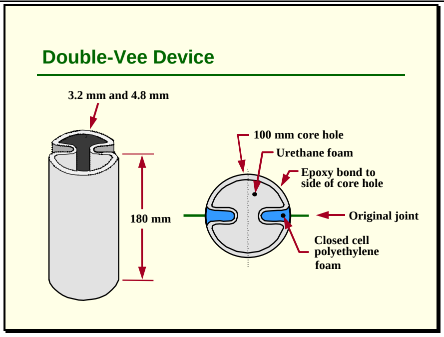
Describe load transfer devices



This type of device was epoxied into a core hole drilled at a transverse joint:

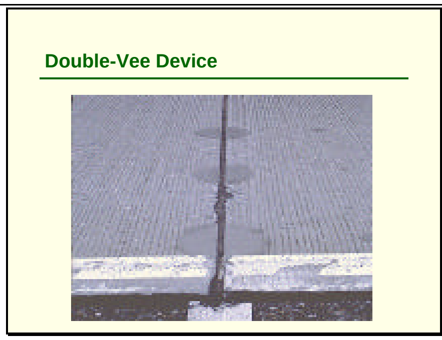
- Did not work
- Failed to stay in place
- Have not been effective in restoring load transfer

(Note that a French company has promoted a similar device for several years that they feel has performed effectively)



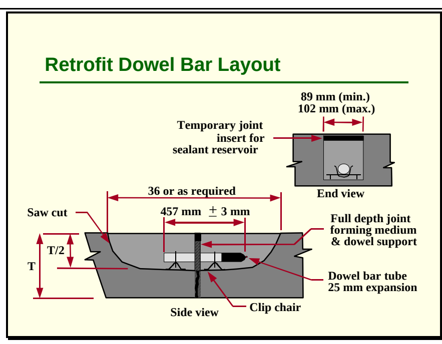
Another device that was compressed & inserted into a core hole at the joint:

- Have been unable to provide satisfactory long-term improvement to load transfer



This is a project on I-10 in Florida in which a number of different devices & installation methods were tried:

- Project was monitored over time & these did not fare well

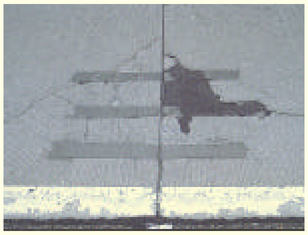


This schematic shows the installation of a commonly used method of LTR:

- Retrofitted dowel bar

Repair Material **Required characteristics** • Little or no shrinkage • Rapid strength development • Good bond with device and with concrete **Types of materials** • Proprietary materials • Polymer concrete • Portland cement concrete • Epoxy-resin adhesives	Discuss the repair material characteristics & types
Applications Joints exhibiting distresses due to poor load transfer (LTE < 50%) Uniform cracks that have not opened or faulted Prior to HMA or bonded PCC overlay More appropriate on pavements experiencing heavy truck traffic Pavements > 200 mm (8 in) thick	Best candidates for LTR: 1. Poor LTE that have not developed significant faulting 2. Cost-effective on heavily trafficked pavements 3. May be used prior to placement of overlay (can be expensive)
Effectiveness Retrofitted dowel bars have performed well Performance of double-vee device has been poor Not much performance data on other types of devices **Dowel bars are the only recommended devices for load transfer restoration**	Effectiveness: 1. Retrofitted dowel bars are best method 2. Use has gone from experimental to accepted practice over past 10 years

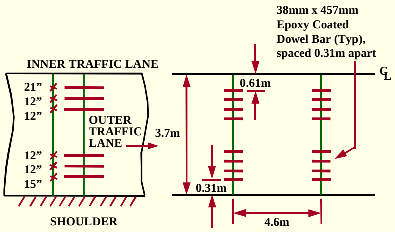
Dowel Bar Design Considerations



Example of dowel bar retrofit test section constructed on I-10 in Florida:

- Compressive failure at joint probably caused by allowing slot backfill mortar to fill joint

Typical Layout (Plan View)



Several different configurations are shown here:

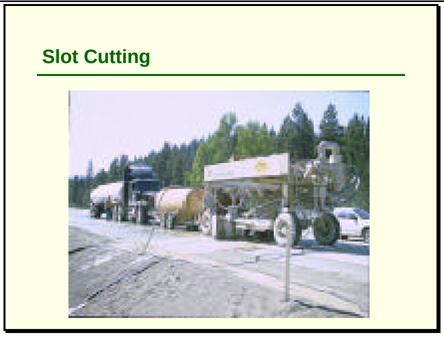
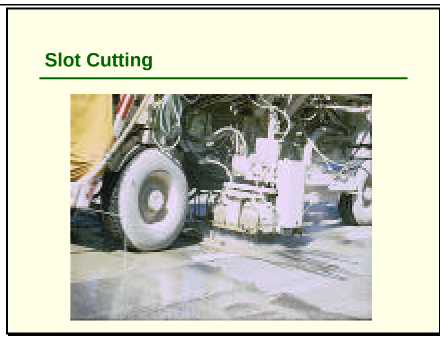
1. Note placement of first dowel in from pavement edge
2. Use of 3-4 dowels in wheelpath
3. Some projects have more dowels in outer wheelpath than inner wheelpath

Pavement Surveys

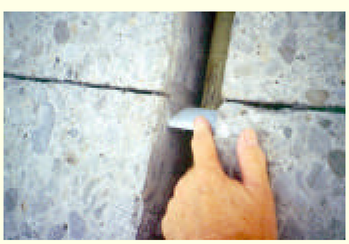
- Measure faulting
- Measure load transfer efficiency
  - Falling weight deflectometer (FWD)
  - Temperatures < 27 °C (80 °F)
  - Outer wheel path of outside lane
  - Account for slab bending effects
- Lift slabs and examine condition
- Examine cores

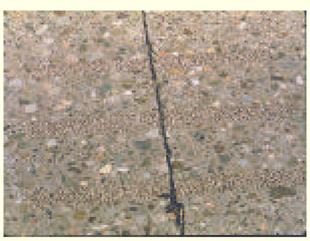
Discuss procedure for a comprehensive pavement survey

Costs Costs are on the decline • Contractor experience • Innovative methods and equipment Typical costs per dowel range from $22 to $50	Discuss costs as shown on slide
Slot Preparation Slots should be parallel to centerline Saw depth should be 13 mm below bottom of dowel bar Remove material with jackhammers or hand tools Caulk joints to prevent intrusion Provide clean surface (a bonding agent is sometimes required)	Describe steps for slot preparation
Slot Sawcuts 	Example of sawcut for slot removal

	Example of sawcutting machine: – Cut slot sides for 6 slots in 90 seconds
	Close up of the slots being sawcut
	Removing the sawed slots is accomplished with a jackhammer: – This removes most the chunks, but may still leave some handwork

Material Removal 	A small jackhammer is used to provide a level bottom for the slot: – Board used to gauge depth
Cleaning Slots after Sandblasting 	The slots are blown out to remove any loose debris: – A clean slot provides a surface that the concrete will more readily bond to
Dowel Bar Placement Lightly grease or oil the full length Expansion cap is required Place at mid-depth on chairs Proper alignment is critical Use filler board or styrofoam at mid-point of dowel bar	Describe steps for dowel bar placement: – Emphasis quality control during placement to ensure performance as intended

Dowel Bar Placement 	Dowels are shown in their chairs, with the styrofoam insert at the center that will align with the joint: – A silicone or other materials should have been inserted into the joint to keep grout or patch material from blocking joint movement – Hammer in the foreground is used to remove any high spots that impede proper alignment of the dowel
Dowel Bar Placement 	The dowels are shown in position : – End caps are clearly visible, as are the styrofoam inserts
Joint Sealed with Caulk 	The joint is being sealed with caulk to keep grout out

Mixing Grout Repair Material 	Mixing backfill material in standard grout mixer
Wetting and Filling Slots 	This product requires that the substrate be moistened prior to placing grout
Finished Dowel Bar Retrofit 	Completed dowel bar retrofit

Retrofit Dowel Project 	Looking into the sun, the retrofitted dowel bars are obvious
Retrofit Dowel Project 	In the opposite direction, the project overview shows that the dowels are barely visible
Summary Increasingly popular method of establishing good load transfer Dowel bars only are recommended New equipment has improved efficiency and cost of process Deflection testing is recommended for evaluation and acceptance	Review/summarize key points: 1. What are the criteria for considering a LTR project? – Thickness, poor LTE, faulting<critical level 2. Other things to consider – contractor experience – condition of base – cause of faulting

Module 4-10 ***Shoulder Rehabilitation Considerations***	Although shoulders do not affect rideability & don't require any special rehab techniques: – On rigid pavements there are several performance-related features that should be considered during rehab
Objectives **List common shoulder distresses** • **HMA shoulders** • **PCC shoulders** **Discuss procedures for shoulder rehabilitation** **Describe the benefits of using a tied PCC shoulder**	Present objectives listed
Introduction **Purpose** • **Safety zone for errant vehicles** • **Auxiliary area for emergency stops** • **Provide lateral structural support** • **Drain water away from mainline** **Generally designed to a lower structural capacity** **Only paved shoulders are considered**	In addition to items listed, shoulder often carries traffic during rehab of one lane

Critical Distresses on HMA Shoulders Pumping Fatigue cracking Lane-shoulder drop off Block cracking Shoving Differential support Weathering and raveling	HMA shoulder distress evaluation: 1. Same as HMA mainline 2. Additional distresses – Lane-shoulder drop off – Differential support 3. Shoulders will have more raveling & weathering – Less traffic means asphalt ages faster 4. Joints are harder to seal (water infiltration) – Causes drop off, fatigue, & differential support
Critical Distresses on PCC Shoulders Cracking Pumping Faulting Spalling	PCC shoulders distress evaluation: 1. Same as mainline 2. Sendency to repair less frequently 3. Failures are attributed to problems with tiebars
Benefits of Tied PCC Shoulders Reduced edge / corner stresses Improve lateral support Reduce lane-shoulder drop off Reduce lane-shoulder separation Limit infiltration of moisture	Properly tied PCC shoulder can enhance the performance of the mainline pavement: – must be properly designed & constructed

Considerations • Design • Cost • Construction	Discuss factors for consideration
Construction 	Example of retrofitting of a concrete shoulder: 1. What benefits might be sought in this particular project? Note the matching of the joints between the mainline and shoulder pavement.
Construction 	Paving of the shoulder

Summary **Evaluate shoulder condition along with mainline** **Rehabilitation of shoulder should consider condition of mainline** **Techniques are similar to those used on the mainline**	Review/Summarize key points

Module 4-11

Retrofit Edge Drains

Technique:

1. With other techniques
   – grinding & overlay
2. Performance is variable
   – not necessarily due to technique
3. Preferred to install edge drains during construction rather than during rehab

Objectives

Identify sources of moisture

Identify functions of the components of a subsurface drainage system

Discuss criteria for selecting a filter system

Understand subsurface drainage design

Discuss design modifications for retrofitted drainage

Describe objectives:

1. Similar to drainage design for new pavements
   – Fewer components because important factors already decided
2. Identify what moisture can be removed

Introduction

Many sources of moisture in pavements

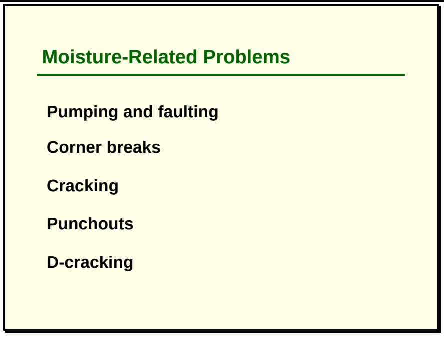
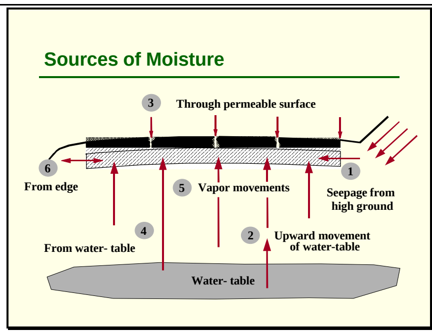
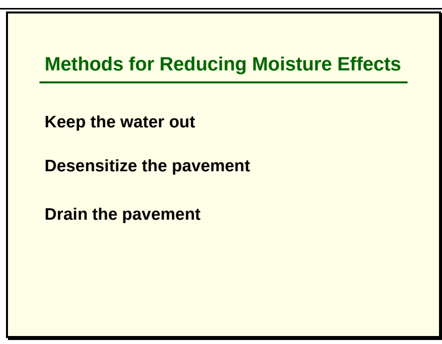
Moisture is a major cause of distress

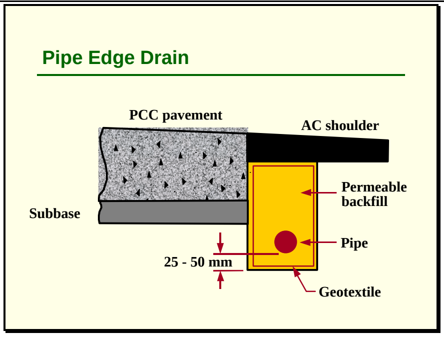
Drainage components

- **Longitudinal drains**
- **Transverse drains**
- **Permeable bases**
- **Separator layers**

Ask participants to discuss:

1. What sources of moisture are different in rehab than in new design?
2. What limitation affect drainage retrofit?

 	Describe moisture-related distresses: 1. Indication of drainage problem 2. Candidate for adding drainage? – Age – Type, severity, extent of distress – Pavement design
 	This slide illustrates various sources of moisture
 	Minimizing moisture: 1. Draining the pavement is only feasible method in rehab – Not very successful



View of pipe edge drain

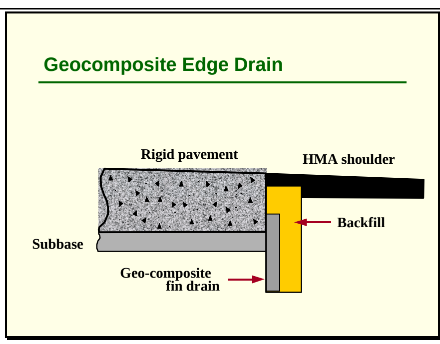
Pipe Edge Drains

Pipe diameter
- Function of flow rate, grade, and outlet spacing
- ≥ 100 mm (4 in) recommended

Longitudinal slope
- > 1% for smooth pipes
- > 2% for corrugated pipes

Top of pipe should be 50 mm (2 in) below subgrade

Explain definition:
Longitudinal drains placed in a trench at the edge of the pavement
- Have performed fairly well



View of geocomposite edge drain (description on next slide)

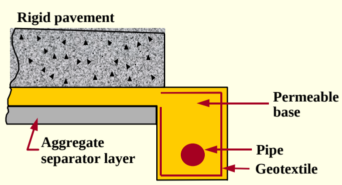
Geocomposite Edge Drains

Prefabricated drain consisting of filter fabric around a plastic core

Typically 300 mm (12 in) deep

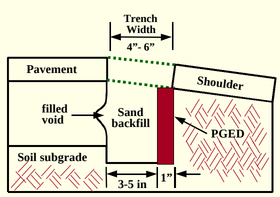
Describe geocomposite edge drains

Permeable Base and Edge Drain



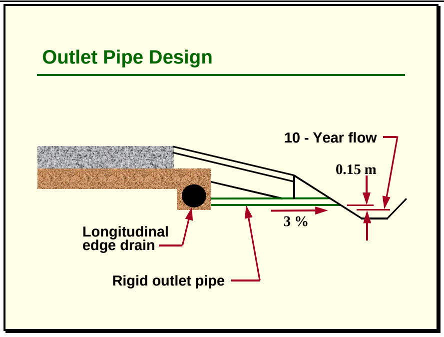
Discuss how permeable base and edge drain work

Recommended Design for Geocomposite Drains



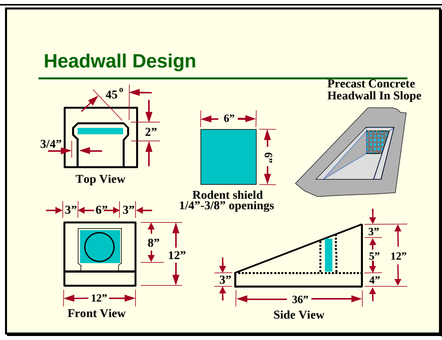
(b) Recommended location of PGEDs for future placement methods

Discuss recommended design for geocomposite drain



Critical component of drainage design:

1. Keeps pipe edge from being crushed
2. Makes it easy to locate
3. Allows access for cleaning



Headwalls are recommended:

1. Protect outlet pipe
2. Prevent slope erosion
3. Facilitate location of outlet pipes

Considerations

Design

- Surveys
- Costs

Construction

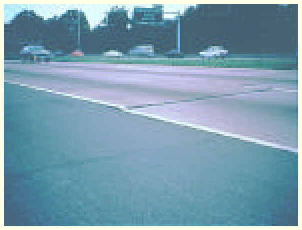
Maintenance

Discuss items listed

Summary Moisture is a major cause of distress Subdrainage systems can effectively remove infiltrating water Subdrainage systems can extend life when used under right circumstances Good design, construction, and maintenance practices are required	Review/summarize key points

Module 4-12 ***Recycling Concrete Pavements***	This module describes PCC recycling for deteriorated pavement: – Object is to obtain aggregate for use in some layer or part of a pavement reconstruction process
Objectives **Identify conditions for recycling** **Identify potential benefits** **Describe the recycling process** **Understand properties of recycled aggregate and concrete** **Describe implications to mix design and structural design**	Discuss objectives listed
Reasons to Reconstruct **Little or no remaining life** **Substantial foundation movement** **Extensive joint deterioration** **Extensive durability problems** **Outdated geometric standards**	PCC recycling considered part of reconstruction project: – Review reasons why pavement might be considered candidate

Reasons to Reconstruct



Discuss why might want to reconstruct

Reasons to Reconstruct

Example of severe D-cracking:

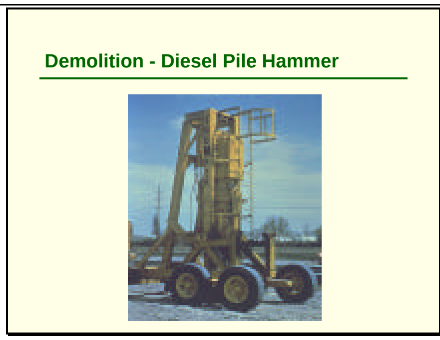
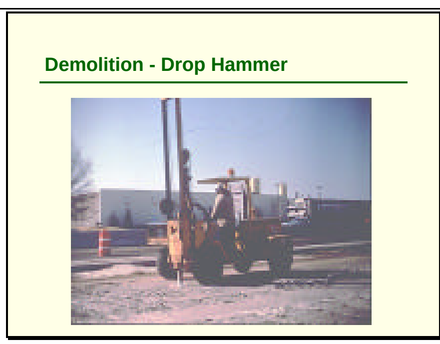
- Generally occurs at every joint
- Can present ongoing maintenance problem
- Distress mechanism is inherent in aggregate
- Only solution is complete removal of pavement

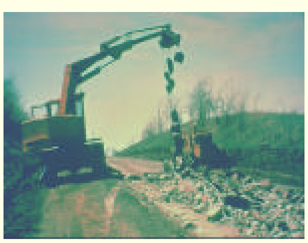
Concrete Recycling

- Break up the existing pavement
- Haul to crushing plant
- Use as aggregate for new concrete
- Recycled coarse aggregate is more useful
- Pavements with durability problems can be recycled

Describe concrete recycling process

Reasons for Recycling Dwindling landfill space Increasing disposal costs Conservation of materials Scarcity of high-quality aggregate Reduction in project cost	Cost reasons associated with either the procurement of virgin aggregate or the disposal of existing pavement material: – Agency policy – Contractor experience
Uses of Recycled Concrete Aggregate HMA pavements PCC pavements Aggregate bases Stabilized bases Fill material Filter material Drainage layer	Describe uses of RCA
Limitations Harsher mix (less workability) Lower strengths Higher shrinkage Greater thermal expansion Less abrasion resistance	Slightly different properties than virgin materials: 1. Water-cement ratio – Items listed on slide 2. Can be overcome with – Lower w/c – High range water reducer – Elimination of recycled fines in the mix – Structural design (short joint spacing, dowels at transverse)

	Example of HMA surface removal
	Example of a trailer-mounted diesel hammer used to break up concrete
	Example of a drop hammer

Demolition - “Headache” Ball 	Example of a headache ball which is generally not recommended due to its breaking of the PCC into less salvageable pieces & its potential for damage to underground utilities
Demolition - Resonant Frequency Pavement Breaker 	Example of a vibrating beam breaker: – Imparts a high-frequency, low-amplitude impact force to a 305 by 305 mm plate – Much quieter – Does not disturb underground utilities – Suited to urban use
Steel Removed On Site 	After demolition of the concrete, it must be removed: – Some early projects suffered from steel entangling during the removal operation

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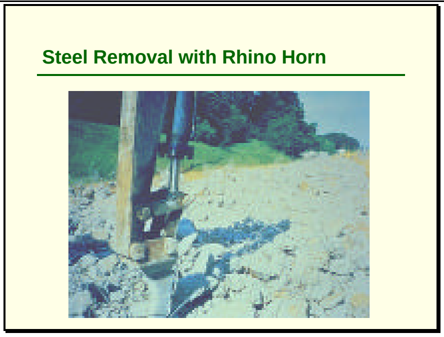
<td>
</td>
<td>Introduction of the rhino horn:
– Attached to a backhoe or front end loader
– Has proven effective in hooking steel & removing it from the concrete fragments</td>
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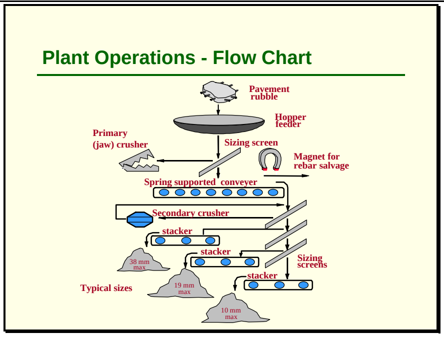
<td>
</td>
<td>Illustration of the sequence of operations at a concrete recycling plant</td>
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<tr>
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</td>
<td>The material is first hauled to a crushing plant:
– Here a plant has been set up in the center of a cloverleaf of a freeway construction project</td>
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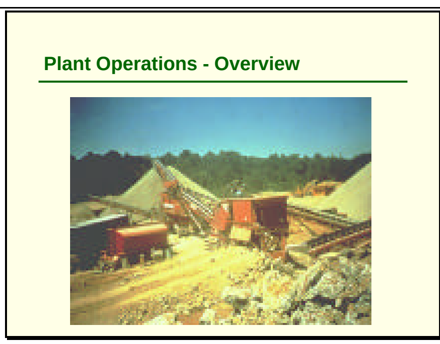
	Concrete rubble is being placed in a hopper
	Example of sizing screens
	Overview of plant operations

End Product - RCA

After the crushing operations, the material is stockpiled by size:

– This is a close-up of one stockpile of RCA
– Size that the materials will be crushed to will vary depending on the expected use of the aggregate

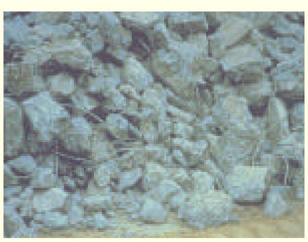
Potential Contaminants

Reinforcing steel
Dowel bars and baskets
Chemical admixtures
Deicing salts
Oil
Joint sealant
Material from underlying layers

Contaminants found in concrete rubble :

1. First two are removed during crushing operation
   – Not believed to have effect on RCA use in concrete mix
2. Effects of chemicals & salts is not known
   – Studies show chloride contents are within acceptable limits
3. Effects of oil & sealant – negligible
4. Base & subgrade (clay balls) may affect PCC strength if not removed

Plant Operations - Steel Removal



Example of rubble requiring steel removal

	Significant development in aggregate processing is steel removal: – Recovered steel can be sold for about $44 per metric ton
	Electromagnet placed over the conveyor belt removes virtually all steel
	A minimum amount of handwork is required to ensure that no steel enters the sizing screens

Comparison of Aggregate Properties

Property	Virgin	RCA
Shape	Varies	Angular
Texture	Varies	Rough
Absorption, %	0.8-3.7	3.7-8.7
Specific Gravity	2.4-2.9	2.1-2.4
L.A. Abrasion, %	15-30	20-45
Sodium Sulfate, %	7-21	18-59
Magnesium Sulfate, %	4-7	1-9
Chloride Content, kg/m^3	0-1.2	0.6-7.1

RCA has different properties than conventional virgin aggregate:

1. Primary properties
   - Angular shape
   - High absorption capacity
   - Lower specific gravity
   - Higher abrasion loss
2. Characteristics due to presence of mortar on aggregate particle & can have adverse effect on workability of new PCC mix

PCC Mix Design

Follow conventional mix design

Adjust the amount of each component

Limit recycled fines to 30 %

Substitute portion of cement with flyash

Require higher air content

Explain procedure for PCC mix design using RCA

Concrete Properties

For same water-cement ratio

- **Up to 40% lower compressive strength**
- **20-40% lower elastic modulus**
- **8% lower flexural strength**

Greater resistance to freeze-thaw

Greater resistance to D-cracking

Properties of hardened RCA concrete is somewhat different from that produced using virgin aggregates

HMA Mix Design Requires more asphalt cement Less need for anti-stripping agent	RCA in AC mixtures: – porosity (due to old mortar fraction) of the RCA requires greater amount of asphalt cement – may preclude the use of RCA due to increased costs – less susceptible to stripping (due to mortar fraction)
Design Considerations Properties affecting design • Smaller aggregate top size • Lower abrasion resistance Design recommendations • Use dowels at all transverse joints • Use higher reinforcement contents • Use stiffer foundation	Small size & lower abrasion resistance of RCA: 1. Are not effective in providing aggregate interlock load transfer across joints & cracks
Construction Consideration Techniques and equipment are the same as those for normal construction	No special requirements are needed for the construction of PCC pavements containing RCA

Cost Benefits RCA production costs = $8-11/ton Virgin aggregate costs = $13-15/ton Eliminate disposal costs Project savings up to 65% have been reported	Disposal costs are eliminated: – RCA can be a very attractive alternative to the use of virgin materials
Summary Recycling is cost-effective alternative (scarcity of virgin aggregate) Requires adjustment to mix design and pavement design Good performance has been reported No specialized techniques or equipment	Review/summarize key points

Module 4-13

PCC Overlays

This module describes design & use of PCC overlay:

1. Three types
   - Bonded, unbonded & whitetopping
2. Characterized by
   - Type of existing pavement
   - Bonding condition between pavement & overlay

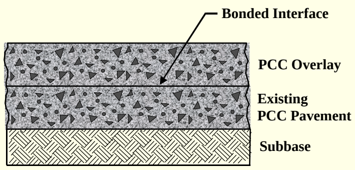
Objectives

- List PCC overlay types
- Discuss importance of bonding condition
- Identify conditions for which each overlay type is most suitable
- Describe thickness design approaches
- Determine the amount of preoverlay repair required

Discuss objectives shown on slide:

1. PCC overlay increasing in use
   - More effective pavement evaluation procedures
   - Improved PCC materials
   - Advancements in paving technology
   - Typically longer life, less maintenance than HMA overlays

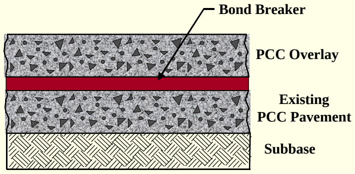
Bonded PCC Overlay



Importance of good bond:

1. Bonded overlays are thin
   - no heavy traffic; will quickly deteriorate if become unbonded
2. Methods to insure bond
   - Surface prep (sandblasting)
   - Cement grout just ahead of paver
   - Preoverlay repair

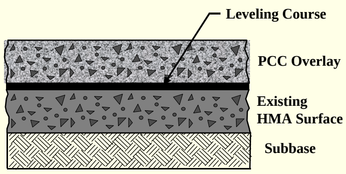
Unbonded PCC Overlay



Use of bond breaker:

1. Common material
   - Thin HMA interlayer covered with membrane curing compound
   - Thickness range 25-50 mm (1-2 in)
2. Interlayer will prevent reflection cracking

Whitetopping



Definition – placement of PCC over an existing HMA pavement (becoming common):

1. Rehab for rutting, shoving, fatigue
2. Limited amount of preoverlay repair
3. Sometimes cold milling ruts & surface irregularities
4. Design considers HMA layer as base course

Overlay Section

Detailed pavement evaluation
- Condition survey
- FWD testing
- Coring

Consider the cause of deterioration

Major considerations
- Construction feasibility
- Desired performance period
- Available funding

Discuss selection criteria for overlay candidate

Construction Feasibility Traffic control Constructability Contractor experience Clearances and elevation changes Environmental constraints	Discuss factors to consider for construction feasibility
Construction of Bonded Overlay 	Example of paving
Construction of Bonded Overlay 	Example showing paving of bonded overlay

Construction of Bonded Overlay

Example of construction of bonded overlay

Overlay Design Approaches

PCC Mix
- Thickness
- Engineering judgment
- Structural deficiency
- Mechanistic fatigue damage

There is no universally accepted design procedure for PCC overlays

Design Considerations

Overlay thickness (thick vs. thin)

Bonding condition

Drainage

Reinforcement

Transverse and longitudinal joints

There is more to design than slab thickness:

1. Discuss factors listed
   – Reinforcement is same as for new pavement
   – Bonded: Joints should match those in underlying pavement (reflection cracking occurs)
   – Unbonded: Joints offset 1.0 m (3ft) to provide area of support

Factors Affecting Preoverlay Repairs Type of overlay Structural adequacy Pavement condition (distress) Future traffic loadings Physical constraints Overall cost	Preoverlay repair: 1. Type of overlay (influences repairs most) – bonded: all distresses that may reflect – if repairs too extensive, may be more cost-effective to construct unbonded overlay – unbonded: minimal repairs
Repairs for Bonded PCC Overlays Full-depth repair of deteriorated joints Load transfer restoration or full- depth repair of working cracks Grinding of minor joint faulting Cross stitching on working longitudinal cracks	Failure to correct these distresses will result in premature failure of the overlay
Repairs for Unbonded PCC Overlays Full-depth repair of severely deteriorated joints and cracks Milling/grinding of faulting > 6 mm (0.25 in) Full-depth repair of punchouts on CRCP	Major benefit of an unbonded overlay is that extensive preoverlay repair does not have to be performed

Repairs for Whitetopping Localized repair of failed areas Cold milling • Restore profile • Remove rutting and shoving Leveling course to produce uniform surface for paving	Whitetopping overlays have been placed directly on rutted & distressed surface with success: 1. Overlay will fill area of rutting & provide additional thickness in wheelpath
Summary Bonded overlays - good condition Unbonded overlays - poor condition Whitetopping - deteriorated HMA All types have performed well when used appropriately The type and amount of preoverlay repairs affects performance	Review/summarize key points in this module

Module 4-14 ***HMA Overlays of Rigid Pavements***	HMA overlays are most widely used method of PCC rehab: 1. Important aspects 2. How they affect pavement performance
HMA Overlays **Hot-mix asphalt indicates high-quality asphaltic concrete mixtures produced in a facility** **Functional overlays** • **Minimum thickness** • **Typically 25 to 100 mm (1 to 4 in)** **Structural overlays** • **Thickness based on projected traffic** • **Typically 75 to 200 mm (3 to 8 in)**	Review the difference between functional & structural deficiencies: 1. Functional – Are not designed to add or maintain load carrying capacity 2. Structural – emphasized here
Considerations for Overlay Selection **Construction feasibility** • **Traffic control** • **Constructability** • **Clearances and elevation changes** **Performance period** **Reflection cracking** **Permanent deformation**	Factors to consider HMA overlays: 1. Faster to construct 2. Can be problems with clearance 3. Performance period – How long does the overlay need to last? 4. Preoverlay repairs needed – more repairs that are made, the longer the overlay will perform

HMA Overlay Design Approaches

Mixture

Thickness

- Engineering judgment
- Structural deficiency
- Mechanistic fatigue damage

Most promising approach is mechanistic:

- modeling all factors that affect performance is still difficult

Reflection Cracking

Appears on surface above underlying joints and cracks

Caused by movement at joints and cracks

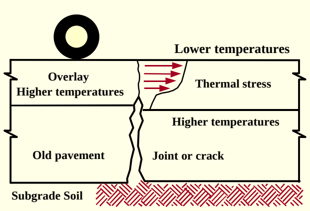
- Low temperatures
- Traffic loads

Initiates at bottom of HMA overlay and propagates upward

Most significant factor that affects HMA overlay performance is reflection cracking:

- Common occurrence

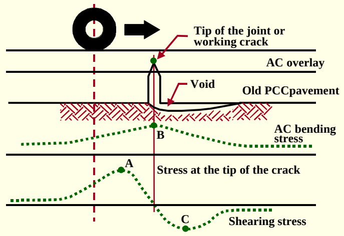
Thermal Stress in HMA Overlay



Thermal stress in overlay:

1. Changes in temperature cause underlying pavement to move
2. Creates thermal stress in overlay
3. Overlay itself experiences thermal stress from thermal gradient
4. Repeated strains will exceed strength of material & crack will develop

Shearing and Bending Stresses in HMA Overlay



Other stresses that accelerate the onset of cracking:

1. If load transfer at joint or crack in underlying layer is not good, differential movement experienced by overlay as load passes contributes to crack development

Design Issues

Rate of propagation through overlay

Number of reflected cracks

Rate of deterioration of reflected cracks

Amount of water that can infiltrate through the cracks

Knowing that these stresses will develop, many approaches to control reflection cracking:

1. Which of items listed is most important to control?
2. Most cost-effective is rate of deterioration

Reflection Crack Control Measures

Fabrics
Stress-relieving interlayers
Crack-arresting interlayers
Pre-overlay repairs
Fractured slab techniques
Sawing and sealing joints
Increased overlay thickness

These are the most commonly used reflection crack control measures:

1. Which are effective?
2. Is one treatment best?
   – Success depends on original objectives & how outcome is measured

Crack Control Effectiveness

Delay the occurrence of cracking

Reduce the number of cracks

Control the crack severity

Provide other benefits

- Reduce overlay thickness
- Enhance waterproofing capabilities

Measuring effectiveness:

1. What's important?
2. No single measure stands out
3. Success of any of these should be measured not only on effectiveness but also cost

Fabrics

Woven or non-woven synthetic materials

Provide restraint to resist crack formation

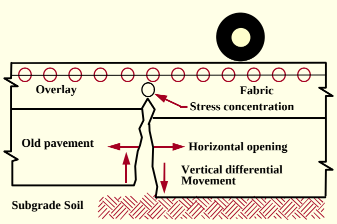
Most effective with smaller joint movements

- Longitudinal joints
- Differential vertical movements between 0.08 and 0.20 mm

Purpose is to resist crack formation & reduce moisture infiltration:

- Work best where underlying movement is minimal

Fabrics



Fabrics:

1. Common to place directly on old pavement (prior to overlay)
2. Between lifts, performance is better
3. Less effective
   - cold & wet climates
   - large differential vertical or horizontal movement
4. Rule of thumb: fabric is about as good as 25 mm of additional overlay thickness (delays cracking 1 year)

Fabric Application

Tack coat has been sprayed on underlying pavement & then fabric applied (note effort made to keep fabric taut & wrinkle free):

- Is this a particularly good application for rigid pavements?

Objective is to reduce reflection cracking at joints and cracks:

- This treatment is being applied to places where there are no cracks

Fabric Application

View of the finished application:

- What happens if there are wrinkles in the fabric? (These could reflect through & initiate a crack in the overlay)
- As best, the fabric is well-bonded to the PCC & wrinkle-free:
- At worst, fabric has few wrinkles that can be cut out

Influence of Differential Vertical Deflections

Deflection	Fabric	Control
0.00 mm	0	44
0.05 mm	29	54
0.10 mm	88	74
0.15 mm	88	100
0.20 mm	100	100

Greater differential vertical deflection, the less difference between reflection cracking on the fabric-treated and control sections (study by McGhee in Virginia)

- What causes differential vertical deflection? (poor load transfer, loss of support, heavy loads & insufficient structure, etc)
- Are these common for your rehab project?

Stress-Absorbing Interlayers

Dissipates movements and stresses

Ineffective for working cracks or large movements

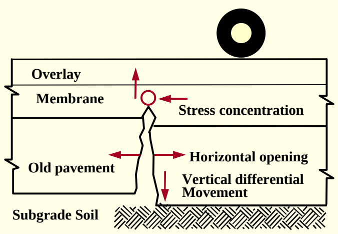
SAMIs
- Spray application of rubber or polymer-modified asphalt
- Seating of aggregate chips

Proprietary materials available (usually band-aid treatments)

Treatments have been tried on PCC but more common on HMA (especially structurally compromised pavements):

1. Are not as effective for types of movements expected in PCC pavements

Stress-Absorbing Interlayers



Commonly found as sandwich of fabrics & modified asphalt cement layer:

1. Usually placed in strips immediately over joint/crack
   – Known as band-aid treatments
2. Many products are proprietary & fairly expensive
3. Performance results are also variable

Stress-Absorbing Interlayers

This application happens to be over a flexible pavement, but the concepts are the same:

– First a tack coat is sprayed on the clean pavement surface

In this non-proprietary treatment, a layer of chips is spread over the tack coat:

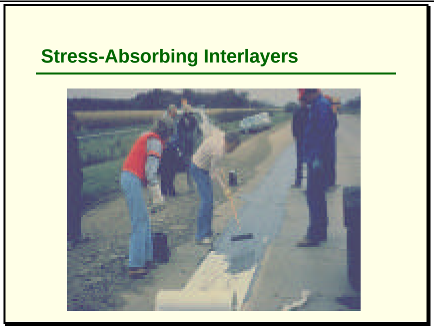
- In effect creating a localized chip seal treatment over the joint

(This method of chip application is not endorsed)

Next step is to seat the chips in the tack coat

This is an application of proprietary membrane:

- The tack coat has already been applied & the fabric is being stretched out over the joint
- Recalling the purported benefits of these treatments, (such as retarding the rate of reflection cracking & waterproofing), this may be a very good use of this type of treatment



With this particular treatment, another application of tack coat is applied over the membrane:

- Some newer treatments have the adhesive as an integral part of the membrane
- A concern with these treatments is getting a thick layer under a thin layer that eventually causes cracks

This can occur if:

- the membrane slips around
- problems during paving
- good compaction is not obtained

The finished application shows the membrane over the longitudinal edge-shoulder joint & at transverse joints:

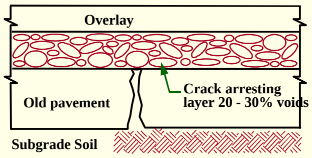
- Pavement is now ready for the application of the HMA overlay

Effect on Reflection Cracking

Material	Trans.	Long.
Polyguard 665	35 %	0.3 %
Royston #108	90 %	0 %
Royston #10AR	35 %	0 %
PavePrep	5 %	2 %
Roadglas	29 %	0 %
Biuthene H.D.	50 %	0 %
Petrotac	30 %	0 %

The results shown here compare reflection crack percentages from a study performed by PennDOT

Crack Arresting Interlayers



Thick layers of open-graded aggregate placed between PCC pavement & HMA overlay:

1. Voids in this thick layer blunt crack propagation
2. Even with significant movement of the underlying slab, cracks can't find a path to the surface before their energy is dissipated
3. How thick is total layer? How thick does overly need to be?

Preoverlay Repairs

Slab stabilization

Grinding/milling

Full- and partial-depth repairs

Slab replacement

Load transfer restoration

Retrofitted subdrainage

Common reflection crack control treatments:

1. All intended to reduce movement in concrete pavement which is major cause of reflection cracks

These were covered in other modules (emphasis is on fractured slab techniques)

Fractured Slab Techniques

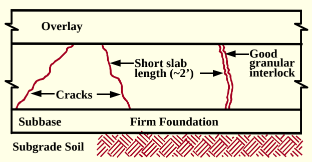
Crack and seat (JPCP)

Break and seat (JRCP)

Rubblize (JPCP, JRCP, CRCP)

Discuss fractured slab techniques:

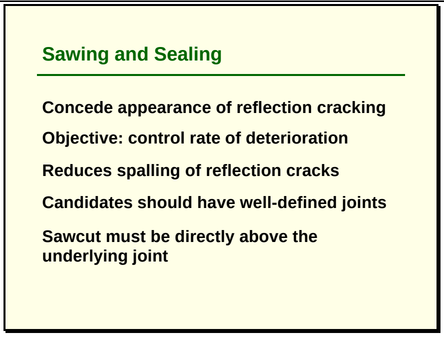
- crack & seat (JCP without steel)
- break & seat (JRCP)
- rubblization (any)

Cracking and Seating Shortens effective slab length Standard practice in many States Not recommended on poor subgrades Design methods (overlay thickness)	Crack & Seat: 1. Broken pieces range from 0.46 by 0.6 m to 1.8 by 1.8 m 2. Size will affect movement
Cracking and Seating 	Illustration of crack & seat: 1. Slab is broken into smaller pieces 2. Pieces are expected to retain aggregate interlock but move less than larger slabs they replace 3. Important to seat slab into subbase 4. If good support not available, pieces are likely to rock & cause reflection cracking anyway
Favorable Conditions for Cracking and Seating Seriously faulted joints and cracks Working cracks Rocking slabs Patch deterioration Lane separation Durability distress Corner breaks	Once pavement is cracked, all other repair options disappear & all that's left is thick overlays or reconstruction: – May be used when pavement exhibits serious structural and/or material distresses (but not so bad that overlay will perform worse)

Important Factors Quality of subgrade Severity of deterioration Size of broken pieces Full-depth cracks Weight of roller	Discuss factors that have been found to affect performance in various studies are listed
Types of Equipment Modified pile drivers Guillotine hammers Whip-hammers Impact hammers	Describe types of equipment used: 1. Production rates can range from 0.25 km/day to 6.4 km/day 2. Common device is guillotine 3. Whip hammer is good 4. Do not use if edge drains present
Equipment - Guillotine Hammer 	Not all of the available equipment has proven to be effective in rupturing the steel: – The guillotine hammers have worked well, but other devices, such as the whip hammer have not – Kentucky has found an impact hammer to be effective

Fractured Slabs from Guillotine Hammer 	Cracked pattern from guillotine hammer: – Minimal surface damage is noted – With some devices the cracks are so clean & tight that the pavement must be sprayed with water to verify that it is cracked
Equipment - Heavy Roller 	Seating pushes the broken pieces into the subgrade: – It is done to keep the slabs from rocking – Just as with compacting HMA, proper seating requires specifying a type of machine & number of passes – As an example, Kentucky uses a 32 metric ton pneumatic tire roller with 7 passes
Breaking and Seating **Additional issues (by contrast with crack and seat)** • Break bond between concrete and steel • Effect on underlying structures	If bond is not broken, the broken pieces will want to act like a larger slab & move more: – Reflection cracking will continue to occur

Rubblization Break existing rigid pavement into small pieces - high quality aggregate base	Rubblization: 1. Most cost-effective on badly deteriorated pavements 2. Common equipment is the resonant pavement breaker
Equipment - Resonant Frequency Pavement Breaker 	Example of resonant breaker at work: – The foot is at the end of a long vibrating arm, & it will only break up an area about the size of the foot – Repeated passes are made to break up the entire pavement
Equipment 	Closer view gives a sense of the particle size after rubblization: – Incidentally, steel does not need to be broken up of removed – Since the bond between the concrete & steel is completely destroyed, the steel will not contribute to the development of reflection cracking



Sawing & sealing:

1. Widely used in east as reflection crack control technique
2. Does not eliminate or retard reflection cracking; it anticipates them & controls the outcome

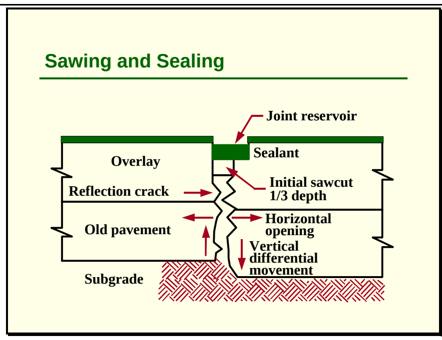


Illustration of saw & seal method:

1. Saw the joint in the AC overlay directly over the underlying joint in the original concrete
2. Movement of underlying slab is forced to be reflected through the sawed joint
3. More readily maintained than a reflective crack

The sawed & sealed joints are easily distinguishable from a reflection crack:

– They are uniform, well sealed, and show no signs of spalling

Sawing and Sealing

Here the joint is sawed & sealed in the mainline pavement but not in the shoulder:

- Point out the difference in the appearance of the reflected crack

Sawing and Sealing

The critical aspect of the construction of this type of project is making the sawcut in the AC directly over the joint in the concrete:

- Most studies agree that if the sawcut misses by more than 25 mm, the result will be a reflective crack that parallels the sawed joint

Recommended Sawcut Dimensions

Slab Length	Width	Depth
< 15.2 m	13 mm	16 mm
15.3 – 18.9 m	16 mm	16 mm
18.9 – 22.9 m	19 mm	16 mm
19.0 – 26.5 m	22 mm	19 mm
26.5 – 30.5 m	25 mm	22 mm

Slab movement is affected by slab length, materials, & temperature:

1. Guide to sawcut dimensions
2. Depth can range from one-third of the thickness of the overlay, all the way into the joint itself

Increased Overlay Thickness

Delays the occurrence of reflection cracking

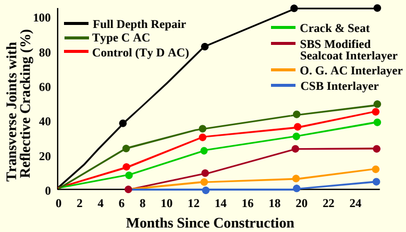
Cracks propagate about 25 mm per year

Reduces temperature fluctuations in underlying pavement

Increased overlay thickness:

1. Not most economical
2. Problems with clearance, rutting guardrails

Comparison of Reflection Crack Control Methods



Comparison of results:

1. Poor results from full-depth repairs
2. Many of other treatments are performing in grouping
3. In order to pick best treatment, intended benefits must be weighed against costs

Summary

Reflection cracking is a major concern, but perhaps more in terms of crack severity and moisture infiltration

Balance between preoverlay repairs and overlay thickness

Many control methods are available

Best method based on:

- Pavement type
- Joint movements
- Level of deterioration
- Cost effectiveness

Review/summarize key points:

1. What have participants found that work?
2. Treatments should be tried & demonstrated effective for local conditions

Module 4-15

Identification of Feasible Alternatives

This module presents logical processes that can be followed to identify & choose feasible PCC pavement rehab alternatives

Objectives

Recognize importance of framework

Analyze project information and develop feasible alternatives

Describe decision trees and charts

Describe limitations of strict use of a decision tree

Objective is to encourage agencies to consider a variety of techniques

- Improve overall performance using new methods & keep methods that already work

Decision Systems

Network level

Project level

This course only addresses project level decisions

Difference between network & project level:

1. Network level
   - Pavement may be identified as candidate for rehab without specifying strategy

Selection Process Collect project information Evaluate pavement condition Identify and select feasible alternatives Develop designs for alternatives	Selection Process: 1. Collect information – Construction, environmental, traffic 2. Evaluate condition (block 2) 3. Alternatives (block 4)
Determination of Feasible Alternatives Each project is unique Must address all problems together Available tools • Pavement management systems • Knowledge-based systems No substitute for experience	Determining feasible alternative encourages agencies not to apply a standard treatment (such as a standard overlay)
Decision Tree Helps determine realistic approaches Can be extremely complex Refer to figures 4-15.2, 4-15.3 and table 4-15.2	Discuss decision trees shown in participant's manual

Decision Table Helps determine realistic approaches Presents information in clearer manner than a decision tree Refer to table 4-15.3	With class use table 4-15.3: 1. Pick a typical distress – Would they agree with the appropriate strategies shown? – Do they have others?
Limitations Need to be continually updated Should be considered design aids, not rules Engineering judgment is required	Decision trees & tables are not rule books but a form of guidance: – Can be adapted to reflect local practice
Summary Selection tools • Matching distress to treatment • Decision tree • Decision table Engineering judgment is essential Must consider all factors together	Review/summarize key point in this module

Module 5-1 ***Selection of the Preferred Rehabilitation Alternative***	Now that participants have become familiar with aspects of rehab design: 1. Next steps in process are: – Identification of feasible rehab alternatives – Selection of preferred alternative
Objectives **The selection of the preferred rehabilitation alternative for a given pavement section requires a systematic, step-by-step approach that considers all relevant factors** **This modules outlines the major steps and procedures in this process**	Explain objectives
Introduction • **There is always more than one alternative rehabilitation design available** • **The preferred alternative is the one that meets all engineering criteria and is cost effective** • **Alternatives have associated costs, constructability, performance life, reliability, maintainability, and other unique characteristics**	Historically, overlays have been most common rehab technique used: 1. Have been constructed without regard to applicability or cost-effectiveness

Rehabilitation Alternatives

Numerous alternatives available

- Overlay, recycle, reconstruction
- Full and partial depth repairs
- Joint and crack sealing
- Slab stabilization
- Diamond grinding or milling
- Subdrainage
- Surface treatments

Describe the rehabilitation alternatives available:

1. Requires engineering judgment
2. Requires engineering analysis

Timing of Rehabilitation

Alternate A:

Expense	$600k			$600k			$600k
Year	0	5	10	15	20	25	30

Total Additive Cost ……………………..= $1,800,000
Present Worth …………………..………..= $1,118,280
Equivalent Uniform Annual Cost …… = $64,637

Explain life-cycle costs for two similar, adjacent pavements:

– subject to same traffic & climate
– have different rehab strategies

(next slide included)

Timing of Rehabilitation

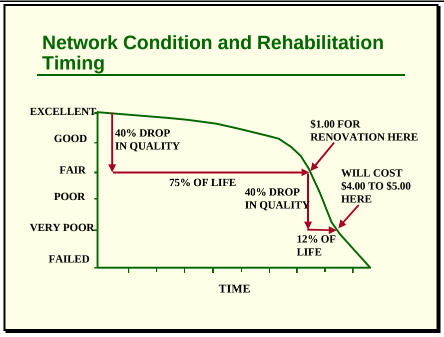
Alternate B:

Expense	$600k	$250k		$300k			$400k
Year	0	5	10	15	20	25	30

Total Additive Cost ……………………..= $1,400,000
Present Worth …………………..………..= $975,400
Equivalent Uniform Annual Cost …… = $56,378

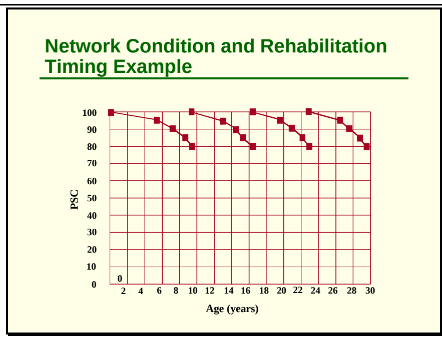
Example continued from previous slide

Development of Rehabilitation Alternatives Obtain available project information Establish existing condition of pavement Determine cause of distress Develop feasible alternatives Conduct engineering and economic analysis Select preferred alternative Design preferred alternative Follow up review of pavement performance	Discuss steps for developing rehab alternatives
Selection of Preferred Design Life Cycle Cost Analysis • Cost to the highway agency • Cost to the highway user	Discuss process for selection of preferred design: – emphasize life-cycle costs
Selection of Preferred Design Present Worth Analysis $PW = C \times 1 / (1 + i)^n$	LCC are usually expressed in terms of present worth (PW) or equivalent uniform annual costs (EUAC): 1. Using PW, future costs (C), are adjusted to PW using a discount rate (i), (n = time, years)



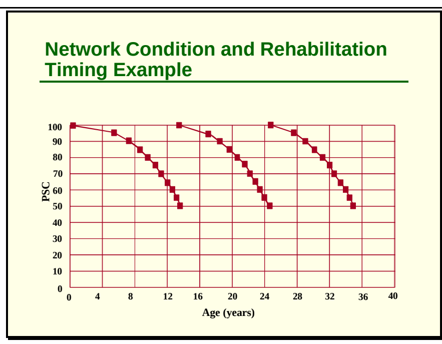
Basic consideration of pavement performance that applies at both project & network level, is high cost of delaying rehab treatments:

1. Discuss graph

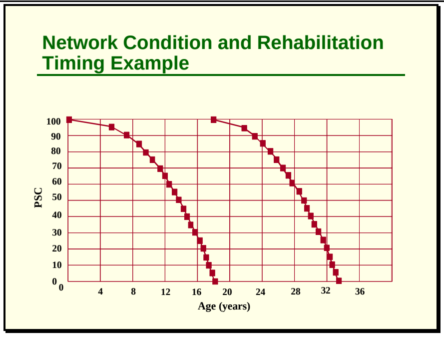


Illustrates the performance curves for treatments at three different program service levels:

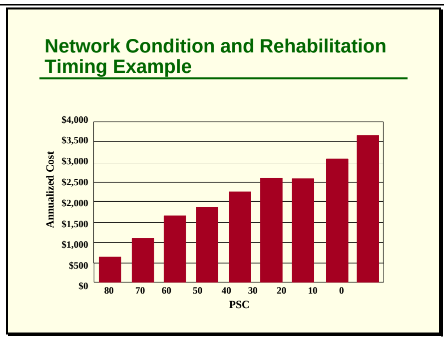
- Pavement deterioration & high cost of scheduling rehab at lower serviceability levels



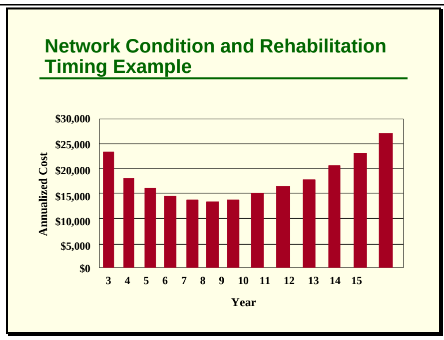
Example with timing set medium pavement deterioration



Example of case where timing set to very poor pavement condition



Example of annualized cost per lane mile for treatments applied at nine different pavement condition levels with their associated timing



Discuss figure:

1. Network costs were achieved when pavement was resurfaced every 7-9 years
   – Corresponds to resurfacing pavement condition level of about 60
2. Shows that more cost-effective to maintain pavements in good condition than to deteriorate to poor condition

Summary **This section covered the basic aspects of treatment selection using life cycle cost analysis and consideration of other possible over-riding factors** **It considered the impact of project timing and treatment selection on the overall condition of the highway network**	Review/ summarize key points

WORKSHOPS

SECTION 3-1

OVERVIEW OF WORKSHOP ON 4R PROJECT DESIGN

1. INSTRUCTIONAL OBJECTIVES

The identification, selection, and design of rehabilitation alternatives for a given pavement requires a logical, step-by-step approach. To illustrate the recommended procedures in this process, several workshops are presented to provide the participants with an opportunity for "hands-on" training in applying those procedures. These workshops contain data from actual rehabilitation projects.

Participants will be able to accomplish the following upon successful completion of this module:

1. List the major steps involved in 4R project evaluation and design.
2. Evaluate the data provided for a given 4R project to determine the causes and mechanisms of existing deterioration and to identify the major factors that are likely to affect the rehabilitation design. Determine the need for additional testing and survey data.
3. Based upon the results of the project survey and evaluation, identify several feasible rehabilitation alternatives that repair and prevent the distresses identified or otherwise extend the life of the pavement.
4. Given preliminary cost estimates and other information for several feasible alternatives, conduct an analysis to select the preferred alternative.

2. INTRODUCTION

This module provides course participants with an opportunity to perform the analyses and evaluations that should be involved in the technical development of a 4R project. A framework is provided for workshops in:

- Project survey and evaluation.
- Identification of feasible rehabilitation alternatives.
- Selection of the preferred alternative.

The workshops are conducted at appropriate times throughout the presentation of the technical material. To perform the workshops, the participants will be divided into small groups (e.g., three to six persons) to encourage the active participation of all group members. Each group should include representatives from several agency bureaus (e.g., design, construction, maintenance, planning) to encourage consideration of all factors affecting pavement design and performance.

Example project information will be provided to the groups for their consideration and evaluation. Each workshop will conclude with the presentation of results by each group, and brief discussions by the entire group of participants.

MAJOR STEPS IN 4R DESIGN

The major steps in the development of a 4R project are shown in figure 3-1.1 and are described below:

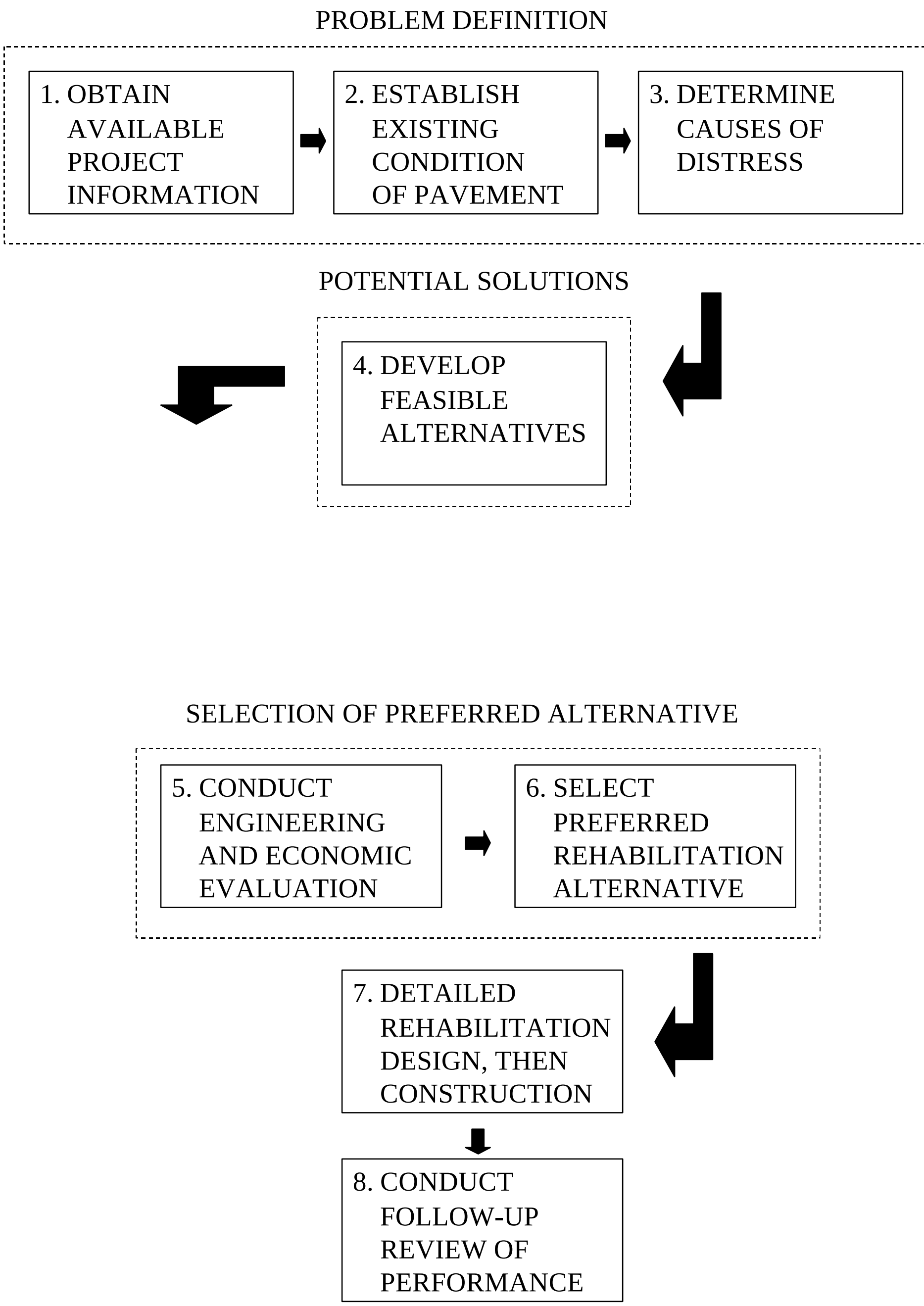


Figure 3-1.1. Rehabilitation alternative design process.

- Conduct a pavement evaluation. Obtain available project information such as design, construction, materials, soils, history of traffic loadings, previous rehabilitation and maintenance, accident data, past performance data (skid, deflection, roughness, distress), and so on. Conduct a project survey and evaluation as described in block 2. Determine the extent and causes of pavement deterioration.

- Identify the primary factors that will affect the selection of preferred rehabilitation alternatives. These may include such things as traffic volume and truck loadings, climate, soil problems, traffic control during construction, special construction considerations, available funding, noise, pollution, and any other major considerations that will constrain or influence the selection of preferred alternatives.

- Develop preliminary feasible alternative designs that both repair the existing distress and prevent its recurrence. Develop strategies over a selected analysis period. Be innovative, but consider the major constraints that may eliminate some alternatives (see blocks, 3, 4, and 5).

- Estimate the life-cycle cost of each feasible alternative over the selected analysis period, as described in block 5. If one alternative is clearly superior, then that alternative becomes the preferred alternative. Skip the next step and proceed to step 6. If two or more alternatives have approximately equal life-cycle costs, then continue with step 5.

- Evaluate the alternatives with respect to the primary decision factors and select the one alternative that best meets the constraints of the project and addresses the decision factors as the preferred design. A procedure for accomplishing this is given in block 5.

- When one alternative is clearly superior to the others based on life-cycle costs and satisfaction of other decision criteria, it is considered the preferred alternative, pending a detailed verification of the design and cost assumptions.

- A detailed design is then performed for the preferred alternative.

- The final detailed design should be reasonably close to the design used in the life-cycle cost analysis. If not, a new life-cycle cost analysis should be performed and the new design should be compared again with the other preliminary alternatives and rechecked against the decision criteria to ensure that it is still the preferred alternative (i.e., go back to step 4 and iterate through the process until the detailed design of the preferred alternative is reasonably close to that assumed in the cost analysis and consideration of decision factors).

- The recommended design is identified and detailed plans, specifications, and construction cost estimates are prepared for bidding and construction.

1. EXAMPLE 4R PROJECT DEVELOPMENT

Example projects (representing different pavement design types and conditions) are included in this module for use by participants for their workshop activities.

Local 4R projects that are of interest may also be used for the workshops if sufficient information is readily available or known by the participants.

It is emphasized that these examples are provided only for the experience of the participants in analyzing a full range of design options. The workshops encourage the participants to consider a wide range of options with no real restrictions on cost. It is recognized that most project's basic cost and general scope decisions are made in the development of an agencies construction program which necessarily place limits on the available funds and general scope of a project at the project level design stage. The analysis conducted in these workshops are used to give hands-on experience covering as much as possible the full range of information and concepts covered in this class. The workshops of necessity assume full funding is available for each problem. They also show different levels of service for different pavement types and designs since they were developed from actual but unique projects. There was no attempt made to find workshop problems that represented average conditions for a pavement type or design, thus each workshop problem is unique and should in no way be construed to indicate the relative performance of any particular type of pavement or design and subsequent 4R work over any other.

Workshop 1: Project Evaluation (conducted after completing block 2)

- The participants are divided into groups of five or more, and each group is assigned a workshop problem. Each group then selects a chairperson and a recorder. The recorder will take notes throughout the workshop and the chairperson will make the presentation to the rest of the class.

- Each group examines the background data and project survey and evaluation data provided under *Information for Workshop 1* for their assigned workshop problem.

- Each group evaluates the information provided and develops:

  - A description or list of the defects or deficiencies that should be addressed in the rehabilitation design.

  - A list of those deficiencies, defects, or other considerations that will control or constrain the rehabilitation design.

  - A list of additional surveys, tests, and evaluations that are recommended or desired for a more thorough evaluation of the existing pavement.

  The project evaluation forms and checklists found in module 2-1 may be helpful in the completion of this workshop. ***Groups are not to identify or select rehabilitation options at this time!***

- Each group reports their results to the class which discusses them briefly.

Workshop 2A: Identification of Feasible Alternatives for Flexible Pavements (begun after completing block 3)

- Each workshop group will reform and review their information from workshop number 1.

- Develop two rehabilitation solutions or sets of feasible alternatives that address the problems identified in the previous workshop.

- Develop one solution that your group believes would last for 8 years without rehabilitation.

- Develop a second solution that will last for 15 years without resurfacing or major rehabilitation.

However, this approach does not have to be followed: what is important is that each group consider that there are many different treatments that may be applied to address a pavement's problems and some effort should go into developing such alternatives. Constraints — such as available funds, desired time between rehabilitation, users' interests, pavement condition, and so on — will likely have a tremendous impact on the final selection but should not hinder the development of feasible alternatives.

In developing these alternatives, participants are encouraged to be innovative in the development of these strategies. Do not let currently restrictive agency policies inhibit this activity. ***The final selection should not be made at this time,*** nor is any presentation made after this workshop.

Workshop 2B: Identification of Feasible Alternatives for Rigid Pavements (begun after completing block 4)

- Each workshop group will reform and review their information from workshop number 1.

- Develop two rehabilitation solutions or sets of feasible alternatives that address the problems identified in the previous workshop.

  - Develop one solution that your group believes would last for 10 years without rehabilitation.

  - Develop a second solution that will last for 25 years without resurfacing or major rehabilitation.

  However, this approach does not have to be followed: what is important is that each group consider that there are many different treatments that may be applied to address a pavement's problems and some effort should go into developing such alternatives. Constraints — such as available funds, desired time between rehabilitation, users' interests, pavement condition, and so on — will likely have a tremendous impact on the final selection but should not hinder the development of feasible alternatives.

In developing these alternatives, participants are encouraged to be innovative int he development of these strategies. Do not let currently restrictive agency policies inhibit this activity. ***The final selection should not be made at this time,*** nor is any presentation made after this workshop.

Workshop 3: Selection of the Preferred Alternative (conducted after completing block 5)

- Each group will reform and review the information they have developed from workshops 1, 2A, and 2B, including the rehabilitation alternatives they have developed for each assigned problem. Each group has the option of using the alternatives they identified in workshop 2A or 2B, which will require that they estimate appropriate costs and service lives for their alternative.

- Using one set of two of the alternatives selected from either workshop 2A or 2B in this last exercise, each group will perform a basic life-cycle cost analysis (LCCA) comparing the long-term cost (in terms of present worth) of these two alternatives using an analysis period of 35 years and a discount rate of 4 percent.

To conduct the LCCA, the group will have to:

- Develop a strategy for each alternative that consists of a series of required additional treatments, which best fits the original alternative, and extends the service life of the pavement over the full analysis period. For example, if the typical agencies alternative was to place a 30 mm asphalt concrete pavement (ACP) overlay which normally lasted only 8 years, then a likely strategy for that alternative would be a 30 mm overlay placed at 8, 16, 24, and 32 years, crack sealing at 5, 13, 21, and 29 years. The alternative that provided 25 years service would typically have some minor rehabilitation as crack sealing and grinding within those 25 years followed by a major pavement rehabilitation project at 25 years.

- Each group will then estimate the cost for each treatment that is included in the strategy for each alternative. They will then determine the present worth of the series of treatments for each alternative. Remember that the Present Worth is calculated as:

$$PW = cost[1 - I)^n$$

where i = discount rate (4 percent for workshop)

n = time period or time at which treatment is applied

Table 3-1.1 and figure 3-1.2 are provided for the participants' use in this workshop.

- Each group then evaluates the results of their life-cycle cost analysis. The result should be a final tabulation of the life-cycle cost (LCC) of the alternatives and their associated strategies in their order of cost and the preference to the group if different based on special non-monitory factors.

- Each group reports their results to the class, which discusses them briefly. The group's presentation should include:

  - A brief review of the pavement design and evaluation conclusions.
  - The alternative 4R strategies.
  - The life-cycle cost comparison of the 4R strategies.
  - The final selection of the preferred 4R strategy.

This completes the scheduled workshop activities.

Table 3-1.1. Unit costs for LCCA workshop.

Materials	Unit	Cost ($)	Remarks
PCCP	m^2	20.00	Short jointed doweled (225 mm)
ACP	m^3	70.00	Dense-graded hot-mix in-place
Tack Coat	m^3	0.50	Applied
Crushed Stone	m^3	25.00	In-place compacted
Gravel	m^3	20.00	In-place compacted
Planning PCCP	m^2	3.00	Includes removal of plannings
Planning ACP	m^2	1.00	Includes removal of plannings
Treated Permeable Base	m^3	100.00	In-place
Filter Fabric	m^2	0.75	In-place
Longitudinal Drains	m	50.00	Includes backfill and filter cloth
Drain Outlets	Each	400.00	Includes pipe and backfill
Seal ACP working cr.	m	8.00	Includes routing crack
Seal ACP non-working cr.	m	3.00	Clean crack only
Seal PCCP joints	m	10.00	Includes crack prep and backer

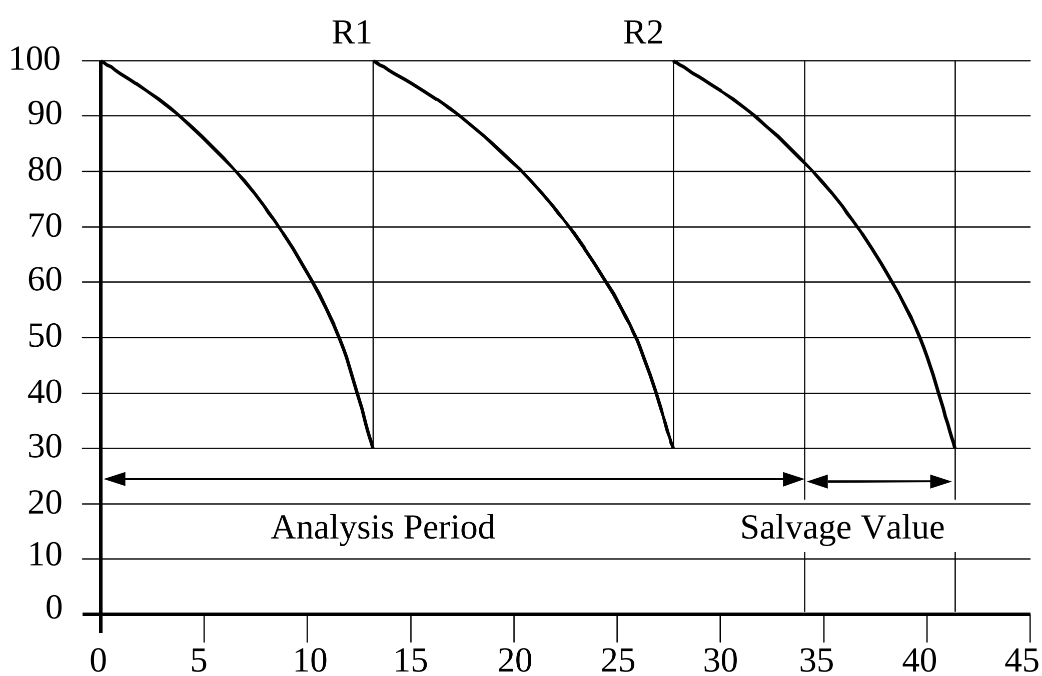


Figure 3-1.2. Example of series of treatments that make up a strategy for a given alternative.

Table 3-1.2. Table that can be used to calculate the present worth of a series of treatments over time which makes up a strategy for a given alternate.

Alternate ________________________

Cash Flow Symbol	**Symbol Definition**	**Cash Flow Amount, $**	**n**	$\frac{1}{(1+i)^n}$	**PW of Cash Flow, $**
IC	Initial Construction Cost		0	1	
(					
SV	Salvage Value				
				TOTAL PW	**$**

* Suggest that R1, R2, etc. be used for rehabilitation treatments and their costs, and M1, M2, etc. be used for maintenance treatments and their costs.

SECTION 3-2

WORKSHOP ON 4R PROJECT DESIGN

1. EXAMPLE 4R PROJECT DEVELOPMENT

Six example projects (representing six different pavement design types) are included in this module for use by participants in accomplishing the workshop activities:

- Example Problem 1: AC Overlay of JRCP (AC/PCC "Composite" Pavement)
  - Asphalt Concrete Overlaid Jointed Reinforced Concrete Pavement (AC/PCC "Composite" Pavement).
- Example Problem 2: AC Pavement
  - Flexible Pavement.
- Example Problem 3: JRCP
  - Jointed Reinforced Concrete Pavement.
- Example Problem 4: JPCP
  - Jointed Plain Concrete Pavement.
- Example Problem 5: CRCP
  - Continuously Reinforced Concrete Pavement.
- Example Problem 6: Full-Depth Asphalt Concrete Pavement
  - Full-Depth Asphalt Concrete Pavement.

Local 4R projects that are of interest may also be used for the workshops if sufficient information is readily available or known by the participants. The use of local projects is strongly encouraged.

It is emphasized that these examples are provided only for the experience of the participants in analyzing a 4R design. The analysis conducted in these examples should in no way be construed to indicate the superiority of a given type of 4R work over any other.

EXAMPLE PROBLEM 1: AC OVERLAY OF JRCP (AC/PCC "COMPOSITE" PAVEMENT)

1. PROJECT BACKGROUND DATA

A summary of important background data is given in table 3-2.1. A cross-section of the existing pavement is given in figure 3-2.1. Traffic data for the pavement is summarized in table 3-2.2. The age of the pavement today is 20 years.

Project Survey and Evaluation

An extensive project survey and evaluation was conducted. The following summarizes the findings from those activities.

- Distress survey—Existing distress in the traffic lanes and shoulders in both directions was recorded. A summary of distress is provided in table 3-2.3.

- Structural survey—Nondestructive (NDT) and destructive tests were conducted. The NDT work was accomplished using a heavy-load Road Rater. The destructive testing consisted of coring the pavement at various locations. Results are given in figures 3-2.2 and 3-2.3.

- Drainage—This project is located in climatic zone IA, which means it is continually wet and subject to deep frost.

- Subgrade—The roadbed soil data indicates the existence of a fine-grained, silty clay subgrade with poor drainage characteristics.

- Coring—The asphalt concrete (AC) and portland cement concrete (PCC) layers were cored and the condition of the material noted. Extensive deterioration of the PCC was found from the joint cores.

Table 3-2.1. Summary of background data for example problem 1.

ORIGINAL CONSTRUCTION DATA	
Facility	Rural, controlled-access freeway, 5.5 mi (8.9 km) long
Original Construction	Jointed reinforced concrete pavement (see figure 3-2.2), 20 years old
Reinforcement	Welded wire fabric—69 lbs/yd^2 (34 kg/m^2)
Transverse Joints	Contraction joints spaced every 50 ft (15.2 m), 1.25-in (3.2 cm) diameter dowels on 12-in (30.48 cm) centers
Longitudinal Joint (between lanes)	Tied
Subgrade	Predominantly silty clay (AASHTO A-6)
REHABILITATION AND MAINTENANCE TO DATE	
Asphalt Concrete Overlay	Year 11—3 in (7.62 cm) of asphalt concrete placed over entire construction section
Repairs Prior to Overlay	Full-depth concrete: 3 percent of lane area Partial-depth: 2 percent of lane area
Distress in Jointed Reinforced Concrete Pavements (JRCP)	Primarily D-cracking spalling of PCC slab

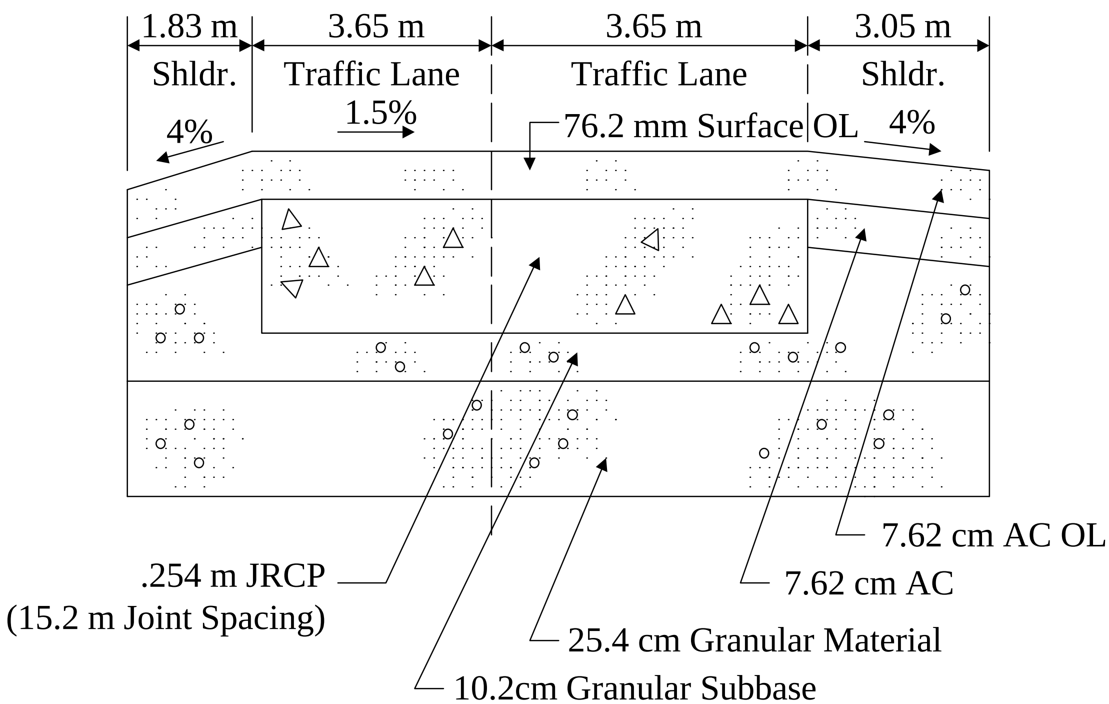


Figure 3-2.1. Typical cross-section for example problem 1.

Table 3-2.2. Summary of traffic data for example problem 1.

Time period, years		Mean one-way ADT	18-kip (80 kN) ESALs in outer lane, millions
PAST	0 to 10	8,000 (12 percent trucks)	3[1]
	11 to 20	9,800 (12 percent trucks)	6
FUTURE	21 to 30	11,900 (13 percent trucks)	11
	31 to 40	14,500 (14 percent trucks)	18
	41 to 50	17,600 (15 percent trucks)	28

[1] Data are for each 10-year period only, and are not cumulative.

Table 3-2.3. Summary of outer lane distresses for example problem 1.

DISTRESS TYPE	COMMENTS
Reflection Cracking (Transverse Joints)	Occurred at every contraction joint. Severity level frequencies are: Low = 70 percent, Medium = 25 percent, and High = 5 percent. Some have been patched with AC.
Reflection Cracking (Centerline Joints)	Occurred throughout the project. Severity level frequencies are: Low = 60 percent, Medium = 35 percent, and High = 5 percent.
Transverse Cracks	Most are reflections of wide cracks in the underlying PCC slab where the steel has apparently ruptured; most are of medium severity.
Weathering and Raveling	Minor, except for one section (inner lane only, about 1 mi [1.6 km] long) exhibits medium- to high-severity raveling.
Pumping	Fines were found pumped onto the shoulder in only a few locations.
Rutting	Average rutting in the outer truck lane is 0.35 in (8.9 mm) in the outer wheelpath.
Patching	Some AC surface patches have been placed at the transverse joints since the AC overlay was placed.
Shoulders	Fair to good condition, with little load-associated cracking. Some raveling exists.

OVERALL DEFLECTION PROFILE

Deflections were measured in the panel centers at 200-ft (61-m) intervals. Joint deflection measurements were made 2 ft (0.6 m) from the slab edge on both sides of the joint (approach and leave) at 1,000-ft (305 m) intervals.

Results: The center-slab deflection profile is shown in figure 3-2.4. Fairly uniform support is present throughout the project. The modulus of subgrade reaction (k), backcalculated from surface deflection data, ranges from 200 to 400 psi/in (54 to 109 KPa/mm).

Joint deflections indicate joint efficiencies ranging from 0 to 100 percent. The severity of the surface distress correlates generally with load transfer efficiency.

Reflective Crack Severity	Mean Joint Efficiency
Low	81 percent
Medium	52 percent
High	20 percent

The deflections were greater on the leave side of the joint at 65 percent of the joints. The reverse was true at 24 percent of the joints, and deflections were equal at 11 percent. There is some evidence of pumping at some joints (as was indicated in the distress survey). This pumping is not extensive, and localized undersealing should be adequate.

DETAILED TESTING

Ten representative areas about 500 ft (152 m) long were selected for detailed testing. In these areas, deflections were taken at each joint and crack, and cores were taken at selected locations.

Results: All cores exhibited some visual signs of deterioration, caused by D-cracking of coarse aggregate. Cores taken closer to joints were far more deteriorated than those taken near mid-panel. Typical coring data are given below:

Location	Average Percent of Core Recovered	Range
At joint	27	0 - 60
6 in (15.24 cm) from joint	38	0 - 90
12 in (30.48 cm) from joint	57	0 - 95
18 in (45.72 cm) from joint	92	60 - 100
At mid-panel	87	60 - 100

Thus, there is considerable deterioration of the underlying slab. Full-depth repairs should extend a minimum of 24 in (61 cm) on either side of the joint to remove deteriorated underlying concrete.

Figure 3-2.2. NDT and coring survey for example problem 1.

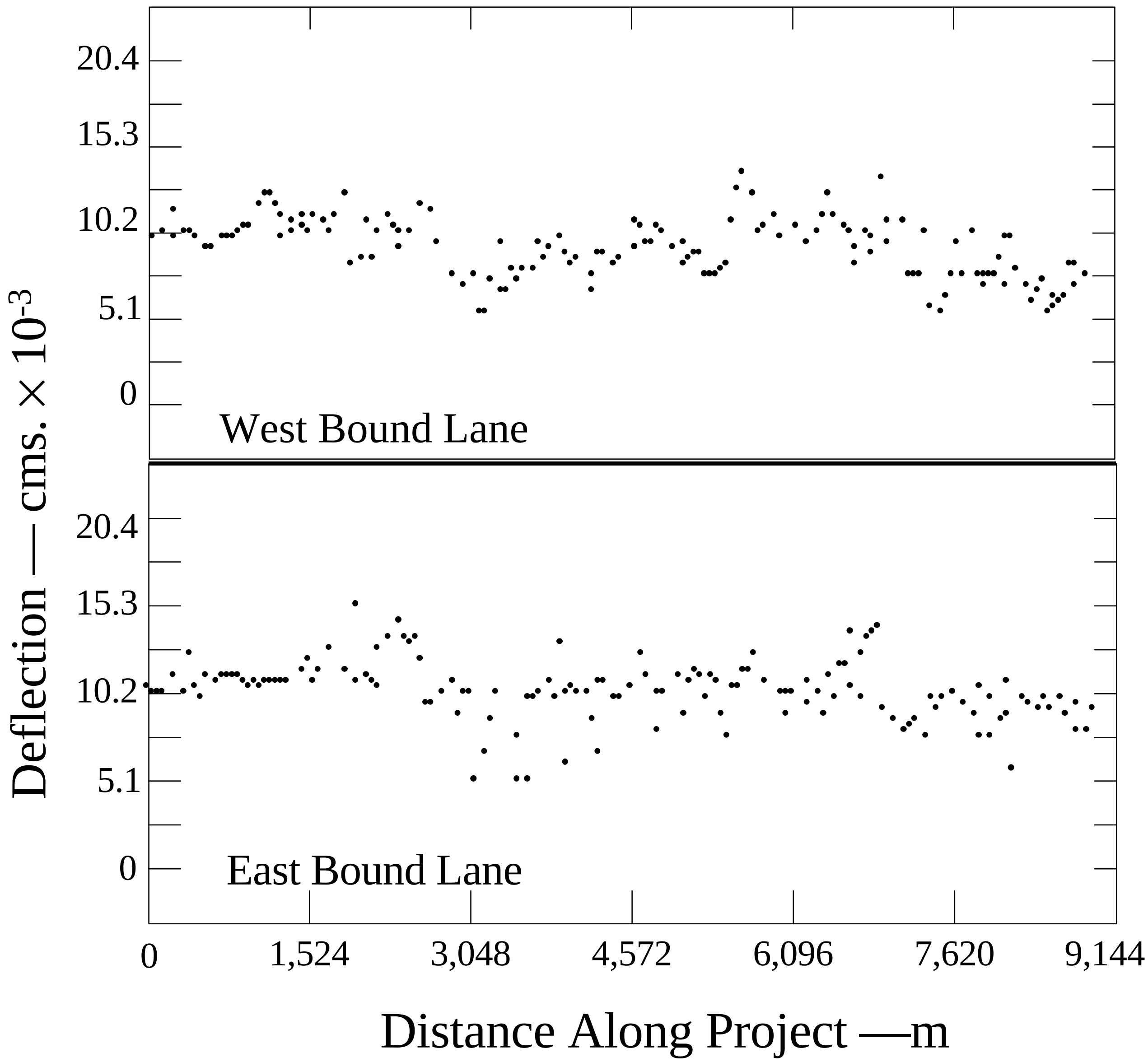


Figure 3-2.3. Center slab deflection profile for example problem 1 (Road Rater with 8-Kip [36 Kn] peak-to-peak load, 15 Hz, testing at 200-ft [61-m] intervals).

2. EXAMPLE PROBLEM 1—WORKSHOP 2

Results from Workshop 1

Figure 3-2.4 (handout) presents typical general evaluation results for this example problem. Group results should be compared with these before proceeding with workshop 2 activities.

Identification of Feasible 4R Alternatives

There are many alternative rehabilitation strategies that can be identified for a particular project. Each has specific advantages and disadvantages that vary with the specific design situation. Some alternatives may not be reliable or possible because of existing pavement conditions, constraints imposed on the design, and other factors. For instance, in this example problem, the deterioration of the existing concrete slab and the presence of the asphalt concrete overlay would preclude the construction of a bonded concrete overlay unless overlay removal and substantial repairs were completed first.

A list of constraints within which the team must work must be assumed. If your group is <u>not</u> developing alternatives along the lines described on pp. 3-1.4, 3-1.5, and 3-1.6 (10 years, 20 years, and agency fix), consider the following constraints:

- A design analysis period of 20 years should be used to compare all alternatives.
- The minimum time between major 4R work should be at least 7 years.
- It is desirable to avoid rerouting traffic.
- A specified minimum clearance beneath bridges currently exists and must be maintained.

PROJECT DEFECTS OR DEFICIENCIES

- Deterioration of cracks and joints in the underlying slab due to PCC materials durability (D-cracking) problems.
- Poor load transfer exists at many joints and cracks, which aggravates a reflection cracking problem.
- Raveling and weathering exists in one major area.
- Pumping is apparent in localized areas, indicating some moisture entry and drainage problem.
- Rutting in the traffic lanes is becoming serious, indicating the possibility of either a material problem or excessive loading.
- The presence of AC patches at transverse joints scattered throughout the project indicates the seriousness of joint deterioration and its progression.
- The natural drainability of the base materials and subgrade is poor.

FACTORS THAT MAY CONSTRAIN THE REHABILITATION DESIGN

- Rapidly increasing traffic growth may require structural strengthening to reduce future rates of pavement deterioration.
- Deterioration of underlying slab due to D-cracking will require full-depth PCC repair.
- Moisture-related damage must be addressed by reducing the entry of water through the pavement surface at the transverse reflection cracks and lane shoulder joint and/or by installing edge drains to remove moisture from the pavement system.
- Traffic can be rerouted onto opposing lanes using a concrete separation barrier.
- Minimum time between major 4R work should be at least 7 years.
- A specified minimum clearance beneath bridges currently exists and must be maintained. This will require special considerations for the use of overlays in these areas.

RECOMMENDED ADDITIONAL SURVEYS, TESTS AND EVALUATIONS

- Gradation and modulus testing of the in-service asphalt concrete overlay to determine the cause of the rutting.
- Acquire maintenance records for additional insight into past performance problems.
- Coring and/or deflection testing near the centerline joints to determine the extent of pavement deterioration at these locations.

Figure 3-2.4. Typical evaluation results from workshop 1 for example problem 1.

3. EXAMPLE PROBLEM 1—WORKSHOP 3

Identification of Feasible Rehabilitation Strategies

Rehabilitation strategies that repair and prevent the pavement distresses and deficiencies should have been developed by each group during workshop 2. A list of additional strategies for this example problem is presented in figure 3-2.5.

Detailed Design and Cost Estimate

Total costs for 4R projects include at least the following: initial rehabilitation construction, future maintenance and rehabilitation, user costs with rehabilitation, and highway modernization costs (e.g., guardrail replacement, bridge repairs, drainage structure repair). Modernization costs are assumed to be the same for each alternative in this example and are, therefore, not considered.

Typical in-place unit costs for the project were obtained (and adjusted for inflation to the present year for construction) from previous agency bid tabulations and experienced contractors.

Due to the various design constraints (and the limited time available for this portion of the training course), use the alternatives developed as part of workshop 2. As an alternative, the options developed in figure 3-2.5 can be analyzed. Other alternatives are certainly feasible and should be considered in the development of an actual 4R project. Specific cross-sections for these rehabilitation designs and initial rehabilitation construction costs are given in figures 3-2.6 through 3-2.9.

Future maintenance and rehabilitation (M & R) costs were estimated over the 20-year design analysis period for each alternative. The following items were considered in estimating future M & R costs:

- While all alternatives have adequate structural designs, deterioration and rutting of the asphalt concrete surfaces will require either re-profiling or the addition of a thin wearing surface at 7- to 10-year intervals. Over 50 percent more traffic loadings are projected over the next 20 years than were applied in the first 30 years.

- Surface repairs will be required in the future for all alternatives. The following future repair estimates (broken down by alternatives) were used:

    - AC overlay—10 percent of the area.
    - PCC overlay—2 percent of the area (100 percent joint resealing after 10 years).
    - AC recycling—2 percent of the area.
    - PCC recycling—2 percent of the area (100 percent joint resealing after 10 years).

- The salvage values of all alternatives at the end of the 20-year analysis period are considered to be approximately equal. Thus, salvage values need not be estimated.

A summary of initial construction costs and future maintenance and rehabilitation costs is given in table 3-2.4. The total cost is expressed as a present worth. Future costs were adjusted using an interest rate of 6 percent and an inflation rate of 4 percent. The results indicate that both overlays have approximately the same total present cost, and that both recycling alternatives are significantly more costly.

A complete economic analysis of 4R alternatives should include estimates of all related costs, including those that are difficult to quantify. Examples of some of those costs include user costs associated with maintaining a pavement section at a lower level of serviceability (vehicle operating costs) and the costs of delays due to lane closures. These costs are often very difficult to estimate, and are excluded from this example to keep it relatively simple and brief. However, it is recommended that such costs should be included in an actual 4R economic analysis.

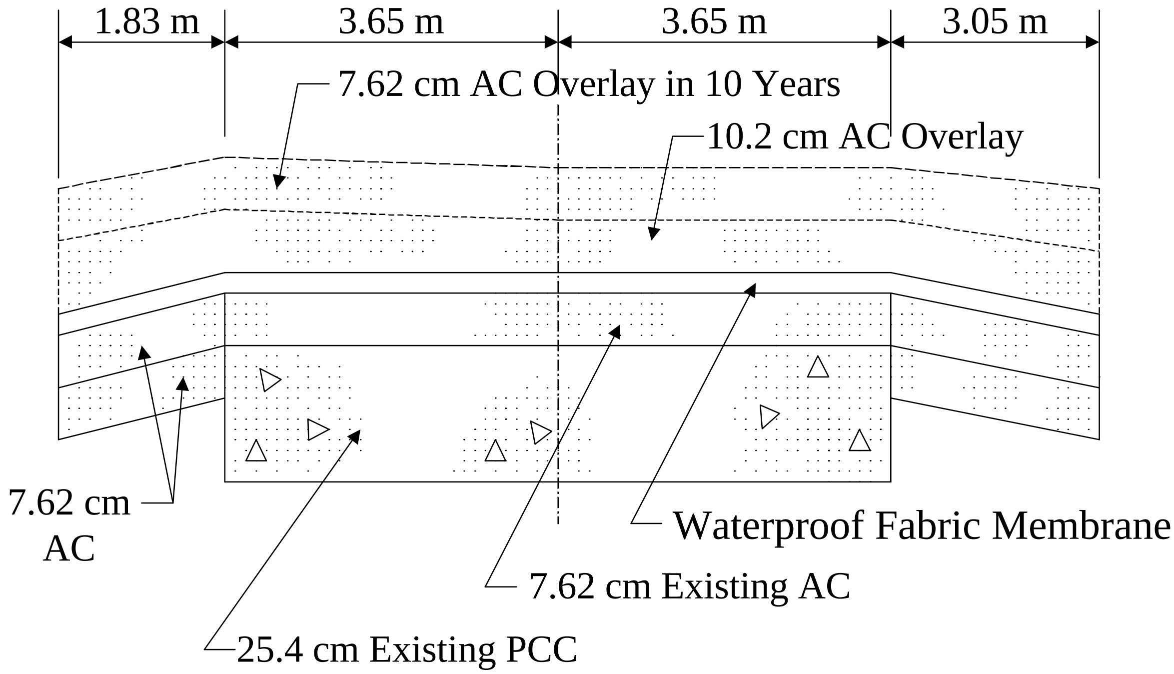
- Resurface with asphalt concrete overlay.
  - Preoverlay Repair: partial- and full-depth repair and localized cement grout undersealing.
  - Asphalt concrete overlay over existing AC to last at least 7 years. Place additional overlays as needed over design analysis period.

- Resurface with unbonded concrete overlay.
  - Preoverlay Repair: some partial- and full-depth repair and localized undersealing.
  - Unbonded Plain Jointed Concrete Overlay: place unbonded plain jointed concrete overlay with concrete shoulders for 20 years of service.

- Rehabilitation—Asphalt Recycling.
  - Remove AC surface and PCC slab.
  - Recycle both materials into new AC.
  - Place asphalt pavement utilizing recycled and new materials. Leave most of existing shoulder in place.

- Rehabilitation—Concrete Recycling.
  - Remove AC surface and PCC slab.
  - Recycle AC and PCC.
  - Place plain jointed composite concrete pavement. Leave most of the existing shoulder in place.

Figure 3-2.5. List of 4R alternatives for example problem 1.



Notes:

1. Preoverlay Repair: patch medium- to high-severity cracks in existing AC and PCC; underseal localized areas of pumping with cement grout; remove and replace one area (approximately 1 mi [1.6 km] long, one lane wide) of weathered/raveled asphalt; place subdrainage in local areas.

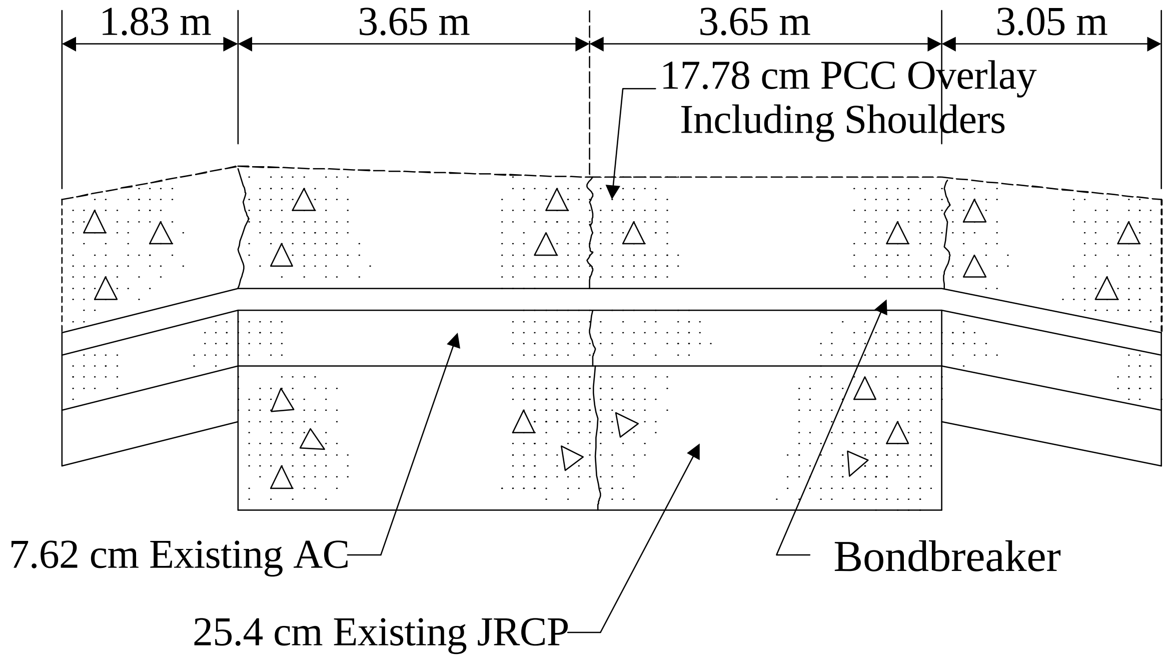
2. Place waterproof membrane over entire surface.

3. Place 4-in (10.2 cm) AC overlay with high friction surface over entire pavement area.

4. Place 3-in (7.62 cm) AC overlay at approximately 10 years.

5. Pavement initial construction cost = $3,200,000.

Figure 3-2.6. AC overlay resurfacing alternative for example problem 1.



Notes:

1. Preoverlay — patch only seriously deteriorated areas.

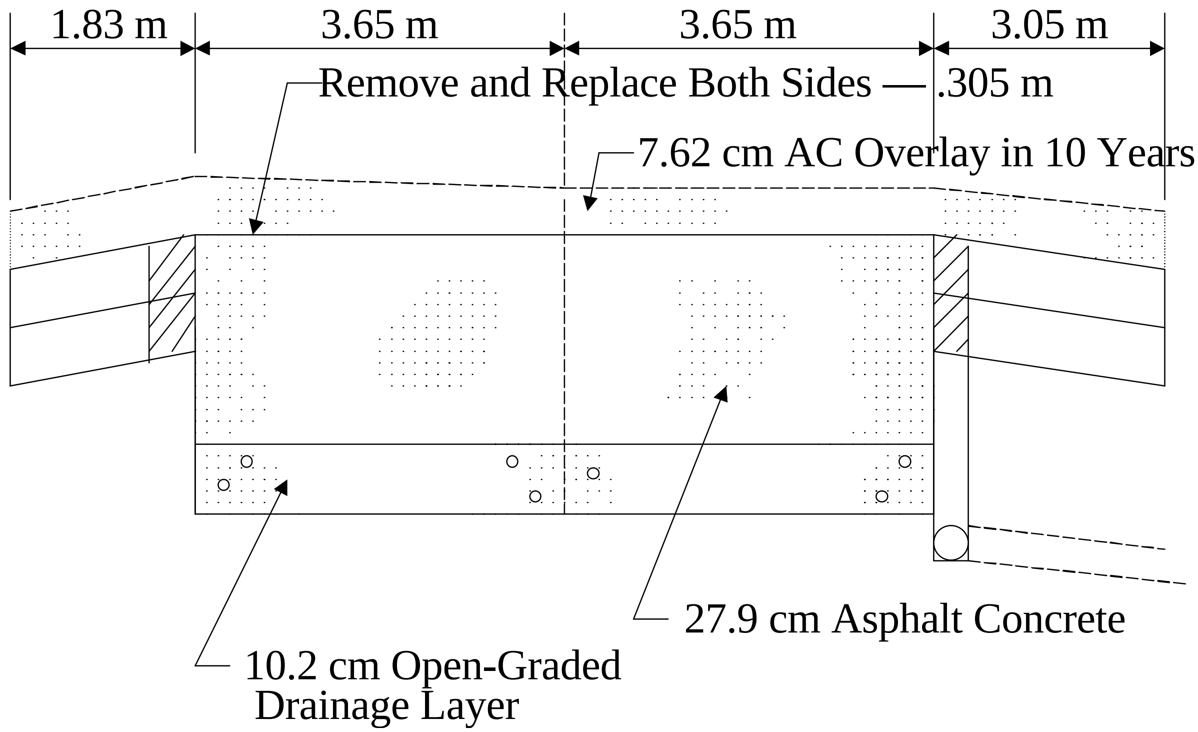
2. Place AC separation layer over entire surface.

3. Place 7-in (17.78 cm) plain jointed PCC overlay with random 12-to 17-ft (3.65 to 5.2 m) joint spacing (with dowels). Place mainlane, then shoulders (tie shoulders with double number of rebar).

4. Seal longitudinal joints with hot-poured sealant, and transverse joints with preformed sealant.

5. Pavement initial construction cost = $4,210,000.

Figure 3-2.7. Unbonded concrete resurfacing alternative for example problem 1.



Notes:

1. Remove existing AC and PCC traffic lanes pavement. Crush PCC for use as aggregate in recycled AC. Crush AC and use in recycling.

2. Recompact and level subbase, add 4 in (10.2 cm) of open-graded material. Existing base acts as filter layer.

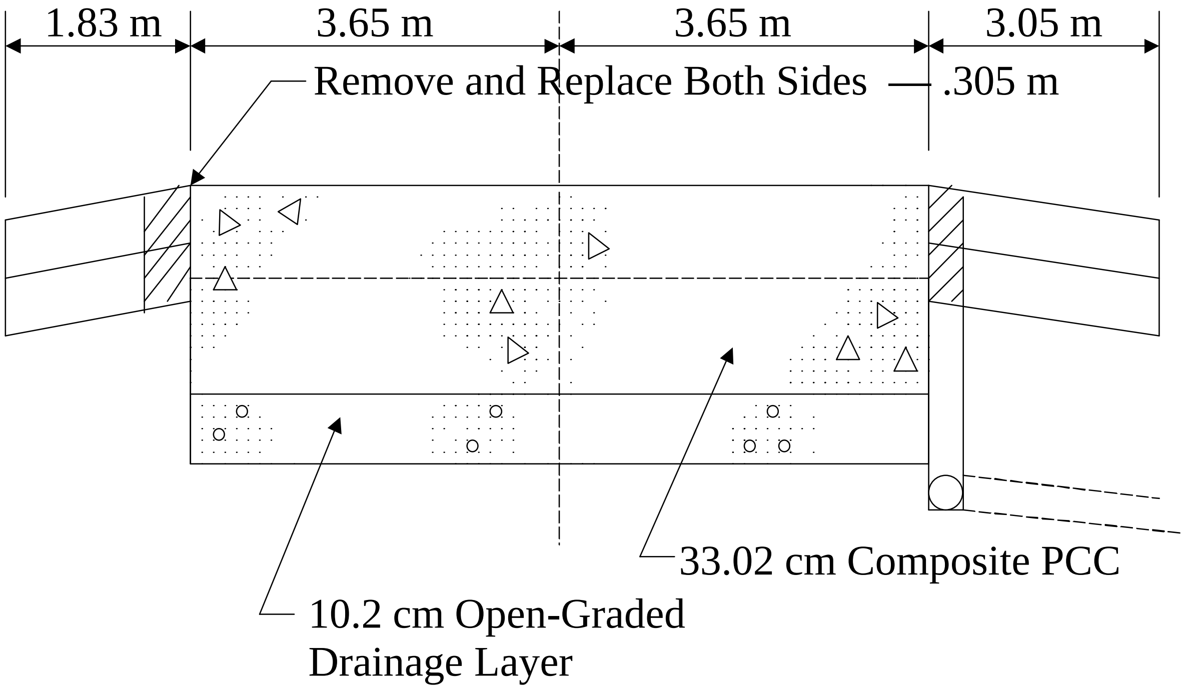
3. Place 11 in (27.9 cm) of asphalt concrete pavement in appropriate layers and design mixes using recycled materials and adequate high friction surface.

4. Place longitudinal drain with laterals.

5. Repair shoulder and heater/scarify surface.

6. Pavement initial construction cost = $5,323,000.

Figure 3-2.8. Asphalt recycling alternative for example problem 1.



Notes:

1. Remove existing AC and PCC traffic lanes pavement. Crush PCC for use as concrete aggregate. Recompact and level subbase.

2. Place open-graded drainage layer (existing subbase acts as filter layer).

3. Place 13-in (33.02 cm) composite concrete slab: a) place 8-in (20.32 cm) low-strength layer; b) immediately follow with 5-in (12.7 cm) high-strength top layer. Use crushed concrete as coarse aggregate.

4. Joint spacing is random 12 to 17 ft (3.65 to 5.2 m) (with dowels). Place preformed sealants in transverse joints.

5. Repair shoulder and heater/scarify surface.

6. Pavement initial construction cost = $5,266,000.

Figure 3-2.9. Concrete recycling alternative for example problem 1.

Table 3-2.4. Total cost summary for 4R alternatives for example problem 1.

COST ITEM	COSTS BY REHABILITATION			
	Asphalt Overlay	Concrete Overlay	Asphalt Recycling	Concrete Recycling
Pavement Construction	$3,200,000	$4,210,000	$5,323,000	$5,266,000
Ramp Overlay	$369,000	$369,000	$303,000	$330,000
Traffic Control	$500,000	$500,000	$500,000	$500,000
Guardrail	$55,000	$55,000	- - -	- - -
Miscellaneous	$96,000	$96,000	$96,000	$96,000
Engineering	$472,000	$573,000	$622,000	$620,000
Total Initial Construction Cost	$4,692,000	$5,803,000	$6,844,000	$6,812,000
20-year M&R[1]	$1,322,000	$207,000	$919,000	$207,000
Total Present Cost	$6,014,000	$6,010,000	$7,763,000	$7,019,000

[1] Present worth cost.

EXAMPLE PROBLEM 2: AC PAVEMENT

1. PROJECT BACKGROUND DATA

A summary of important background data is given in table 3-2.5. A cross-section of the existing pavement is given in figure 3-2.10. Traffic data for the pavement is summarized in table 3-2.6.

Project Survey and Evaluation

An extensive project survey and evaluation were conducted:

- Distress survey—Existing distress was recorded in the 6th, 8th, and 10th year. The distress data indicate that the pavement could be divided into sub-projects, each containing distinctly different levels of distress. Figure 3-2.11 shows a strip map of alligator cracking and rutting. Table 3-2.7 summarizes this data in two subprojects.

- Structural—Nondestructive deflection testing was performed using a Road Rater with 8,000 lb (36 Kn) peak-to-peak load at 15 Hz. The deflection results are given in figure 3-2.11 plotted along the project.

- Materials—The base material is a dense-graded granular material containing 5 percent fines. The asphalt concrete properties were extracted from cores and are presented in table 3-2.8.

- Drainage—The project is located in climatic zone IA, which means it is continuously wet and subject to deep frost penetration.

Table 3-2.5. Summary of background data for example problem 2.

ORIGINAL CONSTRUCTION DATA	
Facility	Rural, primary State highway, 3.0 mi (4.8 km) long
Original Construction	Flexible asphalt concrete (AC) pavement (see figure 3-2.13
Age Today	10 years
Subgrade	Predominantly silty clay (AASHTO A-6)

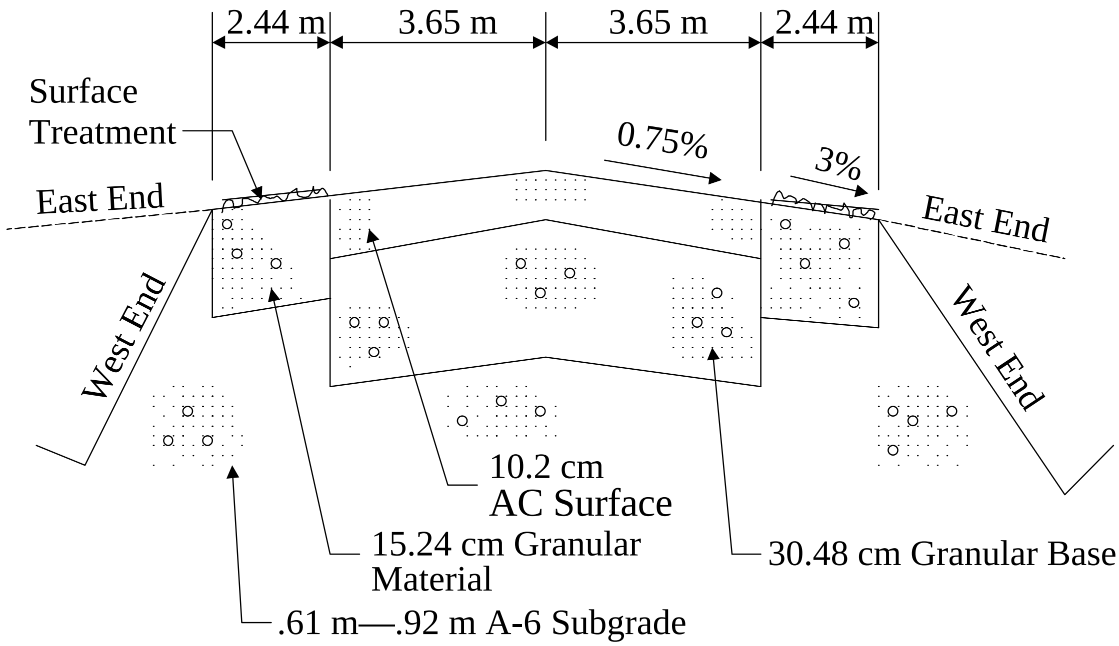


Figure 3-2.10. Typical cross-section for example problem 2.

Table 3-2.6. Summary of traffic data for example problem 2.

TIME PERIOD, YEARS		MEAN ONE-WAY ADT	18-KIP (80 KN) ESALS IN EACH LANE
PAST	0 to 10	4,500 (8 percent trucks)	370,000[1]
FUTURE	11 to 20	6,000 (9 percent trucks)	900,000
	21 to 30	8,500 (10 percent trucks)	1,500,000

[1] Data are for each 10-year period only, and are not cumulative.

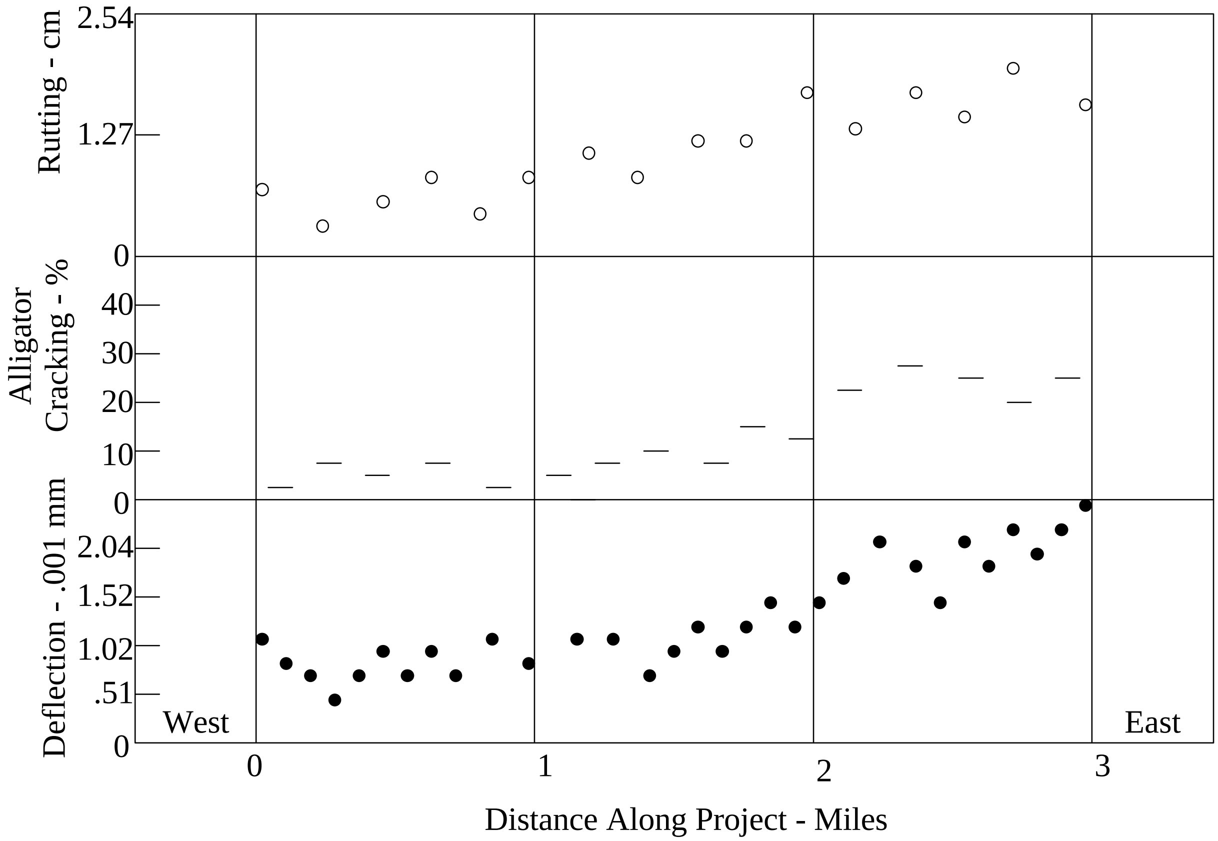


Figure 3-2.11. Strip map showing key distresses and slab deflections for example problem 2.

Table 3-2.7. Distribution of distress and serviceability for example problem 2.

DISTRESS	YEAR	WEST 2 MI (3.2 KM)		EAST 1 MI (1.6 KM)		
		Low	Medium	Low	Medium	High
Alligator Cracking	6	0%	0%	2%	1%	0%
	8	2%	1%	8%	4%	2%
	10	5%	2%	10%	7%	5%
Rutting	6	0.08 in (.20 cm)		0.25 in (.64 cm)		
	8	0.12 in (.30 cm)		0.32 in (.81 cm)		
	10	0.17 in (.43 cm)		0.58 in (1.47 cm)		
Transverse Cracks (ft/mi)	10	443 (Medium) 1647 (Low)		102 (Medium) 711 (Low)		
PSR	6	3.8		3.0		
	8	3.6		2.8		
	10	3.5		2.3		
Shoulders	10	Fair		Poor (alligator cracking)		

Table 3.2.8. Material properties of asphalt concrete
for example problem 2 (obtained from cores).

Asphalt Content	5.6 percent
Penetration 77 ºF (25 ºC)	20
Viscosity 140 ºF (60 ºC)	65,000 poise
Aggregate Type	Crushed stone
Aggregate Gradation	Dense; 18 percent fines
LA Abrasion	35
Sulfate Soundness	10 percent
Age	10 years

2. EXAMPLE PROBLEM—WORKSHOP 2

Results from Workshop 1

Figure 3-2.12 (handout) presents typical general evaluation results for this example. Group results should be compared with these before proceeding with workshop 2 activities.

Identification of Feasible 4R Alternatives

There are many alternative rehabilitation strategies that can be identified for a particular project. Each has specific advantages and disadvantages that vary with the specific design situation. Some alternatives may not be feasible because of existing pavement conditions, constraints imposed on the design, and other factors.

A list of constraints within which the team must work must be assumed. If your group is not developing alternatives along the lines described on pp. 3-1.4, 3-1.5, and 3-1.6 (10 years, 20 years, and agency fix), consider the following constraints:

- A design analysis period of 10 years should be used to develop all alternatives.
- Traffic can be detoured to other pavements, if necessary, so that this section can be completely closed during rehabilitation for a short period. However, it would cause much less of a problem if traffic could be maintained, at least in one direction.

PROJECT DEFECTS OR DEFICIENCIES

- Pavement serviceability is unacceptable at the east end of the project.
- Alligator cracking has become a serious problem at the east end of the project.
- Rutting in the traffic lanes indicates the possibility of either material problems or excessive loading. The rutting is worst at the east end.
- The shoulder design appears inadequate for the volume and type of traffic being carried by this facility, particularly on the east end.
- The natural drainability of the base and subgrade is very poor.
- Side ditches become very shallow toward the east end of the project. Water cannot drain out of the pavement section.
- The transverse slope is not adequate and must be increased.

FACTORS THAT MAY CONSTRAIN THE REHABILITATION DESIGN

- Current and future traffic levels (including a significant number of heavy trucks) may dictate structural strengthening to reduce future rates of pavement deterioration.
- The potential for additional moisture-related damage must be reduced by removing water from the pavement system (adding edge drains, improving ditch drainage, and so on).
- While rerouting traffic is possible and would probably result in increased worker safety and productivity, it would be considerably more expensive in terms of user delay and mileage costs and payments to other agencies (e.g., the county) for the heavy use of detours.
- Minimum time between major 4R work should be at least 10 years.

RECOMMENDED ADDITIONAL SURVEYS, TESTS AND EVALUATIONS

- Acquire maintenance records for additional insight into past performance problems.
- Further testing of the shoulder areas to determine their structural capability is needed. They may be needed to carry traffic during construction.

Figure 3-2.12. Typical evaluation results from workshop 1 example problem 2.

3. WORKSHOP 3—SELECTION OF THE PREFERRED ALTERNATIVE

Identification of Feasible Rehabilitation Strategies

Rehabilitation strategies that repair and prevent the pavement distresses and deficiencies should have been developed as part of the previous workshop. Figure 3-2.13 presents some possible alternatives for this problem.

Detailed Design and Cost Estimate

Total costs for 4R projects include: initial rehabilitation construction, future maintenance and rehabilitation, user costs with rehabilitation, and highway modernization costs (e.g., guardrail replacement, bridge repairs, drainage structure repair). Except where noted, modernization costs are assumed to be the same for each alternative in this example and are, therefore, not considered.

Typical unit in-place costs for the project were obtained (and adjusted for inflation to the present year for construction) from previous agency bid tabulations.

Due to the various design constraints (and the limited time available for this portion of the training course), use the alternatives developed as part of workshop 2. As an alternative, the options developed in figure 3-2.13 can be analyzed. Other alternatives are certainly feasible and should be considered in the development of an actual 4R project. Specific cross-sections for these rehabilitation designs and initial rehabilitation construction costs are given in figures 3-2.14 through 3-2.17.

Future maintenance and rehabilitation costs were estimated over the design analysis period for each alternative. These costs were based upon the following facts and assumptions:

- It is assumed that a single surface treatment would be applied to all alternatives at 5 to 7 years after rehabilitation construction for preservation purposes.

- Full-depth AC repairs will be required for all alternatives in the 20-year analysis period. The following repair estimates (percent of total area) are used for the various alternatives.

    - 4-in (10.2 cm) AC overlay with minimal preoverlay repair—1 percent.
    - 2-in (5.1 cm) AC overlay with extensive preoverlay repair—6 percent.
    - Hot-mix recycle 4 in (10.2 cm) AC surface—0 percent.
    - Combination recycle and AC overlay—1 percent.

A summary of all costs is presented in table 3-2.9. The total cost is expressed as a present worth. Future costs were calculated using an interest rate of 8 percent and an inflation rate of 4 percent.

A complete economic analysis of 4R alternatives should include estimates of all related costs, including those that are difficult to quantify. Examples of some of those costs include user costs associated with maintaining a pavement section at a lower level of serviceability (vehicle operating costs) and the costs of delays due to lane closures. These costs are often very difficult to estimate, and are excluded from this example to keep it relatively simple and brief. However, it is recommended that such costs should be included in an actual 4R economic analysis.

- Resurface with structural asphalt concrete overlay: preoverlay repair—full-depth repair of potholes only. Place a uniform 4-in (10.2 cm) thick structural bituminous overlay over the project, including shoulders.

- Resurface with thin bituminous overlay: preoverlay repair—full-depth repair of all high-severity alligator-cracked areas and sealing of all longitudinal and transverse cracks. Place a uniform 2-in (5.1 cm) thick overlay over entire project, including shoulders.

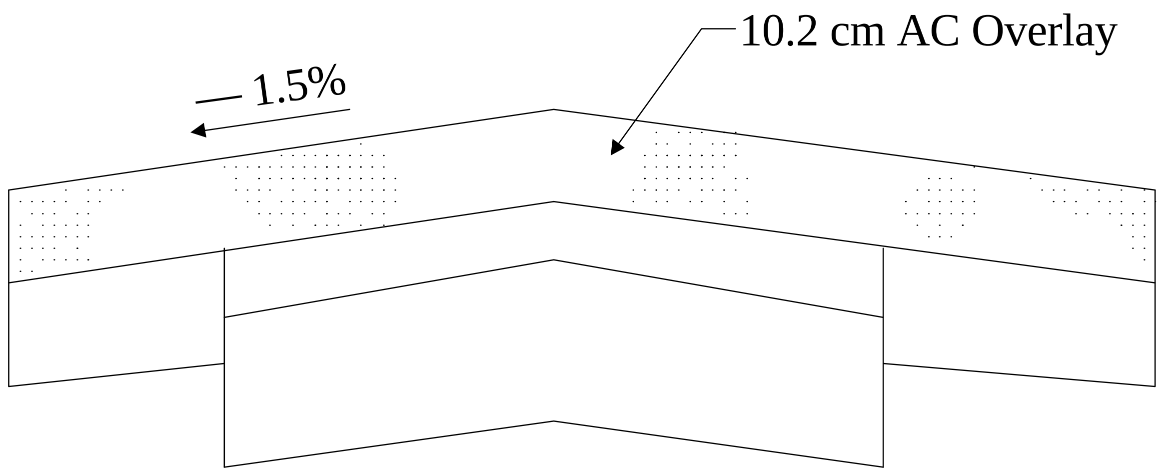
- Hot-mix asphalt concrete recycle: recycle 4 in (10.2 cm) of existing AC surface into a new 7-in (17.78 cm) layer for mainline pavement and shoulders over entire 3 mi (4.8 km).

- Combination bituminous recycle and overlay: recycle top 4 in (10.2 cm) of surface and add virgin material to develop 7 in (17.78 cm) of AC on east 1 mi (1.6 km). Add 2 in (5.1 cm) bituminous overlay on west 2 mi (3.2 km) after repairing locally distressed areas.

- Resurface with variable thickness bituminous overlay: pre-overlay repair—full-depth repair of potholes only. Place bituminous overlay with thickness varied along project (including shoulders) based on condition and deflection. Overlay thickness to be 2 in (5.1 cm) over west 2 mi (3.2 km) and 4 in (10.2 cm) over east 1 mi (1.6 km).

NOTES: The deepening of side ditches at the east end of the project is included in each of the above alternatives. In each case, the shoulders will also receive an asphalt concrete surfacing unless stated otherwise. The cross-slope must be increased to -1.5 percent for all alternatives.

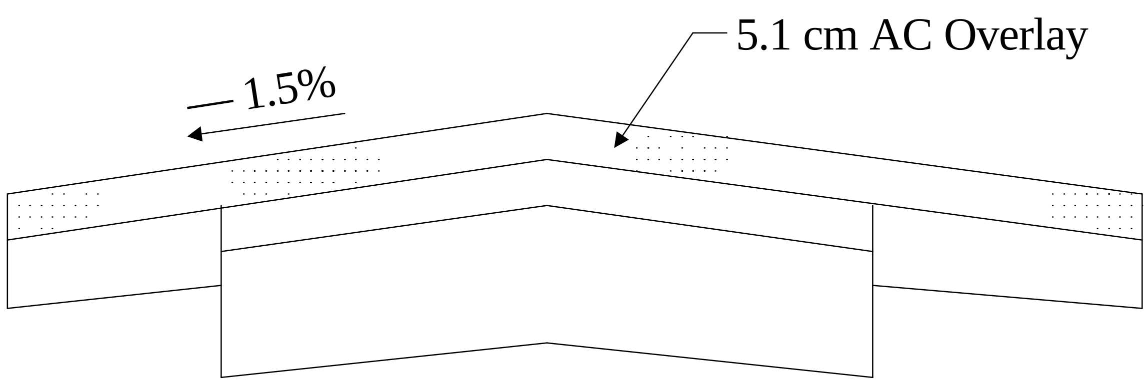
Figure 3-2.13. List of 4R alternatives for example problem 2.



Notes:

1. Preoverlay Repair: repair potholes only.
2. Place a 4-in (10.2 cm) AC overlay over entire project.
3. Pavement initial construction cost = $475,000.

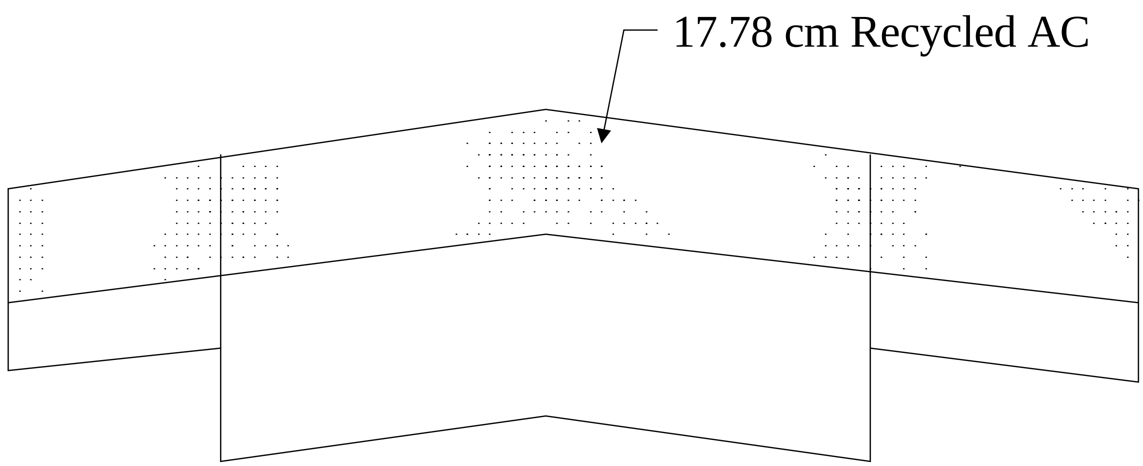
Figure 3-2.14. Uniform thickness structural AC overlay alternative for example problem 2 (minimal preoverlay repair).



Notes:

1. Preoverlay Repair: repair all high-severity alligator-cracked areas.
2. Seal all longitudinal and transverse cracks.
3. Apply 2-in (5.1 cm) AC overlay to entire 3-mi (4.8 km) project.
4. Initial construction cost = $400,000.

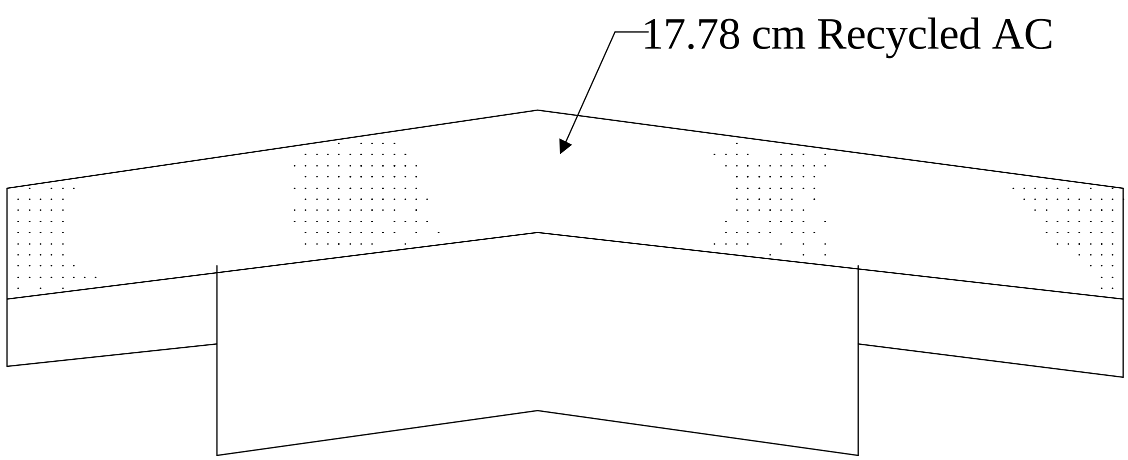
Figure 3-2.15. Uniform thickness AC overlay alternative for example problem 2 (extensive preoverlay repair).



Notes:

1. Hot-mix recycle existing 4-in (10.2 cm) AC surface into new surface for lanes and shoulders. Add virgin material to obtain 7-in (17.8 cm) AC pavement thickness on mainline shoulders.
2. Initial construction cost = $400,000.

Figure 3-2.16. Hot-mix recycling alternative for example problem 2.



Notes:

1. Recycle 4 in (10.2 cm) of existing surface and add virgin material to develop 7 in (17.78 cm) of asphalt concrete material on east 1 mi (1.6 km). Rework base as needed.
2. Place 2-in (5.1 cm) asphalt concrete overlay on west 2 mi (3.2 km).
3. Initial construction cost = $320,000.

Figure 3-2.17. Recycling and overlay alternative for example problem 2.

Table 3-2.9. Total cost summary for 4R alternatives for example problem 2.

COST ITEM	COSTS BY REHABILITATION			
	Structural ACOL	Minimal ACOL	Hot-Mix Recycling	Recycling/ AC Overlay
Pavement Construction	$475,000	$400,000	$400,000	$320,000
Traffic Control	$40,000	$40,000	$40,000	$50,000
Drainage Ditch Repair	$25,000	$25,000	$25,000	$25,000
Engineering	$47,000	$40,000	$48,000	$32,000
Total Initial Construction Cost	$587,000	$505,000	$515,000	$427,000
10-year M&R[1]	$90,000	$80,000	$70,000	$80,000
Total Present Cost	$677,000	$585,000	$585,000	$507,000

[1] Present worth cost.

Note: The present worth of the 10-year maintenance and rehabilitation (M & R) costs for the first and third alternatives were estimated somewhat higher than the others because the alligator cracking was not repaired prior to overlay. The hot-mix recycling option present worth of future M & R was estimated somewhat lower than all other options because it is essentially a new section.

EXAMPLE PROBLEM 3: JRCP

1. PROJECT BACKGROUND DATA

A summary of important background data is given in table 3-2.10. A cross-section of the existing pavement is provided in figure 3-2.18. Traffic data for the pavement are summarized in table 3-2.11.

Project Survey and Evaluation

An extensive project survey and evaluation was conducted at age 25 years.

- Distress Survey—Existing distress in the traffic lanes and on the shoulders in both directions was recorded. A summary of distress is provided in table 3-2.12. The shoulders were in fair condition, having experienced moderate raveling and weathering and some minor breakup at the outside edge.

- Structural Survey—Nondestructive (deflection) and destructive (coring) testing was performed. The NDT work was accomplished using a falling weight deflectometer (FWD) while coring operations provided samples for destructive testing. Results are given in figures 3-2.19 through 3-2.21.

- Drainage—The project is located in climatic zone IA, which means it is continually wet and is subject to deep frost.

- Coring—Several cores were taken at, and at various distances from, transverse joints. Examination of these joints showed significant deterioration near the joints of the portland cement concrete (PCC).

Table 3-2.10. Original construction data for problem 3.

ORIGINAL CONSTRUCTION DATA	
Facility	Rural, controlled-access freeway, 2.0 mi (3.2 km) long
Original Construction	Jointed reinforced concrete pavement (see figure 3-2.23), age 25 years
Reinforcement	Welded wire fabric—69 lbs/yd^2 (34 kg/m^2)
Transverse Joints	Contraction joints spaced every 70-ft (21.3 m), 1.25-in (3.2 cm) diameter dowels on 12-in (30.48 cm) centers
Longitudinal Joint (between lanes)	Tied, No. 4 deformed bars on 30-in (76.2 cm) centers
Subgrade	Predominantly silty clay loam till (AASHTO A-6)

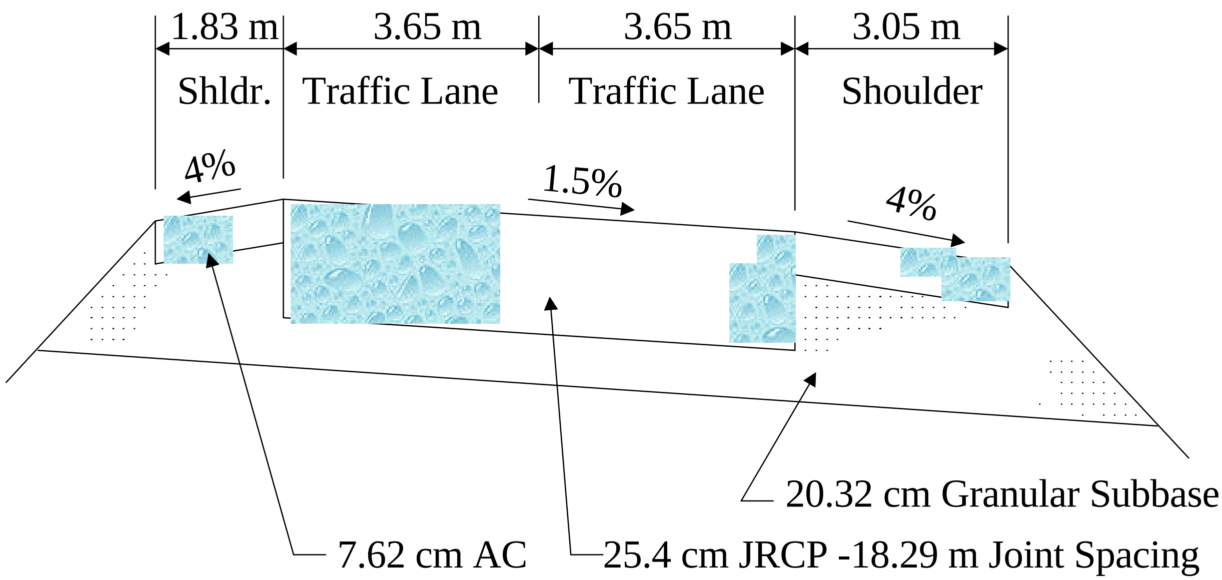


Figure 3-2.18. Typical half-section for example problem 3.

Table 3-2.11. Summary of traffic data for example problem 3.

Time period, years		Mean one-way ADT	18-kip (80 kN) ESALs in outer lane, millions
PAST	0 to 14	8,300 (12 percent trucks)	3.1[1]
	15 to 25	12,900 (12 percent trucks)	6.5
FUTURE	26 to 35	18,700 (14 percent trucks)	10.6
	36 to 45	22,200 (15 percent trucks)	21.9

[1] Data are for each 10-year period only, and are not cumulative.

Table 3-2.12. Summary of outer lane distress and comments for example problem 3.

DISTRESS TYPE	COMMENTS
Transverse/Diagonal Cracking	A minor amount of deteriorated cracks occur throughout the project (100 ft/mi [19m/km] in the outer lane are working cracks; 89 ft/mi [16.8m/km] are working in the inner lane.)
Transverse Joint Spalling	Many medium- and high-severity joint spalls were found (30/mi [18.6/km]). Some permanent and temporary repairs have been placed. Joint seals are generally missing and a large amount of incompressibles are present.
Faulting	Severe faulting (0.34 in [.86 cm] on average) of outer lane joints exists throughout the project. Lower levels of faulting exist in the inner lane (0.10 in [.25 cm], on average).
Corner Breaks	Low-severity corner breaks were found at 3 percent of the transverse joints.
Pumping	Water was observed bleeding out of the lane/shoulder joint after rainstorms. Fines were found pumped onto the shoulder in several locations.
Shoulder Condition	Shoulders are in fair condition, with some raveling and weathering evident. The lane/shoulder joint is unsealed and open.
Present Serviceability Index	Outer Lane = 2.8 Inner Lane = 3.8

OVERALL DEFLECTION PROFILE

Deflections were measured in the panel centers at 360-ft (110 m) intervals (every sixth slab). The results show a very uniform support over the project length. Joint deflection measurements were made at the corner on both sides of the joint (approach and leave) at the same interval locations.

The corner slab deflection profile is shown in figure 3-2.25. The results clearly indicate the presence of voids under most of the leave corners. Figure 3-2.26 shows a plot of corner deflections versus load transfer that can be used to estimate void sizes for this project using techniques from NCHRP Report 281.

Modulus of subgrade reaction (k) values, backcalculated from mid-slab surface deflection data, range from 250 to 350 psi/in (67 to 95 kPa/mm). Concrete modulus of elasticity (E) values (also backcalculated assuming 10 in [25.4 cm] of sound PCC present) range from 4.5 to 5.5 million psi (31 to 38 million kPa).

Joint deflections indicate joint efficiencies ranging from 21 to 90 percent, with an average efficiency of 42 percent. Deflections on the leave side of the joint averaged 70 percent higher than on the approach side, indicating that sufficient pumping has taken place to cause some loss of support near the joints. These findings are supported by the distress survey data.

DETAILED TESTING

Two representative areas about 600 ft (183 m) long were selected for detailed testing. In these areas, deflections were taken at each joint and crack, and cores were taken at selected locations. Most cores exhibited some visual signs of deterioration. Cores taken closer to joints were more deteriorated than those taken near mid-panel. Typical coring data is given below:

Location	Average Percent of Core Recovered	Range
At joint	80	50 - 90
12 in (30.48 cm) from joint	85	55 - 95
24 in (60.96 cm) from joint	87	55 - 95
Mid-panel	90	60 - 100

Joint and crack efficiencies are tabulated below:

Location		Average Efficiency
Joint	- Inner Wheelpath	58 percent
	- Outer Wheelpath	42 percent
	- Corner	39 percent
Crack	- Inner Wheelpath	100 percent
	- Outer Wheelpath	59 percent
	- Corner	45 percent

Figure 3-2.19. NDT and coring survey summary for example problem 3.

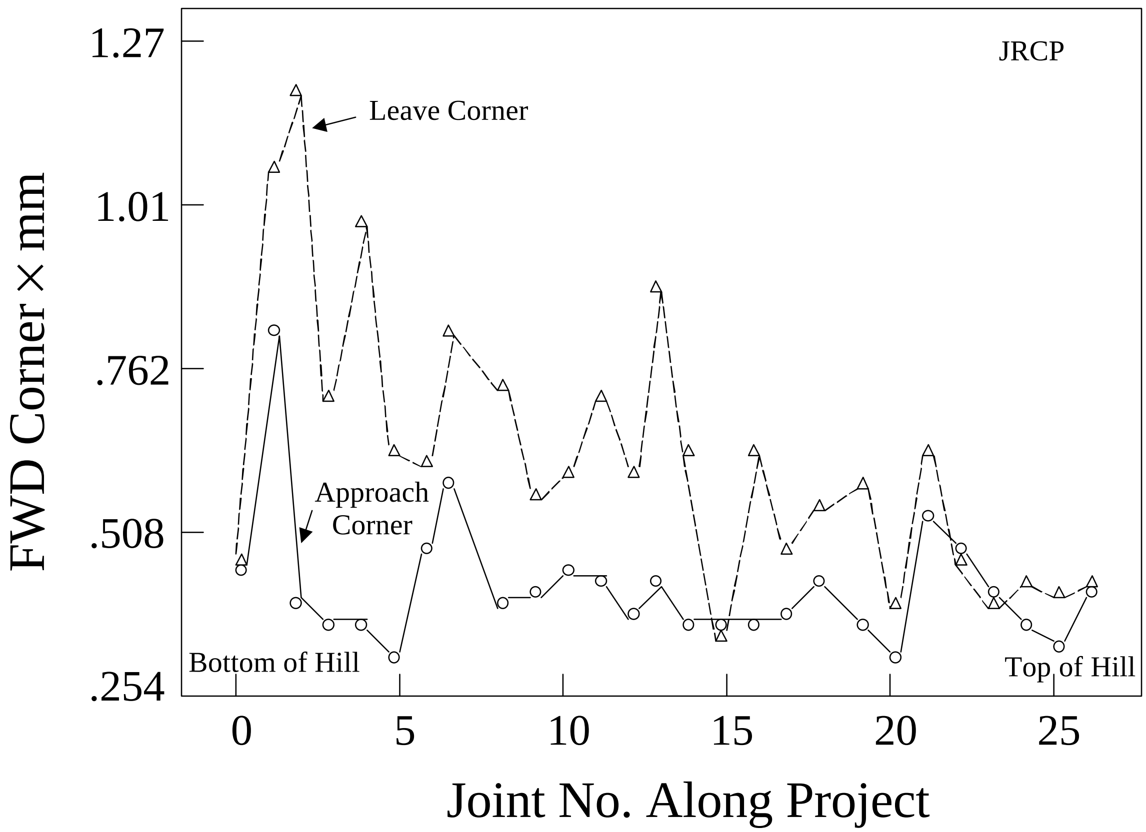


Figure 3-2.20. Corner-slab deflection profile (outer lane) for example problem 3 (FWD 9-kip [80 kN] impulse load).

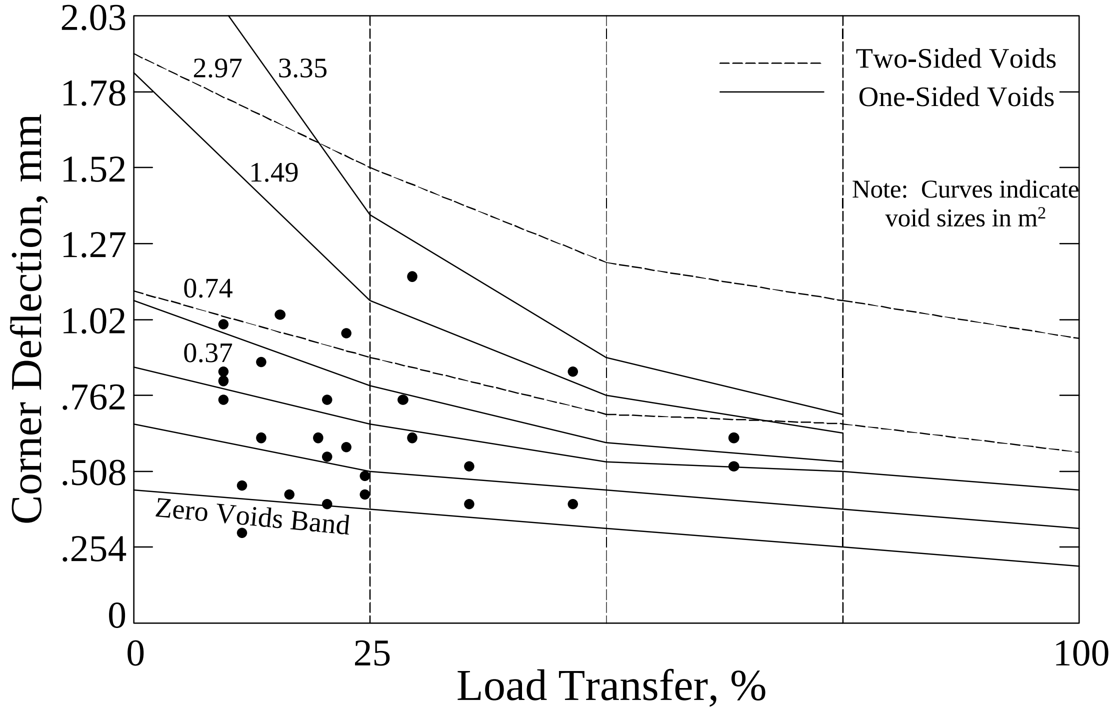


Figure 3-2.21. Plot of corner deflection versus load transfer to estimate void sizes for example problem 3 (FWD 9-kip [40 kN] impulse loading).

2. WORKSHOP 2—IDENTIFICATION OF FEASIBLE ALTERNATIVES

Results from Workshop 1

Figure 3-2.22 (handout) presents typical general evaluation results for this example problem. Group results should be compared with these before proceeding with workshop 2 activities.

Identification of Feasible 4R Alternatives

There are many alternative rehabilitation strategies that can be identified for a particular project. Each has specific advantages and disadvantages that vary with the specific design situation. Some alternatives may not be reliable or possible because of existing pavement conditions, constraints imposed on the design, availability of equipment and other factors.

A list of constraints within which the team must work must be assumed. If your group is not developing alternatives along the lines described on pp. 3-1.4, 3-1.5, and 3-1.6 (10 years, 20 years, and agency fix), consider the following constraints:

- A design analysis period of 20 years should be used to compare all alternatives.
- Minimum time between major 4R work should be at least 10 years.
- It is desirable to avoid rerouting traffic.
- Overhead clearances and horizontal obstacles must be provided for.
- Special equipment may be required for some alternatives.

PROJECT DEFECTS OR DEFICIENCIES:

- Joint seals are missing from most transverse joints and much spalling has taken place, due to the infiltration of incompressibles.
- The lane/shoulder longitudinal joint is unsealed.
- Some underlying deterioration of the concrete is taking place near the joints, although materials problems are not apparent on the pavement surface. Load transfer at the joints is also generally unacceptable.
- Pumping and erosion of the base is a problem throughout the project, as evidenced by the corner breaks, severe faulting, and observation of fines and water being pumped onto the shoulder. This is probably related to poor drainage of subbase and subgrade materials and aggravated by missing transverse and lane/shoulder joint seals in a wet climate.
- Shoulders are beginning to ravel and weather.
- The natural drainability of the base and subgrade materials is poor.
- The outer lane PSI is fairly low.

FACTORS THAT MAY CONSTRAIN THE REHABILITATION DESIGN:

- Rapidly increasing traffic growth may require structural strengthening to reduce future rates of pavement deterioration.
- The repair of moisture-related damage (loss of support, faulting, corner breaks) will have to be addressed to prevent further pavement deterioration. Pavement roughness due to faulting of the outer lane must be reduced to produce acceptable ride quality.
- The prevention of future moisture-related damage must be addressed by reducing the entry of water through the pavement surface at the lane shoulder joint and/or by installing edge drains to remove moisture from the pavement system.
- It is desirable to avoid rerouting traffic. Thus, rehabilitation work may have to be performed under traffic.
- Minimum time between major 4R work should be at least 10 years.
- A specified minimum clearance beneath bridges currently exists and must be maintained. This will require special details for the use of overlays in these areas.

RECOMMENDED ADDITIONAL SURVEYS, TESTS AND EVALUATIONS:

- Materials tests on concrete materials and aggregates from the original source to determine cause of pavement deterioration near the joints.
- Acquire maintenance records for additional insight into past performance problems.
- Profile of ditch line along of project.

Figure 3-2.22. Typical evaluation results from workshop 1 for example problem 3.

3. WORKSHOP 3—SELECTION OF THE PREFERRED 4R ALTERNATIVE

Identification of Feasible Rehabilitation Strategies

Rehabilitation strategies that repair and prevent the pavement distresses and deficiencies should have been developed by each group during workshop 2. Figure 3-2.23 presents some possible alternatives for this problem.

Detailed Design and Cost Estimate

Total costs for 4R projects include: initial rehabilitation construction, future maintenance and rehabilitation, and user costs with rehabilitation; and highway modernization costs (e.g., shoulder paving, guardrail replacement, bridge repairs, drainage structure repair). Shoulder paving is the only non-pavement, structural item considered in this example. Other modernization and improvement costs are assumed to be identical for each alternative in this example and are, therefore, not considered.

Typical in-place unit costs for the project were obtained (and adjusted for inflation to the present year for construction) from previous agency bid tabulations and experienced contractors.

Due to the various design constraints (and the limited time available for this portion of the training course), use the alternatives developed as part of workshop 2. As an alternative, the options developed in figure 3-2.23 can be analyzed. Other alternatives are certainly feasible and should be considered in the development of an actual 4R project. Specific cross-sections for these rehabilitation designs and initial rehabilitation construction costs are given in figures 3-2.24 through 3-2.27.

Future maintenance and rehabilitation costs were estimated over the design analysis period for each alternative. These costs were based upon the following facts and assumptions:

- It was assumed that an asphalt concrete (AC) surface would require sealing of cracks and reflected joints every 5 years and that PCC surfaces would require joint resealing after 10 years.

- It was assumed that full-depth repairs would be required for some alternatives after 10 years. The following repair estimates were used for the various alternatives:

    - AC overlay—5 percent of the area of both lanes
    - Concrete overlay—1 percent of the area of both lanes
    - Restoration—5 percent
    - Rehabilitation/Reconstruction—2 percent of the inner lane area

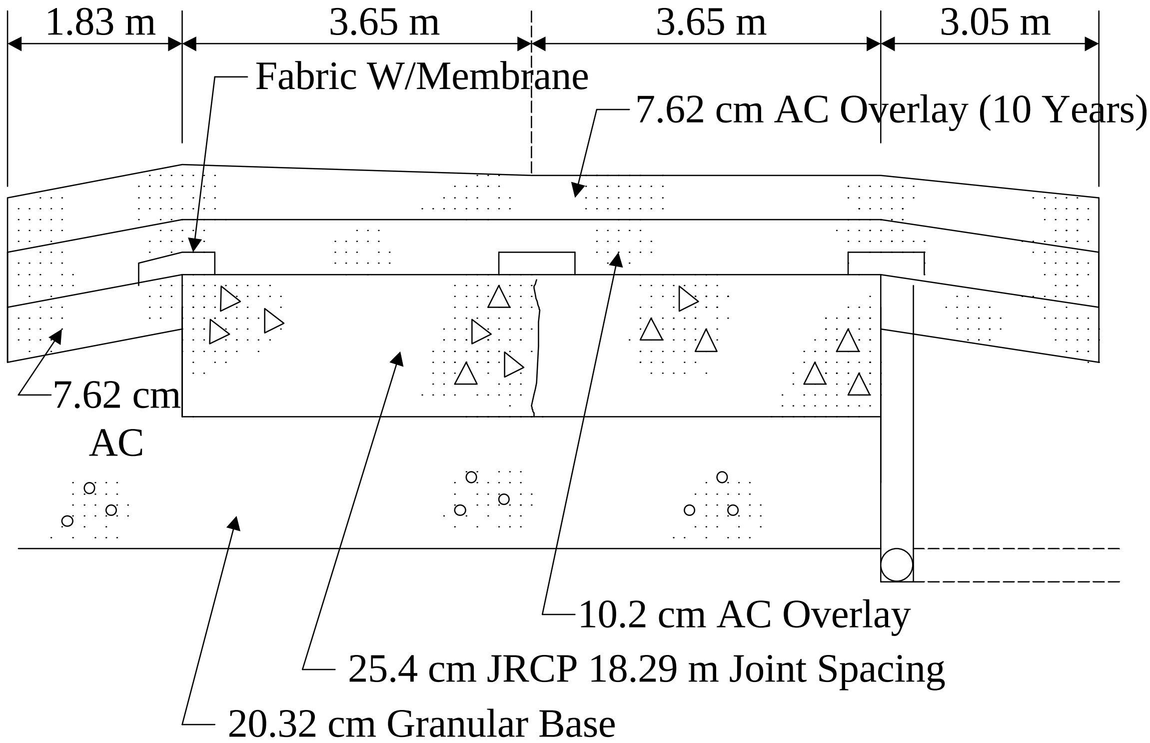
- The salvage values of all alternatives are assumed to be approximately equal at the end of the design period.

A summary of all costs is presented in table 3-2.13. The total cost is expressed as a present worth. Future costs were calculated using an interest rate of 8 percent and an inflation rate of 4 percent.

A complete economic analysis of 4R alternatives should include estimates of all related costs, including those that are difficult to quantify. Examples of some of those costs include user costs associated with maintaining a pavement section at a lower level of serviceability (vehicle operating costs) and the costs of delays due to lane closures. These costs are often very difficult to estimate, and are excluded from this example to keep it relatively simple and brief. However, it is recommended that such costs should be included in an actual 4R economic analysis.

- **Resurface with AC overlay.**
  - Preoverlay Repair: Partial- and full-depth slab repair, localized cement grout under-sealing, installation of edge drains.
  - Asphalt Overlay: Place fabric with membrane over longitudinal joints, place 4-in (10.2 cm) AC overlay to provide 10 years of service, and saw and seal transverse joints.
  - Future Maintenance and Rehabilitation: Seal cracks and joints after 5 years, place 3-in (7.62 cm) bituminous overlay after 10 years, and seal cracks and joints after 15 years.
- **Resurface with unbonded concrete overlay.**
  - Preoverlay Repair: Minor full-depth slab repair, localized undersealing.
  - Unbonded Plain Jointed Concrete Overlay: 1-in (2.54 cm) AC leveling course, placement of 8-in (20.32 cm) jointed plain concrete overlay with tied PCC shoulders.
  - Future Maintenance and Rehabilitation: Minor full-depth slab repairs and reseal all joints after 10 years of service.
- **Concrete pavement restoration.**
  - Restoration: Extensive full-depth slab repair, cement grout undersealing, install edge drains, diamond grinding of outside lane, repair and sealing of shoulders (outside), and resealing of all joints.
  - Future Maintenance and Rehabilitation: Repeat full-depth repairs and undersealing, place 5-in (12.7 cm) AC overlay after 10 years.
- **Rehabilitation/Reconstruction.**
  - Rehabilitation: Full-depth slab repairs (inner lane only), localized undersealing (inner lane only), installation of subdrains, resealing of joints with high-quality silicone sealant).
  - Reconstruction (outer lane and shoulder): Reconstruction of outer lane and shoulder using PCC (including recycling PCC material, and sealing of all joints with high-quality silicone sealant).
  - Future Maintenance and Rehabilitation: Reseal joints and full-depth repair as needed after 10 years.

Figure 3-2.23. List of 4R alternatives to be considered in example problem 3.



Notes:

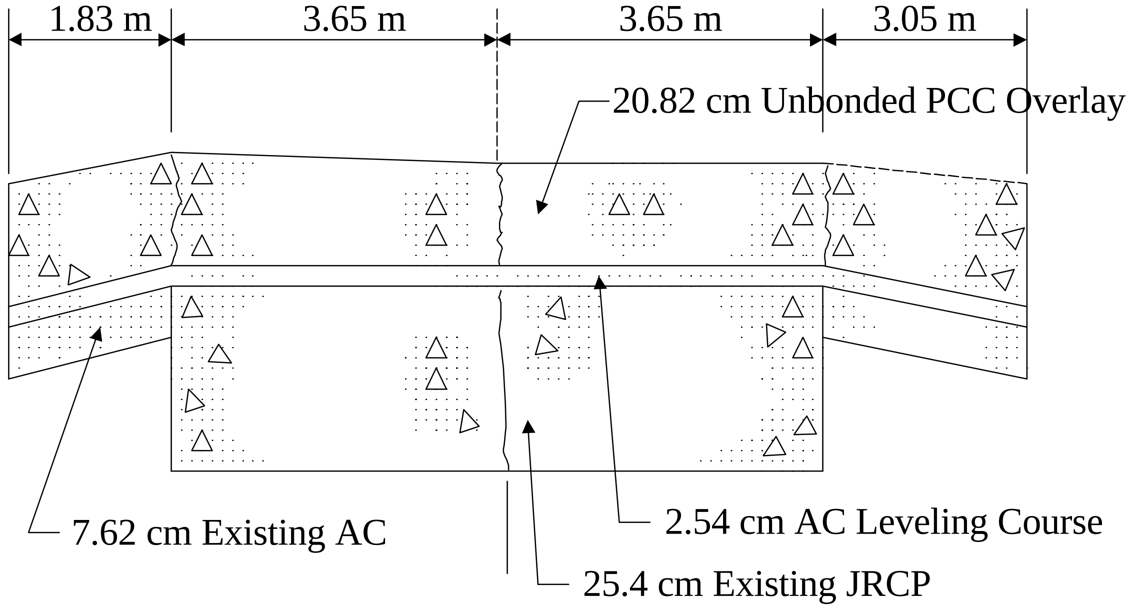
1. Preoverlay Repair: Full-depth slab repair, localized cement grout undersealing and installation of edge drains.

2. Asphalt Overlay: Place fabric with membrane over longitudinal joints to retard reflective cracking, place 4-in (10.2 cm) AC overlay for 10 years of service, saw and seal AC overlay over transverse joints.

3. Future Maintenance and Rehabilitation: Seal cracks and joints after 5 years, place 3-in (7.62 cm) AC overlay after 10 years, seal cracks and joints after 15 years.

4. Initial Construction Cost = $853,000.

Figure 3-2.24. AC overlay resurfacing alternative for example problem 3.



Notes:

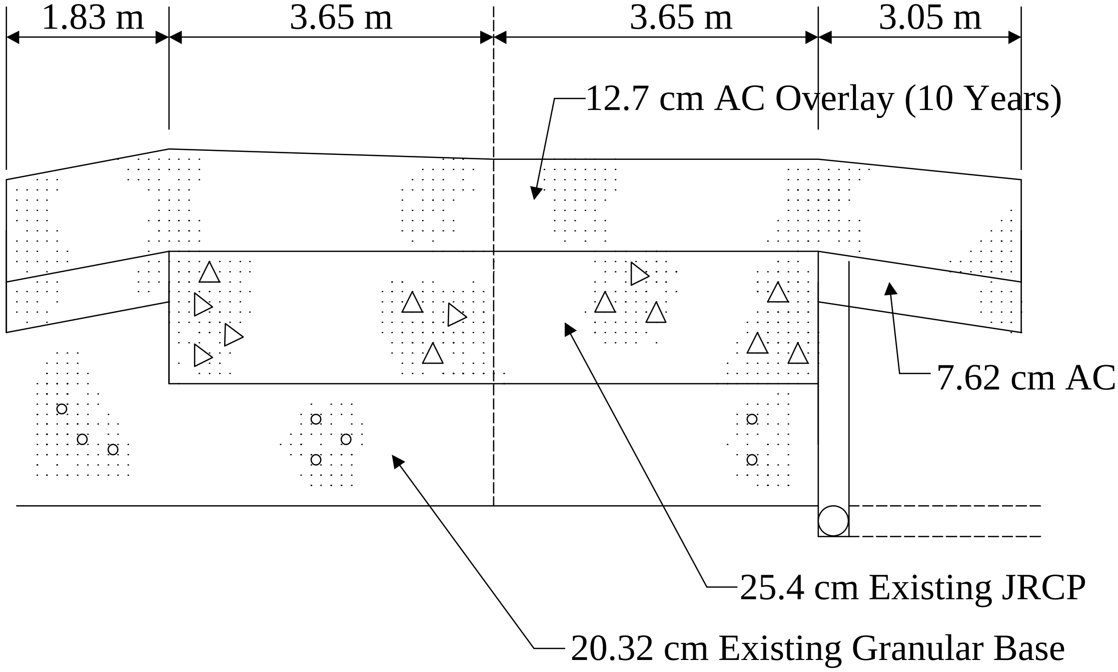
1. Preoverlay Repair: Minor full-depth slab repair, localized undersealing.

2. Unbonded Plain Jointed Concrete Overlay: 1-in (25.4 cm) AC leveling course, 8-in (20.32 cm) jointed plain concrete overlay with tied PCC shoulders.

3. Future Maintenance and Rehabilitation: Minor full-depth slab repairs and saw/seal all joints after 10 years of service.

4. Initial Construction Cost = $l,730,000.

Figure 3-2.25. Unbonded concrete resurfacing alternative for example problem 3.



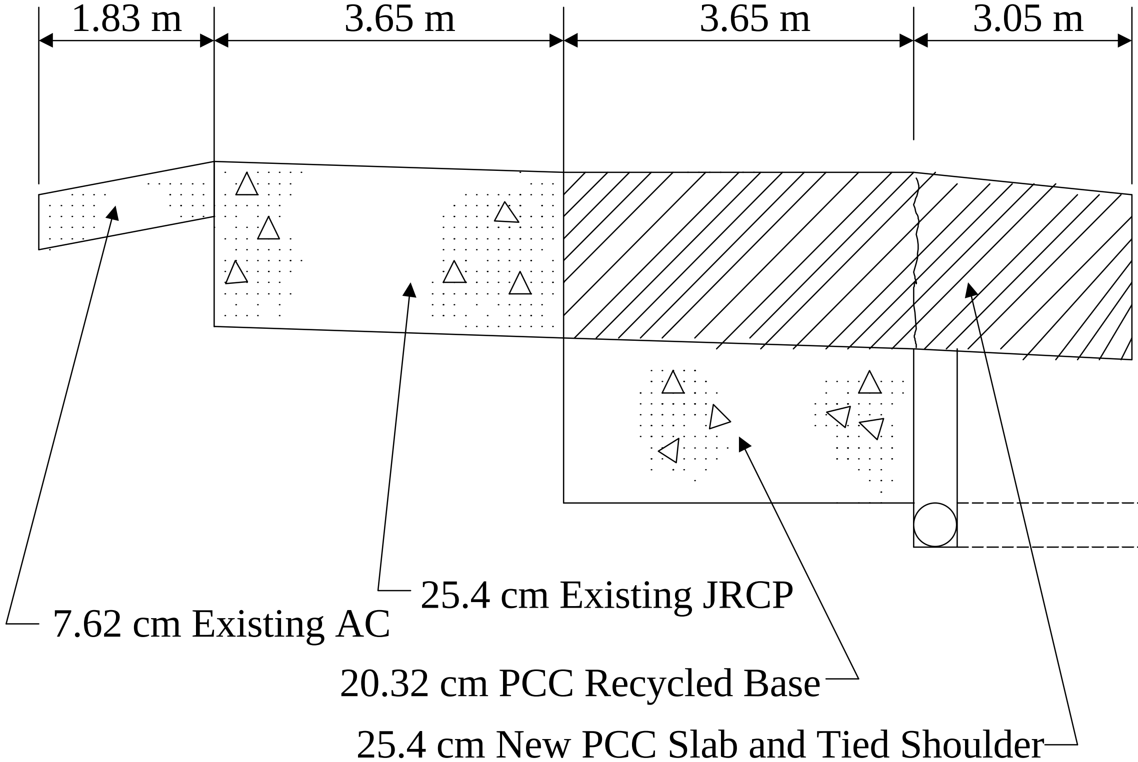
Notes:

1. Restoration: Extensive full-depth slab repair, cement grout undersealing, install edge drains, diamond grinding of outside lane, repair and seal shoulders (outside), and resealing of all joints.

2. Future Maintenance and Rehabilitation: Repeat Full-depth repairs and undersealing, place 5-in (12.7 cm) AC overlay after 10 years.

3. Initial Construction Cost = $523,000 (not including overlay).

Figure 3-2.26. Concrete pavement restoration alternative for example problem 3.



Notes:

1. Restoration: Full-depth slab repairs (inner lane only), localized undersealing (inner lane only), installation of subdrains (outer lane only), resealing of joints with high-quality silicone sealant.

2. Reconstruction (outer lane and shoulder): Reconstruction of outer lane and shoulder using PCC (including recycling PCC material into a new open-graded stabilized base), and sealing of all joints with high-quality silicone sealant.

3. Future Maintenance and Rehabilitation: Reseal joints and full-depth repair as needed after 10 years.

4. Initial Construction Cost = $l,418,000.

Figure 3-2.27. Restoration/reconstruction alternative for example problem 3.

Table 3-2.13. Total cost summary for 4R alternatives for example problem 3.

COST ITEM	COSTS BY REHABILITATION			
	Structural ACOL	**PCC Overlay**	**Restoration**	**Rehabilitation/ Reconstruction**
Pavement Construction	$630,000	$1,400,000	$350,000	$1,100,000
Traffic Control	$75,000	$120,000	$65,000	$100,000
Edge Drains	$53,000	- - -	$53,000	$53,000
Engineering	$95,000	$210,000	$55,000	$165,000
Total Initial Construction Cost	$853,000	$1,730,000	$523,000	$1,418,000
20-year M&R[1]	$313,000	$52,000	$475,000	$100,000
Total Present Cost	$1,166,000	$1,782,000	$998,000	$1,518,000

[1] Present worth cost.

EXAMPLE PROBLEM 4: JPCP

1. PROJECT BACKGROUND DATA

A summary of important background data is given in table 3-2.14. A cross-section of the existing pavement is provided in figure 3-2.28. Traffic data for the pavement are given in table 3-2.15.

Project Survey and Evaluation

An extensive project survey and evaluation was conducted at age 12 years.

- Distress Survey—Existing distress in the traffic lanes and on the shoulders in both directions was recorded. A summary of distress is provided in table 3-2.16.

- Structural Survey—Nondestructive (deflection) testing was performed using a falling weight deflectometer (FWD). Results are given in figures 3-2.29 and 3-2.30. The transverse joints do not contain dowels and the load transfer is consequently very poor. This has resulted in high deflections and increased pumping.

- Drainage Evaluation—The project is located in climatic zone IC, which means that it is continually wet and rarely subject to freezing temperatures. A general description of the drainage is presented in figure 3-2.31. The stabilized subbase is impermeable (except through cracks), and, according to county soil maps of the area, the clayey subgrade is relatively impermeable as well.

Table 3-2.14. Summary of background data for example problem 4.

Facility	Rural controlled-access freeway 3.0 mi (4.8 km) long
Original Construction	Jointed plain concrete pavement
Age Today	12 Years
Transverse Joints	Spaced every 20 ft (6.1 m) no dowels
Longitudinal Joint	Tied—No. 4 deformed bars on 30-in (76.2 cm) centers
Subgrade	Predominantly clayey silt (AASHTO A-7-6)

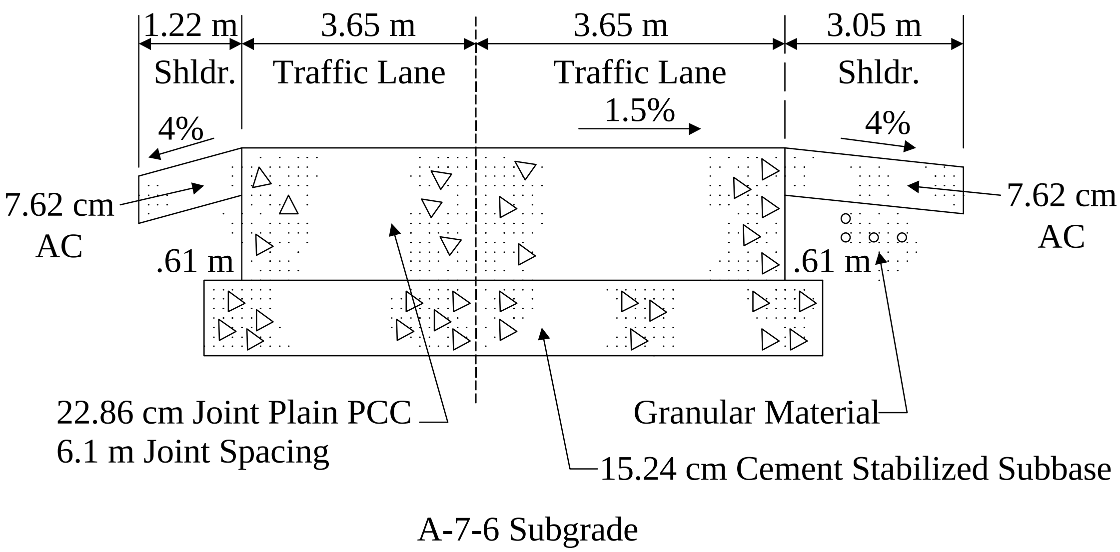


Figure 3-2.28. Typical half-section for example problem 4.

Table 3-2.15. Traffic data for example problem 4.

Time period, years		Mean one-way ADT	18-kip (80 kN) ESALs in outer lane, millions
PAST	0 to 12	5,700 (18 percent trucks)	5.0[1]
FUTURE	13 to 22	9,800 (20 percent trucks)	9.1
	23 to 32	13,500 (23 percent trucks)	14.1

[1] Data are for each time period indicated, and are not cumulative.

Table 3-2.16. Summary of distress and comments for example problem 4.

DISTRESS	OBSERVATIONS
Transverse/Diagonal Cracking	3 percent of the slabs in the outer lane have cracked. These slabs are located throughout the project.
Transverse Joint Spalling	Some low-severity spalls were found and some joints were lightly frayed. No partial-depth or temporary repairs have been placed. Joint seals are generally missing.
Faulting	Serious joint faulting (0.17 in [.43 cm], average) exists throughout the outer lane of the project. Much lower levels of faulting exist in the passing lane (0.05 in [.13 cm], average).
Corner Breaks	Corner breaks were found at 5 percent of the transverse joints. Most of these were observed on the leave side of the joints.
Pumping	Water was observed bleeding out of the lane/shoulder joint after rainstorms. Fines and stabilized base or subgrade material were found pumped onto the shoulder in many locations.
Shoulder Condition	Shoulders are in fair condition, with moderate raveling and weathering evident. No heaving or settlement is apparent. The lane/shoulder joint is unsealed and blowholes (depressions) exist at many of the transverse joints.
Concrete Durability	No durability problems are evident.

OVERALL DEFLECTION PROFILE

Deflections were measured in the panel centers at 240-ft (73 m) intervals (every sixteenth slab). Results indicated uniform deflections through the project length. Joint deflection measurements were made at the leave and approach corners at the same interval locations.

Results: Equivalent modulus of subgrade reaction (k) values (backcalculated from center slab surface deflection data) range from 400 to 1000 psi/in (109 to 270 kPa/mm), with an average of about 800 psi/in (216 kPa/mm). Concrete modulus of elasticity (E) values (also backcalculated assuming 9 in [22.9 cm] of sound PCC present) range from 4.5 to 6.8 million psi (31 to 47 million kPa).

Joint deflections indicate joint efficiencies near the corner ranging from 1 to 29 percent, with an average efficiency of 12 percent. The corner slab deflection profile for a short section is shown in figure 3-2.37. The leave corner deflections are generally much higher than the approach corner deflections.

Deflections on the leave side of the joint averaged 250 percent higher than the approach side, indicating that extensive pumping and erosion has taken place to cause some loss of support near the joints. These findings are supported by the distress survey data.

DETAILED TESTING

Three representative areas about 600 ft (183 m) long were selected for detailed testing. In these areas, deflections were taken at each joint and transverse crack.

Joint and crack efficiencies are tabulated below:

Location			Average Efficiency
Joint	-	Inner Wheelpath	48 percent
	-	Outer Wheelpath	19 percent
	-	Corner	12 percent
Crack	-	Inner Wheelpath	87 percent
	-	Outer Wheelpath	53 percent
	-	Corner	39 percent

Figure 3-2.29. NDT survey (summary and comments) for example problem 4.

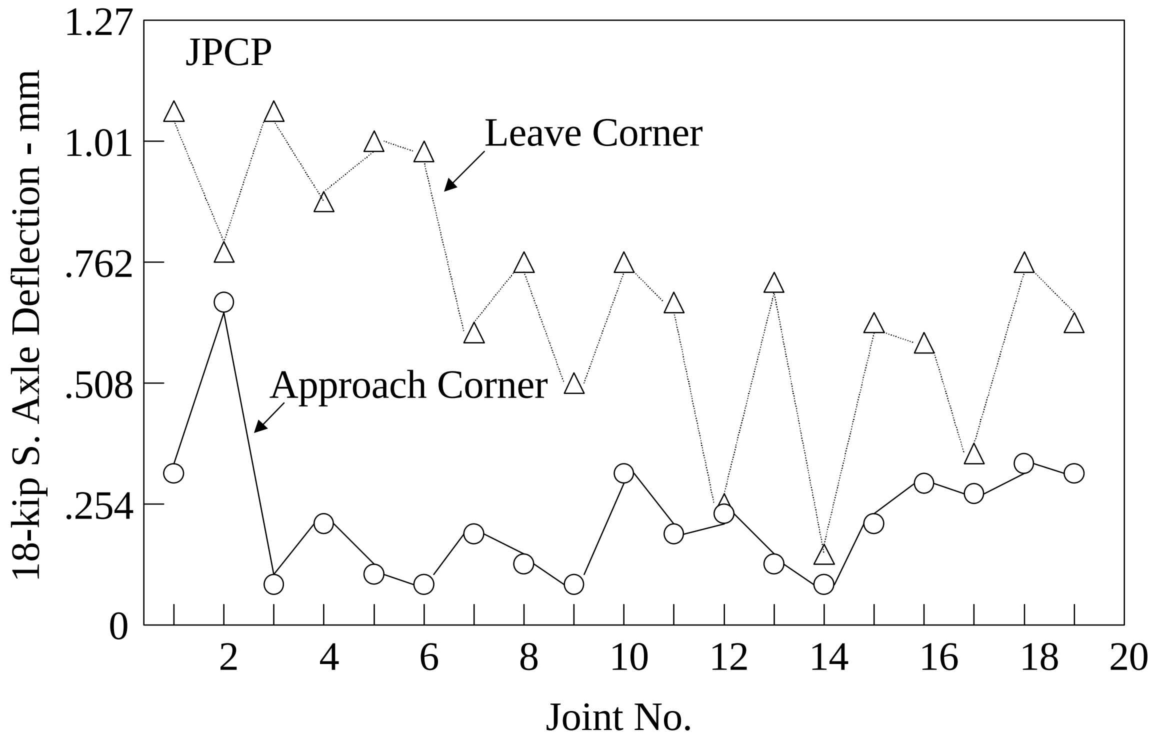


Figure 3-2.30. Corner slab deflection profile (outer lane)
for example problem 4 (FWD 9-kip [40 kN] impulse load).

> The entire project has adequate surface drainage. The bottom of the ditch line is approximately 4 ft (1.22 m) below the bottom of the subbase. Drainage flows to the east and the system appears to function properly because no ponding is observed. The soil moisture level is consistently near saturation at the surface, however.
>
> No longitudinal drains are currently installed anywhere on the project.

Figure 3-2.31. Description of drainage for example problem 4.

2. WORKSHOP 2—IDENTIFICATION OF FEASIBLE ALTERNATIVES

Results from Workshop 1

Figure 3-2.32 (handout) presents typical general evaluation results for this example problem. Group results should be compared with these before proceeding with workshop 2 activities.

Identification of Feasible 4R Alternatives

There are many alternative rehabilitation strategies that can be identified for a particular project. Each has specific advantages and disadvantages that vary with the specific design situation. Some alternatives may not be reliable or possible because of existing pavement conditions, constraints imposed on the design, and other factors.

A list of constraints within which the team must work must be assumed. If your group is not developing alternatives along the lines described on pp. 3-1.4, 3-1.5, and 3-1.6 (10 years, 20 years, and agency fix), consider the following constraints:

- A design analysis period of 20 years should be used to compare all alternatives.
- Traffic must be maintained on at least one lane at all times.
- A specified minimum clearance beneath bridges currently exists and must be maintained.

PROJECT DEFECTS OR DEFICIENCIES

- Cracked slabs must be repaired or replaced.
- The outer traffic lane is unacceptably rough due to faulting.
- Poor load transfer exists at the transverse joints.
- Joint seals are missing from most transverse joints, although little spalling has resulted.
- The lane-shoulder longitudinal joint is unsealed.
- Pumping is a problem throughout the project, as evidenced by the corner breaks, severe faulting, observation of fines and water being pumped onto the shoulder, and blowholes near the lane-shoulder joint. This is probably related to poor drainage of the base and subgrade materials and aggravated by missing transverse and lane-shoulder joint seals.
- Project subgrade soil appears to be near saturation most of the time.
- The shoulders are beginning to ravel and weather.

FACTORS THAT MAY CONSTRAIN THE REHABILITATION DESIGN

- All broken or cracked slabs must be repaired or replaced, regardless of the overall rehabilitation strategy.
- The repair of moisture-related damage (loss of support, faulting, corner breaks) will have to be addressed to prevent further pavement deterioration and to return the pavement to a serviceable condition. In particular, pavement roughness due to faulting must be reduced to produce acceptable ride quality.
- The prevention of future moisture-related damage must be addressed by reducing the entry of water through the pavement surface at the transverse reflection cracks and lane shoulder joint and/or by installing edge drains to remove moisture from the pavement system.
- Traffic must be maintained on at least one lane at all times.
- A specified minimum clearance beneath bridges currently exists and must be maintained. This will require special details for the use of overlays in these areas.
- Poor load transfer must be considered in any rehabilitation alternative to prevent pumping and reflection cracking.

RECOMMENDED ADDITIONAL SURVEYS, TESTS AND EVALUATIONS

- Some coring near the joints may be desirable to identify any pavement deterioration that might exist, particularly the cement-treated base.
- Materials testing of subgrade and subbase materials to determine drainage characteristics and provide input for design of a drainage system.
- Acquire maintenance records for additional insight into past performance problems.
- Locate water table to assist in drainage system design.

Figure 3-2.32. Typical evaluation results from workshop 1 for example problem 4.

3. WORKSHOP 3—SELECTION OF THE PREFERRED ALTERNATIVE

Identification of Feasible Rehabilitation Strategies

Rehabilitation strategies that repair and prevent the pavement distresses and deficiencies should have been developed by each group during workshop 2. Figure 3-2.33 presents some possible alternatives for this problem.

Detailed Design and Cost Estimate

Total costs for 4R projects include: initial rehabilitation construction, future maintenance and rehabilitation, user costs with rehabilitation, and highway modernization costs (e.g., shoulder paving, guardrail replacement, bridge repairs, drainage structure repair). Shoulder paving is the only non-pavement, structural item considered in this example. Other modernization and improvement costs are assumed to be identical for each alternative in this example and are, therefore, not considered.

Typical in-place unit costs for the project were obtained (and adjusted for inflation to the present year for construction) from previous agency bid tabulations and experienced contractors.

Due to the various design constraints (and the limited time available for this portion of the training course), use the alternatives developed as part of workshop 2. As an alternative, the options developed in figure 3-2.33 can be analyzed. Other alternatives are certainly feasible and should be considered in the development of an actual 4R project. Specific cross-sections for these rehabilitation designs and initial rehabilitation construction costs are given in figures 3-2.34 through 3-2.36.

Future maintenance and rehabilitation costs were estimated over the design analysis period for each alternative. These costs were based upon the following facts and assumptions:

- It was assumed that an asphalt concrete surface would require crack sealing every 5 years and that concrete surfaces would require joint resealing after 10 years.

- It was assumed that full-depth slab repair would be required for some alternatives after 10 years. The following repair estimates were used for the various alternatives:

  - Asphalt concrete (AC) overlay—5 percent of the area.
  - Restoration—10 percent of the area plus 4-in (10.2 cm) AC overlay.
  - Restoration/Reconstruction—5 percent of the inner lane area.

- The salvage values of all alternatives at the end of the design period were assumed to be approximately equal.

A summary of all costs is presented in table 3-2.17. The total cost is expressed as a present worth. Future costs were calculated using an interest rate of 8 percent and an inflation rate of 4 percent.

A complete economic analysis of 4R alternatives should include estimates of all related costs, including those that are difficult to quantify. Examples of some of those costs include user costs associated with maintaining a pavement section at a lower level of serviceability (vehicle operating costs) and the costs of delays due to lane closures. These costs are often very difficult to estimate, and are excluded from this example to keep it relatively simple and brief. However, it is recommended that such costs should be included in an actual 4R economic analysis.

RESURFACE WITH AC OVERLAY

- Preoverlay Repair: Full-depth slab repairs, localized cement grout subsealing, and installation of edge drains along outer shoulder.

- Asphalt Overlay: Membrane waterproofing of all joints and 4-in (10.2 cm) asphalt concrete (AC) overlay to last 10 years.

- Future Maintenance and Rehabilitation: Seal cracks every 5 years. Another 4-in (10.2 cm) AC overlay and preoverlay repair will be placed after 10 years.

CONCRETE PAVEMENT RESTORATION

- Restoration: Extensive full-depth slab repairs (10 percent of outer lane area), cement grout subsealing, diamond grinding of outer lane, reconstruction of portland cement concrete (PCC) shoulders, installation of edge drains, and resealing of all joints.

- Future Maintenance and Rehabilitation: Full-depth slab repairs, subsealing, and 4-in (10.2 cm) AC overlay at 10 years.

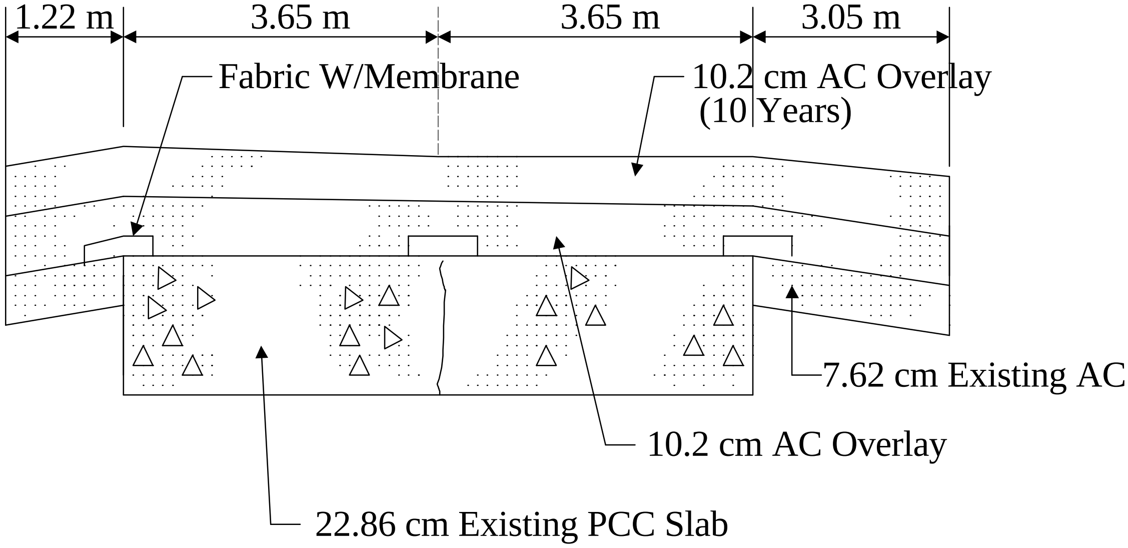
RESTORATION/RECONSTRUCTION

- Restoration (inner lane only): Minor full-depth slab repairs and resealing of joints with silicone sealant.

- Reconstruction (outer lane): Reconstruction of outer lane including recycling portland cement concrete (PCC) material, and sealing of joints with silicone sealant.

- Future Maintenance and Rehabilitation: Reseal joints and full-depth slab repair as needed after 10 years.

Figure 3-2.33. List of 4R alternatives to be considered in example problem 4.



Notes:

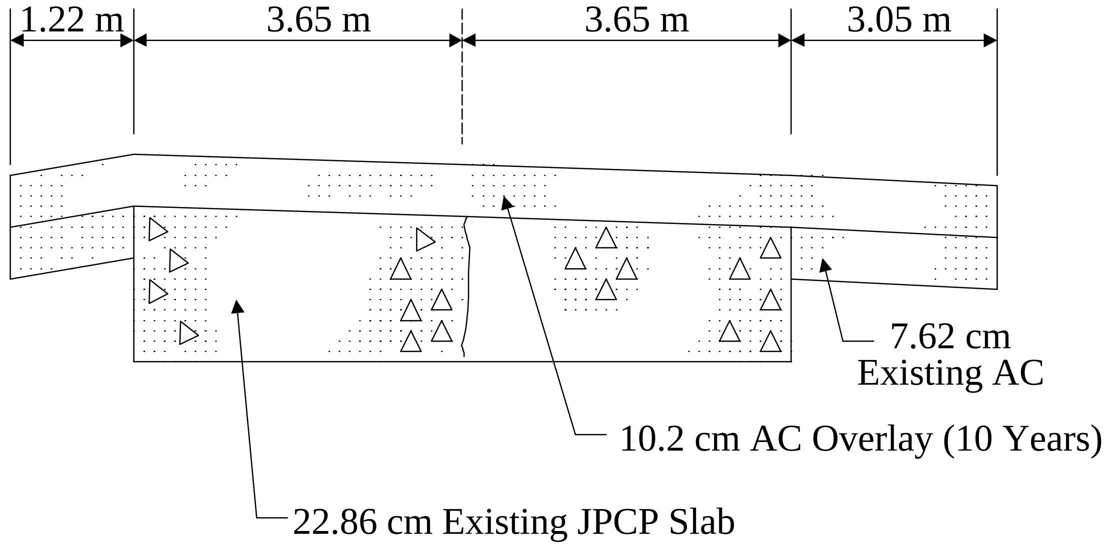
1. Preoverlay Repair: Full-depth slab repairs, localized cement grout subsealing, and installation of edge drains along outer shoulder.

2. Asphalt Overlay: Membrane waterproofing of all joints and 4-in (10.2 cm) AC overlay.

3. Future Maintenance and Rehabilitation: Seal cracks every 5 years. Place another 4-in (10.2 cm) AC overlay and preoverlay repair at 10 years.

4. Initial Construction Cost = $l,l35,000.

Figure 3-2.34. AC overlay resurfacing alternative for example problem 4.



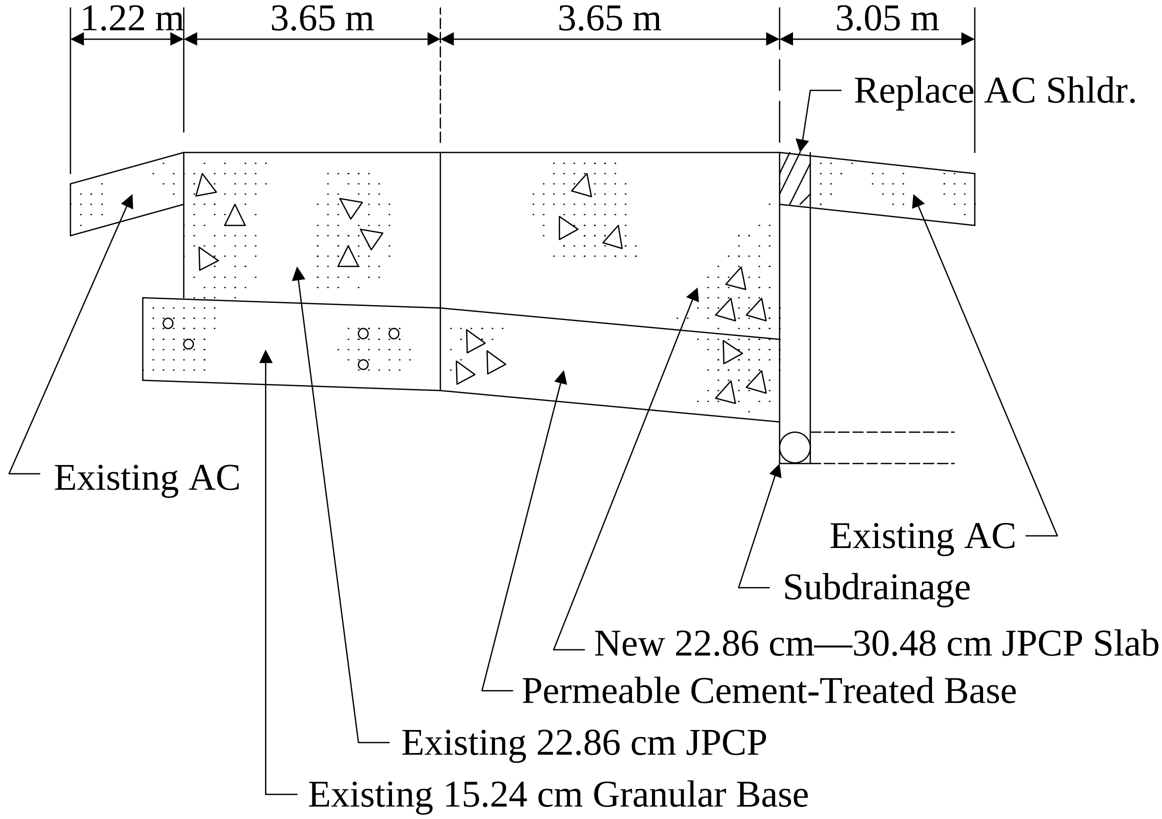
Notes:

1. Restoration: Extensive full-depth slab repairs (5 percent of outer lane area), cement grout subsealing, diamond grinding of outer lane, installation of edge drains, and resealing of all joints.

2. Future Maintenance and Rehabilitation: Repeat full-depth slab repairs, subsealing, diamond grinding, and joint sealing at 10 years (as required).

3. Initial Construction Cost = $635,000.

Figure 3-2.35. Complete concrete pavement restoration alternative for example problem 4.



Notes:

1. Restoration (inner lane only): Minor full-depth slab repairs and resealing of joints with silicone sealant.

2. Reconstruction (outer lane): Reconstruction of outer lane including recycling PCC material, taper from 9 to 12 in (22.86 to 30.48 cm) slab thickness, subdrainage, and sealing of joints with silicone sealant.

3. Future Maintenance and Rehabilitation: Reseal joints and full-depth slab repair as needed after 10 years.

4. Initial Construction Cost = $l,380,000.

Figure 3-2.36. Restoration/reconstruction alternative for example problem 4.

Table 3-2.17. Total cost summary for 4R alternatives for example problem 4.

COST ITEM	COSTS BY REHABILITATION		
	Structural ACOL	Restoration	Restoration/ Reconstruction
Pavement Construction	$837,000	$420,000	$1,000,000
Traffic Control	$150,000	$125,000	$200,000
Engineering	$148,000	$90,000	$180,000
Total Initial Construction Cost	$1,135,000	$635,000	$1,380,000
10-year M&R[1]	$365,000	$400,000	$100,000
Total Present Cost	$1,500,000	$1,035,000	$1,480,000

[1] Present worth cost.

EXAMPLE PROBLEM 5: CRCP

1. PROJECT BACKGROUND DATA

A summary of important background data is given in table 3-2.18. A cross-section of the existing pavement is given in figure 3-2.37. Traffic data for the pavement are summarized in tables 3-2.19 and 3-2.20 for the outside traffic lane and the inside traffic lane, respectively. The age of the pavement today is 7 years.

Project Survey and Evaluation

An extensive project survey and evaluation was conducted. The following summarizes the findings from those activities.

- Distress survey — Existing distress in the traffic lanes and shoulders in both directions was recorded. A summary of distress is provided in table 3-2.21.

- Structural survey — Nondestructive testing (NDT) and destructive testing were conducted. The NDT work was accomplished using a falling weight deflectometer (FWD). The destructive testing consisted of coring the pavement at various locations. Results are given in figure 3-2.38 and in tables 3-2.22 and 3-2.23.

- Drainage — This project is located in climatic zone IC, which means that it is continually wet and rarely subjected to freezing temperatures. The average annual precipitation in the area is 47 in (119.4 cm). The lean concrete base course is impermeable, except through cracks.

- Subgrade — Soil maps show that soils in the project area are well-drained to moderately well-drained, gently sloping to moderately steep, clayey and loamy soils. The subgrade drainability of these soils is rated average to marginal based on the Natural Drainage Index. There are also some sandy areas that have better drainage.

- Coring — The continuously reinforced concrete (CRC) slab and lean concrete base layers were cored and the condition of the material noted. Extensive deterioration of the lean concrete base was found near the lane-shoulder joint.

Table 3-2.18. Summary of background data for example problem 5.

ORIGINAL CONSTRUCTION DATA	
Facility	Rural Interstate, 10 mi (16 km) long
Original Construction	Continuously reinforced concrete pavement (see figure 3-2.44), 7 years old
Longitudinal Reinforcement	0.57% (No. 5 bars on 6-in [15.24 cm] centers)
Shoulders	Asphalt concrete
Subgrade	Predominantly clayey soils (AASHTO A-7)
REHABILITATION AND MAINTENANCE TO DATE	
Transverse Shoulder Drains	Year 4 ! Approximately 40 shoulder drains were installed.
Full-Depth Concrete Repair	Year 4 ! 2,033 yd^2 (1,700 m^2) of full-depth repairs were performed. These were primarily on the outside traffic lanes.
Lane-Shoulder Joints	Year 4 ! All lane-shoulder joints were sealed.

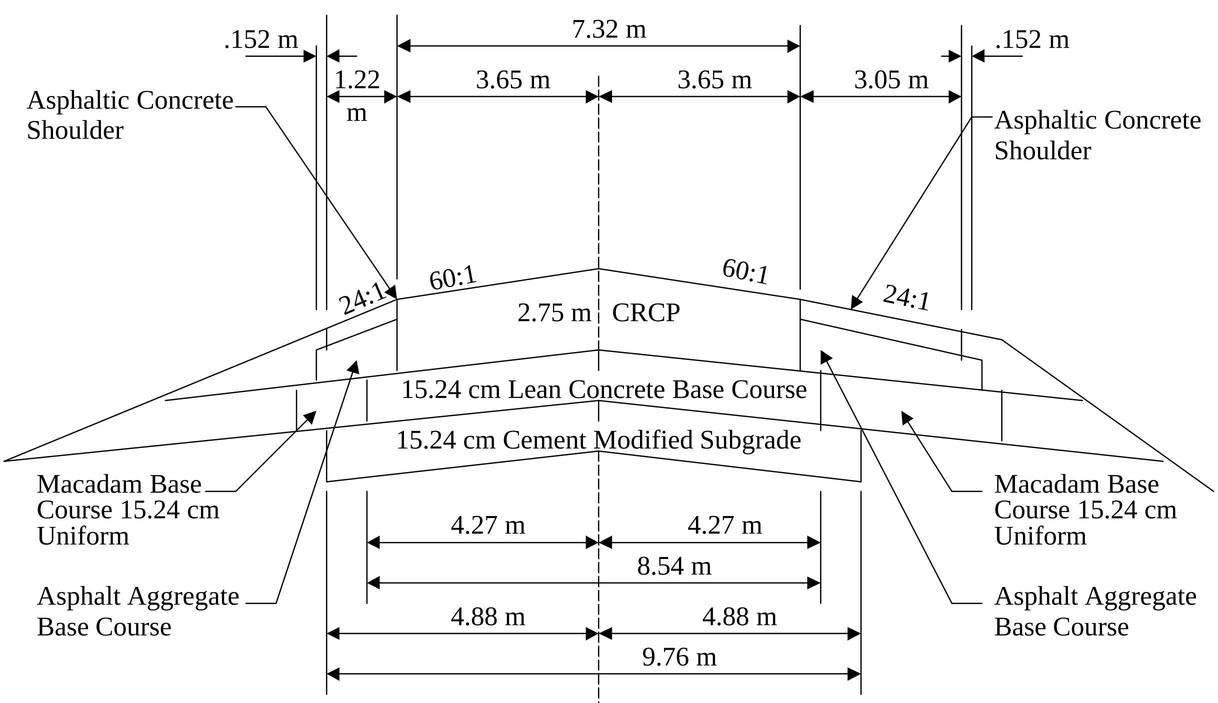


Figure 3-2.37. Typical cross-section for example problem 1.

Table 3-2.19. Traffic data for outside traffic lane of example problem 5.

Year	One-Way ADT	Percent Trucks	Lane Distri-bution Fac-tor	Truck Factor	18-kip ESALs	Cumulative ESALs	ESALs After Rehab
1	3,450	23	0.89	1.26	326,295	326,295	0
2	3,350	23	0.90	1.32	332,826	659,122	0
3	4,250	23	0.88	1.39	434,887	1,094,009	0
4	4,350	25	0.87	1.45	503,604	1,597,613	0
5	4,600	24	0.87	1.53	536,606	2,134,220	0
6	4,990	24	0.86	1.60	604,032	2,738,252	0
7	5,190	24	0.86	1.63	638,353	3,376,606	638,353
8	5,397	24	0.86	1.66	674,615	4,051,221	1,312,969
9	5,613	24	0.85	1.70	712,927	4,764,149	2,025,897
10	5,838	24	0.85	1.73	753,404	5,517,554	2,779,302
11	6,071	24	0.85	1.77	796,168	6,313,722	3,575,470
12	6,314	24	0.84	1.80	841,346	7,155,068	4,416,816
13	6,566	24	0.84	1.84	889,075	8,044,144	5,305,891
14	6,829	24	0.84	1.87	939,497	8,983,642	6,245,389
15	7,102	24	0.83	1.91	992,765	9,976,407	7,238,155
16	7,386	24	0.83	1.95	1,049,037	11,025,445	8,287,192
17	7,682	24	0.83	1.99	1,108,481	12,133,926	9,395,673
18	7,989	24	0.82	2.03	1,171,276	13,305,203	10,566,950
19	8,309	24	0.82	2.07	1,237,609	14,542,812	11,804,560
20	8,641	24	0.82	2.11	1,307,679	15,850,492	13,112,239
21	8,987	24	0.82	2.15	1,381,694	17,232,186	14,493,934
22	9,346	24	0.81	2.20	1,459,875	18,692,061	15,953,809

Table 3-2.20. Traffic data for inside traffic lane of example problem 5.

Year	One-Way ADT	Percent Trucks	Lane Dis-tribution Factor	Truck Factor	18-kip ESALs	Cumulative ESALs	ESALs After Rehab
1	3,450	23	0.11	1.26	38,635	38,635	0
2	3,350	23	0.10	1.32	38,400	77,035	0
3	4,250	23	0.12	1.39	61,048	138,082	0
4	4,350	25	0.13	1.45	71,955	210,037	0
5	4,600	24	0.13	1.53	79,922	289,960	0
6	4,990	24	0.14	1.60	95,366	385,326	0
7	5,190	24	0.14	1.63	103,568	488,894	103,568
8	5,397	24	0.14	1.66	112,415	601,309	215,982
9	5,613	24	0.15	1.70	121,954	723,263	337,937
10	5,838	24	0.15	1.73	132,238	855,501	470,175
11	6,071	24	0.15	1.77	143,322	998,823	613,497
12	6,314	24	0.16	1.80	155,265	1,154,088	768,762
13	6,566	24	0.16	1.84	168,130	1,322,218	936,891
14	6,829	24	0.16	1.87	181,985	1,504,203	1,118,876
15	7,102	24	0.17	1.91	196,904	1,707,107	1,315,780
16	7,386	24	0.17	1.95	212,964	1,914,071	1,528,744
17	7,682	24	0.17	1.99	230,249	2,144,320	1,758,994
18	7,989	24	0.18	2.03	248,849	2,393,169	2,007,843
19	8,309	24	0.18	2.07	268,860	2,662,029	2,276,702
20	8,641	24	0.18	2.11	290,383	2,952,412	2,567,086
21	8,987	24	0.18	2.15	313,531	3,265,943	2,880,616
22	9,346	24	0.19	2.20	338,419	3,604,362	3,219,035

Table 3-2.21. Summary of distresses for example problem 5.

DISTRESS TYPE	COMMENTS
Edge Punchouts	Punchout failures developed within 1 year of opening to traffic. The rate and extent of deterioration has increased to the point where some sections have over 100 failures per mile (62 per km). On the other hand, many portions of the pavement have little to no failures, including the entire inside traffic lane. No ruptured steel was observed at locations where punchouts had deteriorated to the point that the longitudinal steel could be seen. Pumping of base fines onto the shoulder was noted in many of the areas that were exhibiting punchouts.
Wide Transverse Cracks	Most of the wide transverse cracks ($\geq$ 0.05 in (.127 cm) are located in the outer lanes and have began to spall and open up at the outer edge of the outside traffic lane or the point of greatest deflection. The steel has not ruptured at these cracks. In the southbound lanes, approximately 2 percent of the wide cracks were located in the inner lane. In the northbound lanes, approximately seven percent of the wide cracks were located in the inner lane.
Deterioration Adjacent to a Patch	Deterioration adjacent to full-depth concrete repairs was noted at approximately 11 percent of the patch locations in the southbound lanes and 20 percent of the patch locations in the northbound lanes.
Pumping	Pumping on the shoulder was observed throughout the project. The pumping areas were located at transverse cracks of all severity levels.
Longitudinal Cracking	Longitudinal cracking was observed in very limited amounts throughout the project.
Transverse Crack Spacing	The average crack spacing was 5.1 ft (1.6 m). No correlation was found between the occurrence of distress and crack spacing.
Shoulder Condition	Shoulders are in fair to good condition, with little load-associated cracking. Pumping was observed at the lane/shoulder joint.

NONDESTRUCTIVE DEFLECTION TESTING

The entire project could not be tested because of the large number of tests that would have been required. Instead, 100-ft (30 m) sections that were representative of the conditions throughout the project were selected for NDT testing. Thirteen 100-ft (30 m) sections were tested in the outside traffic lane, and four 100-ft (30 m) sections were tested in the inside traffic lane. Within each section, every transverse crack was tested on the leave side of the crack. Three locations in the center of the lane were also tested. Deflection measurements were concentrated at the edge of the pavement because this is where deterioration and loss of support usually begins.

The modulus of subgrade reaction (k), the concrete elastic modulus (E), the load transfer efficiency, and the maximum deflection for each test section are shown in tables 3-2.22 and 3-2.23 for the outside traffic lane and the inside traffic lane, respectively. Modulus of subgrade reaction values, backcalculated from mid-slab surface deflection data, averaged 488 psi/in (132 KPa/mm) for the outside traffic lane and 550 psi/in (149 KPa/mm) for the inside traffic lane. Concrete modulus of elasticity, backcalculated assuming 9 in (22.86 cm) of concrete, averaged 3,600 ksi (25 GPa) for the outside traffic lane and 8,500 ksi (58 GPa) for the inside traffic lane.

Deflections at transverse cracks indicate load transfer crack efficiencies ranging from 9 to 100 percent. The severity of the surface distress correlates generally with load transfer efficiency.

Crack Severity	Mean Crack Efficiency
Low	92 percent
Medium	56 percent
High	46 percent

The average crack load transfer efficiency was 83 percent for the outside traffic lane and 98 percent for the inside traffic lane.

CORING

Cores were taken in many of the sections tested with the NDT. Information from the cores was used to verify layer thickness, longitudinal steel depth, and lean concrete base condition. Of the 25 cores that were taken, 23 were located on top of transverse cracks, and the remaining two were located in the center of the lanes. Most of the cores taken at transverse cracks were located 9 in (22.86 cm) from the CRC slab edge in an attempt to locate the second reinforcing bar and examine the condition of the lean concrete base near the pavement edge.

The thickness of the CRC slab ranged from 8.5 to 9.5 in (21.6 to 24.1 cm) and the thickness of the lean concrete base ranged from 4.0 to 7.25 in (10.2 to 18.4 cm). The depth of the longitudinal steel, as measured from the top of the slab, ranged from 2.5 to 5.5 in (6.4 to 14.0 cm).

Cores taken in the outside lane revealed that the top of the lean concrete base was eroded in most locations. However, little or no erosion had taken place at the top of the lean concrete base in the inside lane.

Figure 3-2.38. NDT and coring survey for example problem 5.

Table 3-2.22. Summary of NDT results for outside traffic lane for example problem 5.

Test Section	k, psi/in	Elastic Modulus, x 10^6 psi	% Load Transfer	Maximum Deflection, mils
1	821	3.6	88	6.9
2	481	2.3	82	12.0
3	597	2.0	61	12.0
4	682	5.0	77	5.8
5	707	5.9	88	5.4
6	208	2.8	89	17.8
7	275	2.0	87	15.2
8	363	3.4	78	10.3
9	491	6.8	87	7.9
10	528	3.5	80	8.9
11	233	2.6	72	18.0
12	355	3.8	98	9.7
13	603	3.1	88	8.8
Average	488	3.6	83	10.7

Table 3-2.23. Summary of NDT results for inside traffic lane for example problem 5.

Test Section	k, psi/in	Elastic Modulus, x 10^6 psi	% Load Transfer	Maximum Deflection, mils
14	606	7.9	98	5.2
15	840	9.3	96	3.9
16	401	8.2	99	6.6
17	353	8.6	99	7.1
Average	550	8.5	98	5.7

2. EXAMPLE PROBLEM 5—WORKSHOP 2

Results from Workshop 1

Figure 3-2.39 (handout) presents typical general evaluation results for this example problem. Group results should be compared with these before proceeding with workshop 2 activities.

Identification of Feasible 4R Alternatives

There are many alternative rehabilitation strategies that can be identified for a particular project. Each has specific advantages and disadvantages that vary with the specific design situation. Some alternatives may not be reliable or possible because of existing pavement conditions, constraints imposed on the design, and other factors. For instance, in this example problem, the erosion of the lean concrete base and the loss of support would preclude the construction of a bonded concrete overlay unless undersealing and substantial repairs were completed first.

A list of constraints within which the team must work must be assumed. If your group is not developing alternatives along the lines described on pp. 3-1.4, 3-1.5, and 3-1.6 (10 years, 20 years, and agency fix), consider the following constraints:

- A design analysis period of 15 years should be used to compare all alternatives.
- The minimum time between major 4R work should be at least 5 years.
- It is desirable to avoid rerouting traffic.
- A specified minimum clearance beneath bridges currently exists and must be maintained.

PROJECT DEFECTS OR DEFICIENCIES

- Failure to seal longitudinal lane-shoulder joints at initial construction has resulted in moisture between the CRC slab and the lean concrete base.
- The lack of subdrainage (bathtub design) along with a relatively weak lean concrete base and heavy truck traffic have caused subsequent deterioration of load transfer at transverse cracks.
- The extent of deterioration in the outside traffic lane is increasing at a substantial rate.
- A relatively low longitudinal reinforcement design content and a large depth to longitudinal reinforcement in the CRC slab has resulted in wide transverse cracks.
- Pumping at the lane-shoulder joint has resulted in loss of support and increased deflections.
- The outside traffic lane is unacceptably rough due to the large amount of failures.

FACTORS THAT MAY CONSTRAIN THE REHABILITATION DESIGN

- Moisture-related damage must be addressed by reducing the entry of water through the pavement surface at the transverse cracks and lane-shoulder joint and installing longitudinal subdrains to remove moisture from the pavement system.
- Poor load transfer must be considered in any rehabilitation alternative to prevent pumping and reflective cracking.
- All of the very wide transverse cracks should be repaired or replaced, regardless of the overall rehabilitation strategy.
- Traffic must be maintained on at least one lane at all times.
- Minimum time between major 4R work should be at least 5 years.
- A specified minimum clearance beneath bridges currently exists and must be maintained. This will require special considerations for the use of overlays in these areas.

RECOMMENDED ADDITIONAL SURVEYS, TESTS, AND EVALUATIONS

- Materials testing of subgrade and subbase materials to determine drainage characteristics and provide input for the design of a drainage system.
- Acquire maintenance records for additional insight into past performance problems.
- Coring and/or deflection testing near the centerline joints to determine the extent of pavement deterioration at these locations.

Figure 3-2.39. Typical evaluation results from workshop 1 for example problem 5.

3. EXAMPLE PROBLEM 5—WORKSHOP 3

Identification of Feasible Rehabilitation Strategies

Rehabilitation strategies that repair and prevent the pavement distresses and deficiencies should have been developed by each group during workshop 2. Figure 3-2.40 presents some possible alternatives for this example problem. Rehabilitation alternatives were not developed for the inside traffic lane because there is no indication that the inside lane will not continue to perform well for at least 15 years. However, some of the alternatives, such as the asphalt and concrete overlays, would need to be applied to both traffic lanes.

Detailed Design and Cost Estimate

Total costs for 4R projects include at least the following: initial rehabilitation construction, future maintenance and rehabilitation, user costs with rehabilitation, and highway modernization costs (e.g., guardrail replacement, bridge repairs, drainage structure repair). Other modernization and improvement costs are assumed to be the same for each alternative in this example and are, therefore, not considered.

Typical in-place unit costs for the project were obtained (and adjusted for inflation to the present year for construction) from previous agency bid tabulations and experienced contractors.

Due to the various design constraints (and the limited time available for this portion of the training course), use the alternatives developed as part of workshop 2. As an alternative, the options developed in figure 3-2.40 can be analyzed. Other alternatives are certainly feasible and should be considered in the development of an actual 4R project. Specific cross-sections for these rehabilitation designs and initial rehabilitation construction costs are given in figures 3-2.41 through 3-2.44.

Future maintenance and rehabilitation (M & R) costs were estimated over the 20-year design analysis period for each alternative. The following items were considered in estimating future M & R costs:

- Deterioration and rutting of the asphalt overlay surface will require either re-profiling or the addition of a thin wearing surface after 10 years.

- It was assumed that an asphalt surface would require crack sealing after 5 years and that a concrete surface would require resealing after 10 years.

- Surface repairs will be required in the future for all alternatives. The following future repair estimates (broken down by alternatives) were used:

  - Asphalt concrete (AC) overlay—10 percent of the area.
  - Portland cement concrete (PCC) overlay—2 percent of the area.
  - Full-depth repair—30 percent of the area.
  - Reconstruction—2 percent of the area.

- The salvage values for both overlay alternatives and for the reconstruction alternative are much higher than the salvage value for the full-depth repair alternative. Therefore, salvage values at the end of the analysis period must be included

.

A summary of initial construction costs and future maintenance and rehabilitation costs is given in table 3-2.24. The total cost is expressed as a present worth. Future costs were adjusted using an interest rate of 7 percent and an inflation rate of 3 percent. The results indicate that the full-depth repair and reconstruction alternatives have approximately the same total present cost, and that both overlay alternatives are significantly more costly. This is because the overlay alternatives must be applied to both traffic lanes, whereas the other alternatives only need to be applied to the outside traffic lane.

A complete economic analysis of 4R alternatives should include estimates of all related costs, including those that are difficult to quantify. Examples of some of those costs include user costs associated with maintaining a pavement section at a lower level of serviceability (vehicle operating costs) and the costs of delays due to lane closures. These costs are often very difficult to estimate, and are excluded from this example to keep it relatively simple and brief. However, it is recommended that such costs should be included in an actual 4R economic analysis.

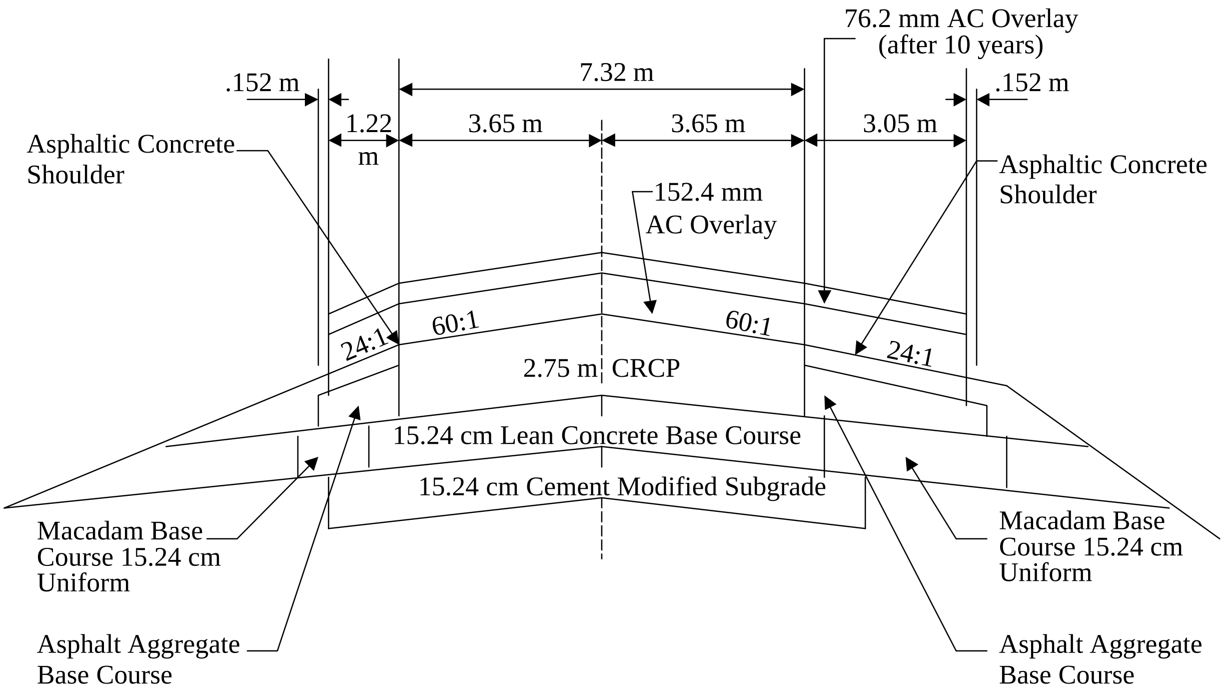
- **Resurface with asphalt concrete overlay.**
  - Preoverlay Repair: partial- and full-depth repair, localized cement grout undersealing, and installation of longitudinal subdrains.
  - Asphalt concrete overlay over existing CRC slab to last at least 10 years. Place additional overlays as needed over design analysis period.

- **Resurface with unbonded concrete overlay.**
  - Preoverlay Repair: some partial- and full-depth repair, localized cement grout undersealing, and installation of longitudinal subdrains.
  - Unbonded Plain Jointed Concrete Overlay: place unbonded plain jointed concrete overlay with asphalt concrete shoulders for 15 years of service.
  - Unbonded Continuously Reinforced Concrete Overlay: place unbonded CRCP overlay with tied PCC shoulders for 20 years of service

- **Full-Depth concrete repair.**
  - Cement grout subsealing.
  - Installation of longitudinal subdrains.
  - Patch the CRC slab with full-depth concrete repairs.

- **Reconstruction.**
  - Removal of the outside traffic lane only.
  - Placement of a non-reinforced jointed concrete pavement with dowel bars at all joints, an open-graded granular base course, and longitudinal subdrains, or reconstruct with a CRCP lane.

Figure 3-2.40. List of 4R alternatives for example problem 5.



Notes:

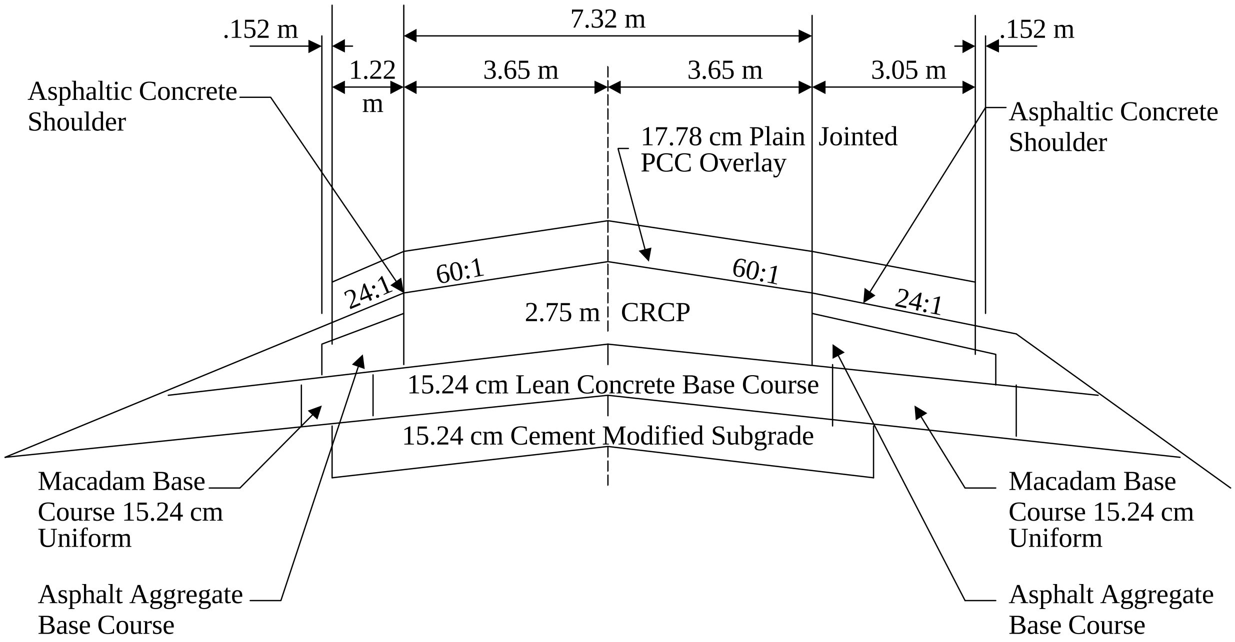
1. Preoverlay Repair: Patch all medium- and high-severity transverse cracks in CRC slab; underseal localized areas of pumping with cement grout; install longitudinal subdrains.

2. Place 6-in (15.24 cm) AC overlay with high friction surface over both traffic lanes and shoulders.

3. Place 3-in (7.62 cm) AC overlay at approximately 10 years.

4. Pavement initial construction cost = $3,200,000.

Figure 3-2.41. AC overlay resurfacing alternative for example problem 5.



Notes:

1. Preoverlay repair: Patch only seriously deteriorated areas.

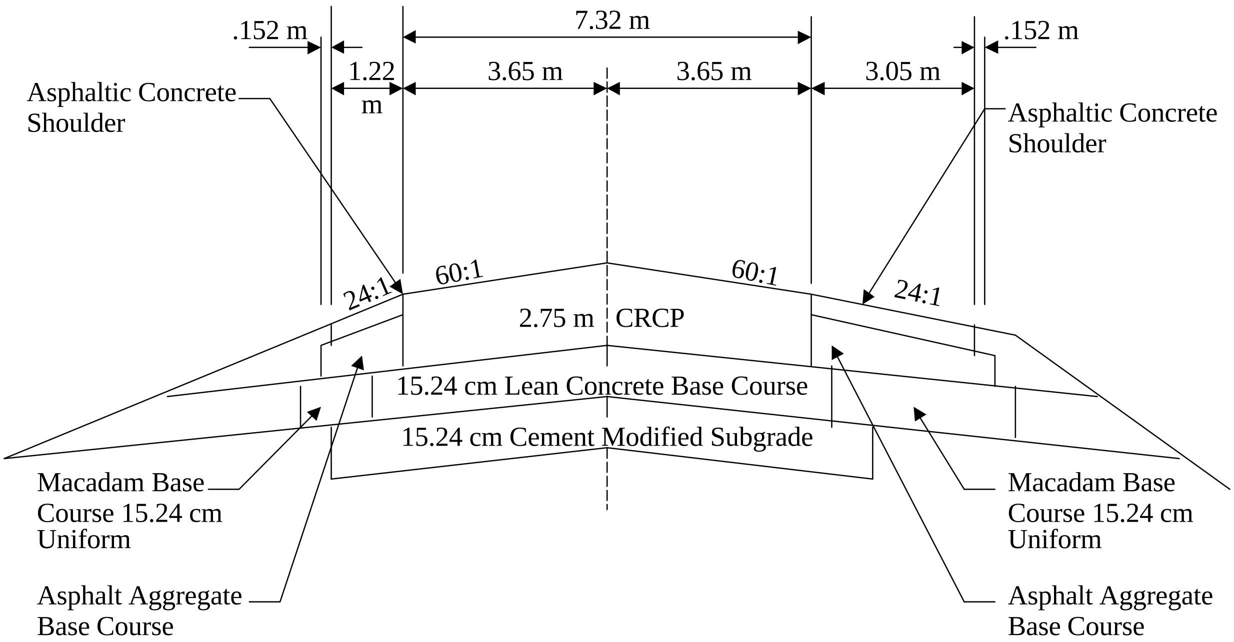
2. Place AC separation layer over entire surface.

3. Place 7-in (17.78 cm) plain jointed PCC overlay with 15-ft (4.6-m) joint spacing and dowel bars. Place mainline, then place AC shoulders.

4. Seal longitudinal joints with hot-poured sealant, and transverse joints with preformed sealant.

5. Pavement initial construction cost = $4,000,000.

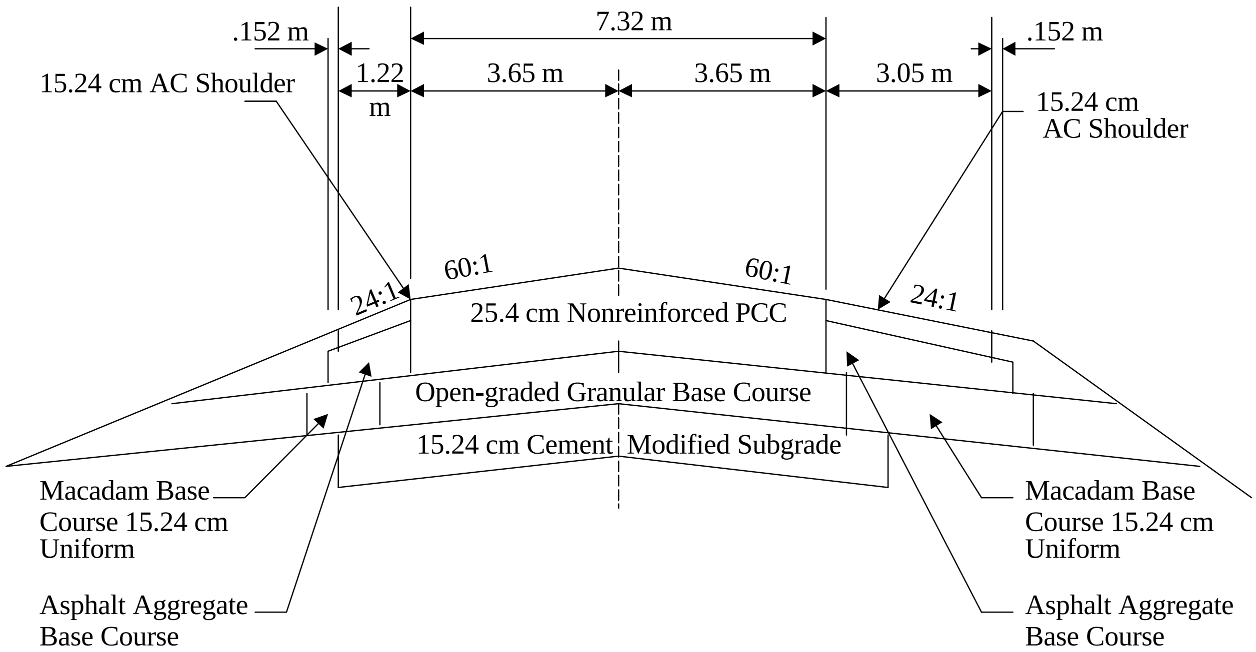
Figure 3-2.42. Unbonded concrete overlay alternative for example problem 5.



Notes:

1. Underseal with cement grout all areas in which pumping exists.
2. Install longitudinal subdrains throughout the length of the project.
3. Patch all deteriorated and failed sections with full-depth concrete repairs.
4. Continue patching deteriorated and failed sections at 2-year intervals.
5. Pavement initial construction cost = $1,200,000.

Figure 3-2.43. Full-depth repair alternative for example problem 5.



Notes:

1. Remove the existing CRC slab and the lean concrete base in the outside traffic lane only.
2. Place open-graded granular base course layer.
3. Place 10-in (25.4 cm) nonreinforced concrete pavement with 15-ft (4.6-m) joint spacing and dowel bars.
4. Install longitudinal subdrains.
5. Place 6-in (15.24 cm) AC shoulder.
6. Pavement initial construction cost = $2,800,000.

Figure 3-2.44. Reconstruction alternative for example problem 5.

Table 3-2.24. Total cost summary for 4R alternatives for example problem 5.

COST ITEM	COSTS BY REHABILITATION			
	Asphalt Overlay	Concrete Overlay	Full-Depth Repair	Reconstruction
Pavement Construction	$3,200,000	$4,000,000	$1,200,000	$2,800,000
Subdrainage	$700,000	$700,000	$700,000	$700,000
Traffic Control	$500,000	$500,000	$500,000	$500,000
Miscellaneous	$100,000	$100,000	$100,000	$100,000
Engineering	$300,000	$300,000	$150,000	$400,000
Total Initial Construction Cost	$4,800,000	$5,600,000	$2,650,000	$4,500,000
20-year M&R[1]	$800,000	$550,000	$1,500,000	$400,000
Salvage[1]	- $250,000	- $350,000	- $50,000	- $ 400,000
Total Present Cost	$5,350,000	$5,800,000	$4,100,000	$4,500,000

[1] Present worth cost.

EXAMPLE PROBLEM 6: FULL-DEPTH ASPHALT CONCRETE PAVEMENT

1. PROJECT BACKGROUND DATA

A summary of important background data is given in table 3-2.25. A cross-section of the existing pavement is given in figure 3-2.45. Traffic data for the pavement is summarized in table 3-2.26.

Project Survey and Evaluation

An extensive project survey and evaluation were conducted:

- Distress survey — Existing distress was recorded at year 15. The distress data indicate that the pavement could be divided into four 1-mi (1.6-km) long subprojects, each containing distinctly different types and levels of distress. Figure 3-2.46 shows a strip map of rutting, alligator cracking, and transverse crack spacing. Table 3-2.27 summarizes this data in four subprojects.

- Structural — Nondestructive deflection testing was performed using a Road Rater with an 8,000-lb (36 KN) peak-to-peak load at 15 Hz. The deflection results are given in figure 3-2.46, plotted along the project.

- Materials — The subbase material is a lime-stabilized silty clay with CBR values as shown in table 3-2.27. No material information is available for the asphalt concrete.

- Drainage — The project is located in climatic zone IA, which means it is continuously wet and subject to deep frost penetration.

Table 3-2.25. Summary of background data for example problem 6.

ORIGINAL CONSTRUCTION DATA	
Facility	Rural, two-lane State highway, 4.0 mi (6.4 km) long
Original Construction	Full-depth AC pavement on lime-stabilized soil (see figure 3-2.52)
Age Today	15 years
Subgrade	Predominantly silty clay (AASHTO A-6); the top 12 in (30.48 cm) is lime-treated

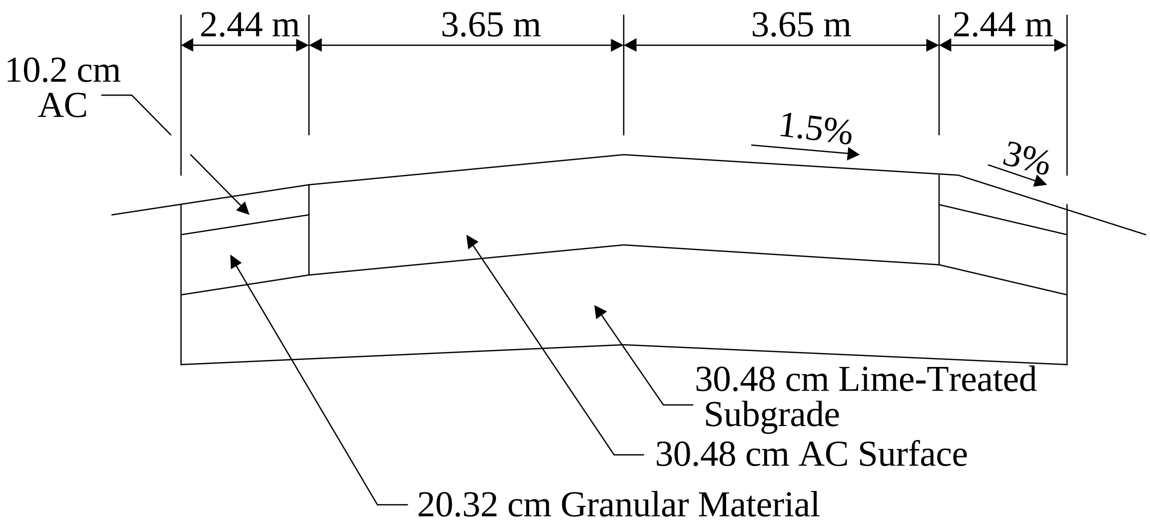


Figure 3-2.45. Typical cross-section for example problem 6.

Table 3-2.26. Summary of traffic data for example problem 6.

TIME PERIOD, YEARS		MEAN ONE-WAY ADT	18-KIP (80 KN) ESALs IN EACH LANE
PAST	0 to 15	9,000 (16 percent trucks)	5,450,000[1]
FUTURE	16 to 25	12,000 (19 percent trucks)	5,580,000
	26 to 35	16,000 (21 percent trucks)	8,220,000

[1] Data are for each period only and are not cumulative.

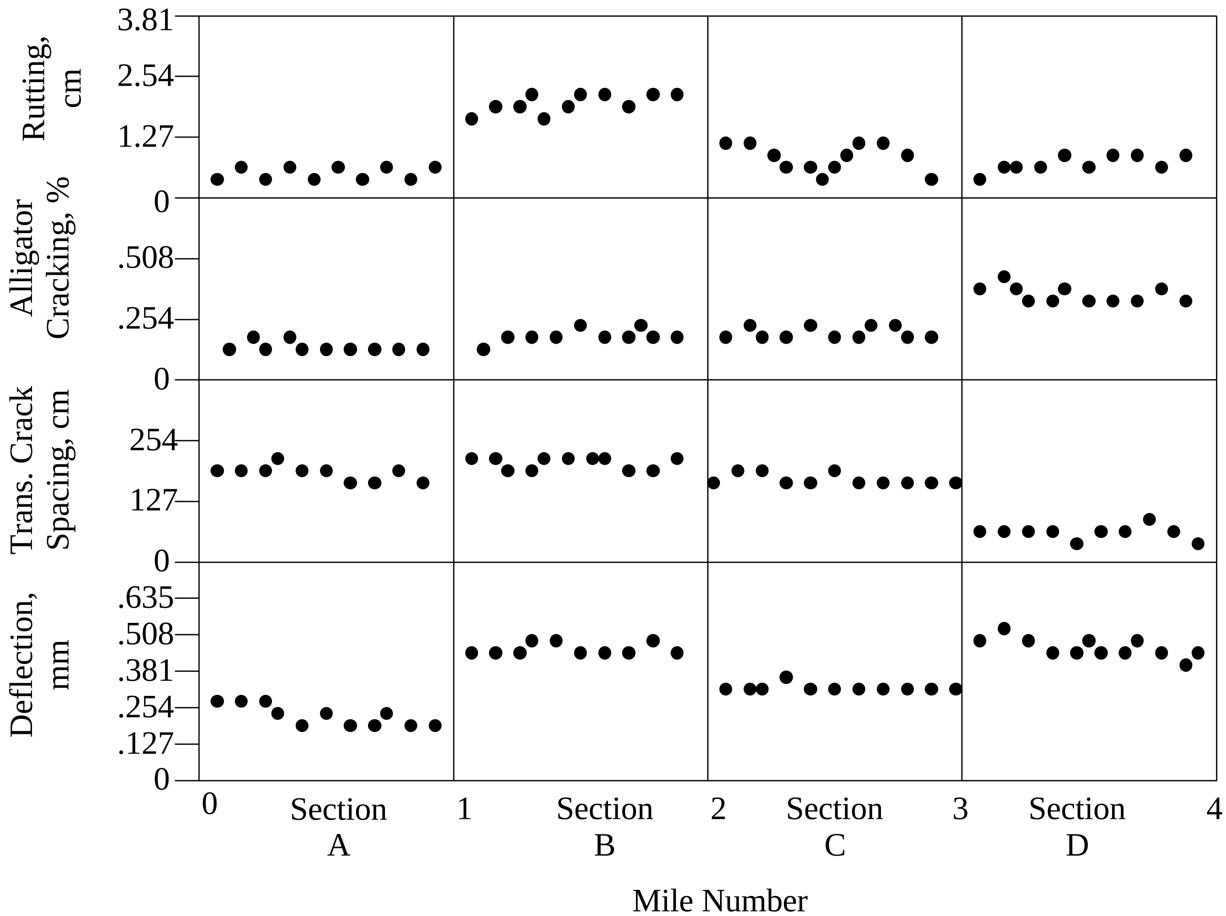


Figure 3-2.46. Strip map showing key distresses and slab deflections for example problem 6.

Table 3-2.27. Distribution of distress for example problem 6.

DISTRESS	**Subproject A**	**Subproject B**	**Subproject C**	**Subproject D**
Rutting, cm	0.71	1.88	0.76	0.66
Alligator Cracking, %	7	6	6	18
Transverse Crack Spacing, cm	157.5	231.1	162.6	88.9
Deflection, mm	.272	.495	.282	.475
Friction Values	18	17	20	31
CBR, top 12 in (30.48 cm)	82	78	85	18
CBR, below 12 in (30.48 cm)	8.2	7.8	7.9	7.4
AC Core Recovery, %	86	48	82	81

2. EXAMPLE PROBLEM 6—WORKSHOP 2

Results from Workshop 1

Figure 3-2.47 (handout) presents typical general evaluation results for this example. Group results should be compared with these before proceeding with workshop 2 activities.

Identification of Feasible 4R Alternatives

There are many alternative rehabilitation strategies that can be identified for a particular project. Each has specific advantages and disadvantages that vary with the specific design situation. Some alternatives may not be feasible because of existing pavement conditions, constraints imposed on the design, and other factors.

A list of constraints within which the team must work must be assumed. If your group is not developing alternatives along the lines described on pp. 3-1.4, 3-1.5, and 3-1.6 (10 years, 20 years, and agency fix), consider the following constraints:

- A design analysis period of 20 years should be used to develop all alternatives.
- Rerouting traffic must be on the local system, and will require strengthening of that system.
- The minimum time between major 4R work should be at least 8 years.
- A specified minimum clearance beneath bridges currently exists and must be maintained.

PROJECT DEFECTS OR DEFICIENCIES

- Excessive rutting in section B indicates the possibility of either material problems or excessive loading.
- Alligator cracking has become a serious problem in section D.
- Side ditches have become very shallow throughout the project. Water cannot drain out of the pavement section.
- Deflections are high in both section B and section D.
- Friction values are low in each of the sections, indicating possible bleeding or polishing.
- Low lime content in section D has resulted in poor support and increased transverse cracking.
- The transverse slope is not adequate and must be increased.

FACTORS THAT MAY CONSTRAIN THE REHABILITATION DESIGN

- Current and future traffic levels (including a significant number of heavy trucks) may dictate structural strengthening to reduce future rates of pavement deterioration.
- Maintaining traffic on the existing pavement during rehabilitation is not possible. Rerouting traffic on the local system will require strengthening of that system.
- Minimum time between major 4R work should be at least 10 years.

RECOMMENDED ADDITIONAL SURVEYS, TESTS AND EVALUATIONS

- Acquire maintenance records for additional insight into past performance problems.
- Conduct a survey to determine severity of transverse cracks and roughness data.
- Core and test the lime-stabilized layer in section D to determine cause of low CBR value.
- Determine asphalt concrete properties from extraction information.
- Further testing of the shoulder areas to determine their structural capability is needed. They may be needed to carry traffic during construction.

Figure 3-2.47. Typical evaluation results from workshop 1 example problem 6.

3. WORKSHOP 3—SELECTION OF THE PREFERRED ALTERNATIVE

Identification of Feasible Rehabilitation Strategies

Rehabilitation strategies that repair and prevent the pavement distresses and deficiencies should have been developed as part of the previous workshop. Figure 3-2.48 presents some possible alternatives for this problem.

Detailed Design and Cost Estimate

Total costs for 4R projects include: initial rehabilitation construction, future maintenance and rehabilitation, user costs with rehabilitation, and highway modernization costs (e.g., guardrail replacement, bridge repairs, drainage structure repair). Except where noted, modernization costs are assumed to be the same for each alternative in this example and are, therefore, not considered.

Typical unit in-place costs for the project were obtained (and adjusted for inflation to the present year for construction) from previous agency bid tabulations.

Due to the various design constraints (and the limited time available for this portion of the training course), use the alternatives developed as part of workshop 2. As an alternative, the options developed in figure 3-2.48 can be analyzed. Other alternatives are certainly feasible and should be considered in the development of an actual 4R project. Specific cross-sections for these rehabilitation designs and initial rehabilitation construction costs are given in figures 3-2.49 through 3-2.51.

Future maintenance and rehabilitation costs were estimated over the design analysis period for each alternative. These costs were based upon the following facts and assumptions:

- It is assumed that a single surface treatment would be applied to all alternatives 10 years after rehabilitation construction for preservation purposes.

- Full-depth asphalt concrete (AC) repairs will be required for all alternatives in the 20-year analysis period. The following repair estimates (percent of total area) are used for the various alternatives.

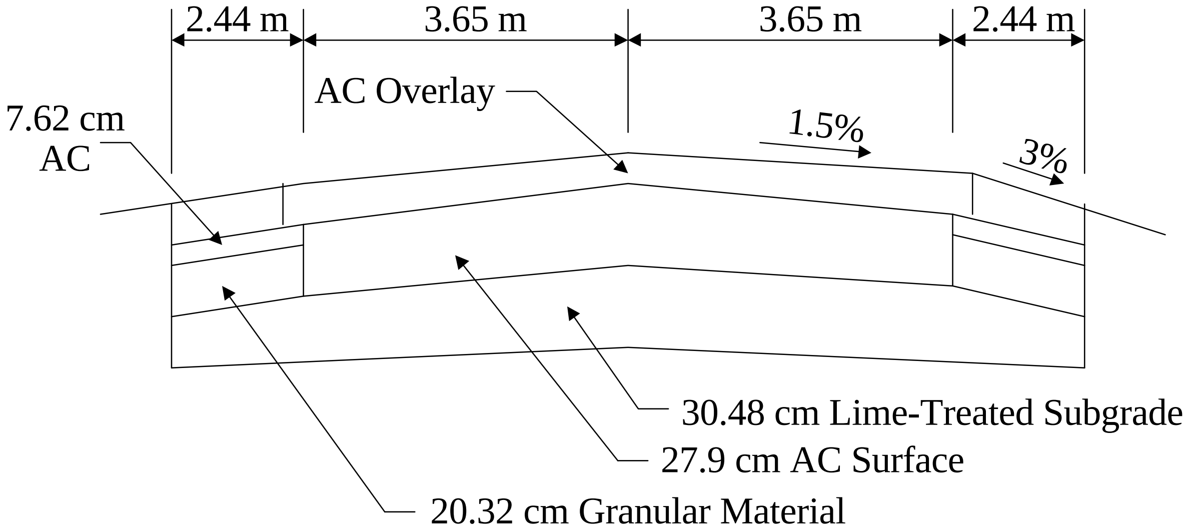
    - AC overlay—8 percent.
    - Recycle and overlay—6 percent.
    - Hot surface recycle with added AC—12 percent.

A summary of all costs is presented in table 3-2.28. The total cost is expressed as a present worth. Future costs were calculated using an interest rate of 6 percent and an inflation rate of 2 percent.

A complete economic analysis of 4R alternatives should include estimates of all related costs, including those that are difficult to quantify. Examples of some of those costs include user costs associated with maintaining a pavement section at a lower level of serviceability (vehicle operating costs) and the costs of delays due to lane closures. These costs are often very difficult to estimate, and are excluded from this example to keep it relatively simple and brief. However, it is recommended that such costs should be included in an actual 4R economic analysis.

- **AC overlay.**
  - Patch all transverse cracks.
  - Mill 1 in (2.54 cm) and place a 2-in (5.1-cm) AC overlay in sections A and C.
  - Mill 1 in (2.54 cm) and place a 6-in (15.24 cm) AC overlay in section B.
  - Mill 1 in (2.54 cm) and place a 4-in (10.2 cm) AC overlay in section D.
  - Clean ditches and increase cross slope.
- **Recycle and overlay.**
  - Remove and recycle existing AC in sections B and D.
  - Lime stabilization in upper 12 in (30.48 cm) of subgrade in section D.
  - Patch transverse cracks in sections A and C.
  - Overlay the entire project with 2 in (5.1 cm) of AC surface course.
  - Clean ditches and increase cross slope.
- **Hot surface recycle with added AC.**
  - Hot surface recycle top 2 in (5.1 cm) of sections A and C, and add virgin aggregate for increased skid resistance.
  - Add 6-in (15.24 cm) AC to section B.
  - Add 4-in (10.2 cm) AC to section D.
  - Clean ditches and increase cross slope.

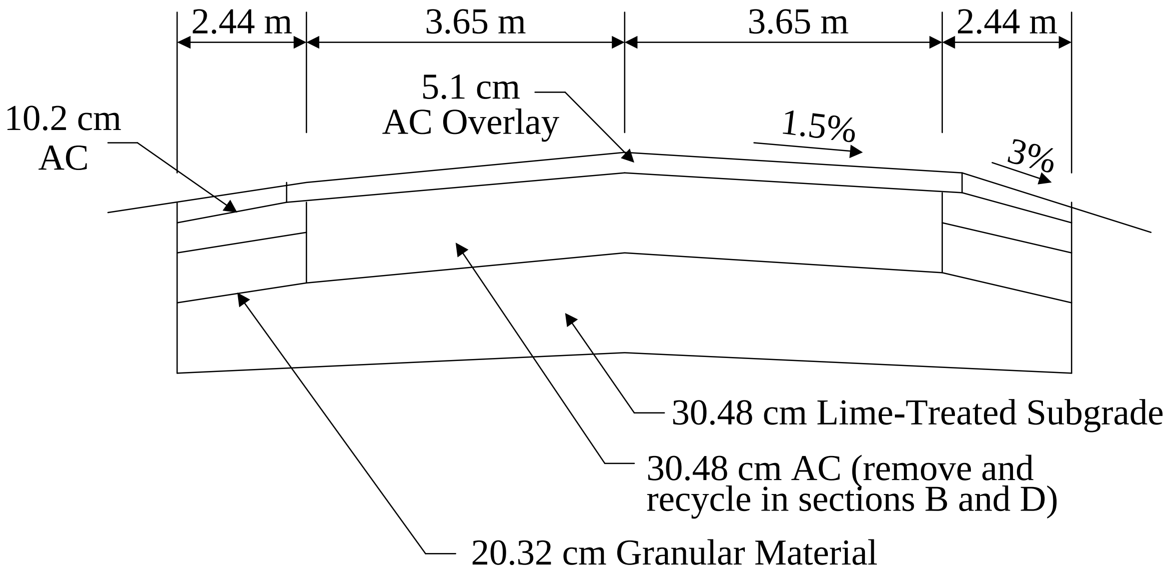
Figure 3-2.48. List of 4R alternatives for example problem 6.



Notes:

1. Patch all transverse cracks.
2. Mill 1 in (2.54 cm) and place a 2-in (5.1-cm) AC overlay in sections A and C.
3. Mill 1 in (2.54 cm) and place a 6-in (15.24-cm) AC overlay in section B.
4. Mill 1 in (2.54 cm) and place a 4-in (10.2 cm) AC overlay in section D.
5. Clean ditches and increase cross slope.
6. Pavement initial construction cost = $610,400.

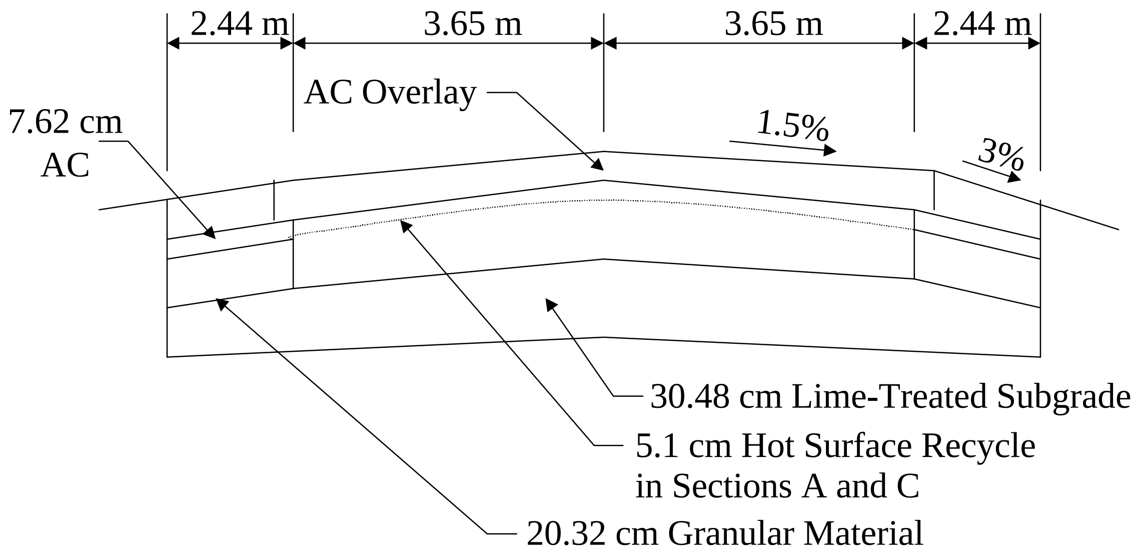
Figure 3-2.49. AC overlay alternative for example problem 6.



Notes:

1. Remove and recycle existing AC in sections B and D.
2. Lime stabilization in upper 12 in (30.48 cm) of subgrade in section D.
3. Patch transverse cracks in sections A and C.
4. Overlay the entire project with 2 in (5.1 cm) of AC surface course.
5. Clean ditches and increase cross slope.
6. Pavement initial construction cost = $463,600.

Figure 3-2.50. Recycle and overlay alternative for example problem 6.



Notes:

1. Hot surface recycle top 2 in (5.1 cm) of sections A and C, and add virgin aggregate for increased skid resistance.

2. Add 6 in (15.24 cm) AC to section B.

3. Add 4 in (10.2 cm) AC to section D.

4. Clean ditches and increase cross slope.

5. Pavement initial construction cost = $480,400.

Figure 3-2.51. Hot surface recycle with added AC alternative for example problem 6.

Table 3-2.28. Total cost summary for 4R alternatives for example problem 6.

COST ITEM	COSTS BY REHABILITATION AC Overlay	Recycle & Overlay	Hot Surface Recycle with Added AC
Pavement Construction	$610,400	$463,600	$480,400
Traffic Control	$60,000	$60,000	$60,000
Drainage Ditch Repair	$25,000	$25,000	$25,000
Engineering	$50,000	$50,000	$50,000
Total Initial Construction Cost	$745,400	$598,600	$615,400
20-year M&R[1]	$90,000	$80,000	$120,000
Total Present Cost	$835,400	$678,600	$735,400

[1] Present worth cost.

3.3 EXAMPLE PROBLEMS

The major themes of the example problems are to provide the instructor with an evaluation of student learning, customizing the course for local concerns, and serving as a break from the lecture/discussion format of the class. These problems are to be used at the beginning of each major time-block (i.e., morning/afternoon sessions). There are no notes with the attached visuals of the problems. The following strategies, however, can be used throughout the examples.

Evaluation of Student Learning

The key strategy here is to show the visual and discuss how it relates to items discussed previously. You will notice that several visuals are repeated throughout the examples. This is to provide the students with analyzing situations, noting that observation can have several different interpretations. The key is to be patient with the students. If there is silence, count to ten before asking individuals by name. Have the students discuss the answers amongst themselves for further evaluation of learning.

Customization

Once it is has been determined what the students have learned during the sessions, it is necessary to apply it to the local area. Key questions for this theme would be:

- How does this information apply to your current job?
- What recent situations required this information?
- How would you change a recent situation if you had this knowledge?
- Is the information relevant to you?

Asking these questions should prolong the discussion, and hopefully, the students should start teaching each other with potential resources within the sponsoring agency established for future discussion.

Mode of Instruction

The course uses lecture\discussion techniques for delivery of much of the course. Employing the example problems serves as a major break from this format as well as establishes the importance of interaction. Emphasizing the example problems will show that student input for the class is highly valued.

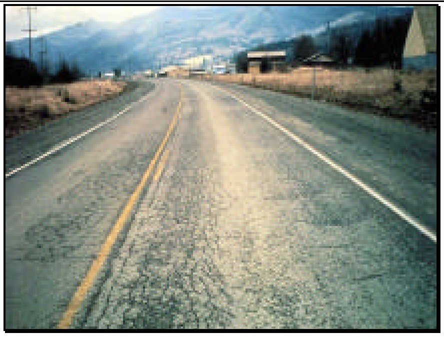
Example Review Problems

Number 1

Review of Material Covered

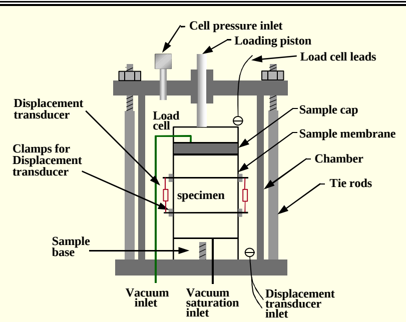
The following slides cover some aspect of the material covered over the previous half day.

Describe what distresses are shown on the slide and what may have caused those distresses



Review of Material Covered

Describe what is shown on the next set of slides and how it is used in pavement analysis



 ROADWAY	
	

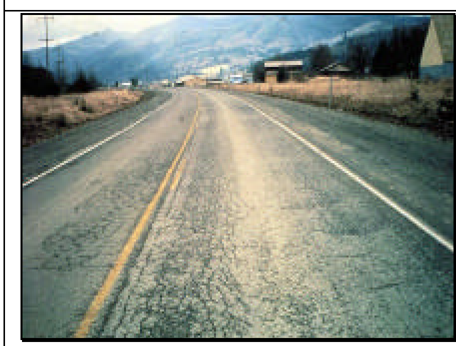
Example Review Problems

Number 2

Review of Material Covered

The following slides cover some aspect of the material covered over the previous half day.

Describe what specific problem is shown on each slide and how it should be sealed or patched

Example Review Problems

Number 3

Review of Material Covered

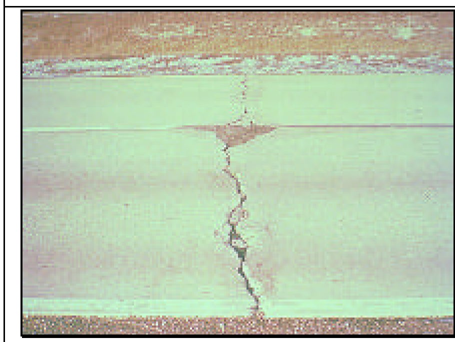
The following slides cover some aspect of the material covered over the previous half day.

Describe what specific process is shown on each slide and its attributes and limitations for your use.

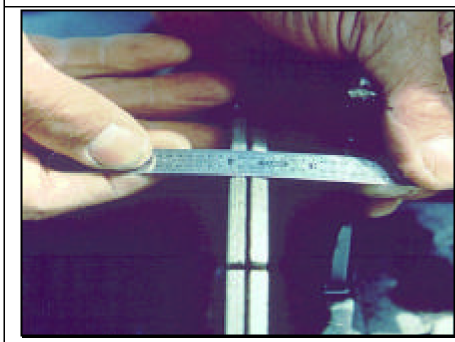
Example Review Problems ***Number 4***	
Review of Material Covered **The following slides cover some aspect of the material covered over the previous half day.** **Describe what specific PCCP distress is shown and treatments are appropriate.**	
	



Review of Material Covered

The following slides cover some aspect of the material covered over the previous half day.

Describe what specific process is shown on each slide and its attributes and limitations for your use.

Example Review Problems ***Number 5***	
Review of Material Covered **The following slides cover some aspect of the material covered over the previous half day.** **Describe what specific process is shown on each slide and its attributes and limitations for your use.**	
	

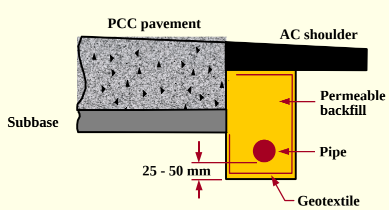
Example Review Problems

Number 6

Review of Material Covered

The following slides cover some aspect of the material covered over the previous half day.

Describe what specific process is shown on each slide and its attributes and limitations for your use.



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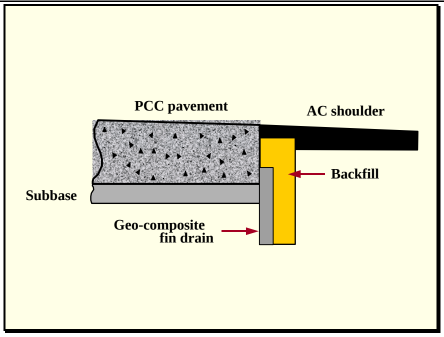
<tr><td>
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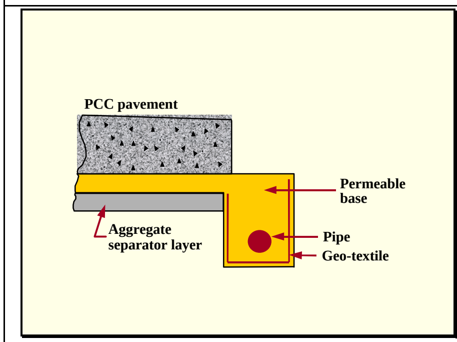
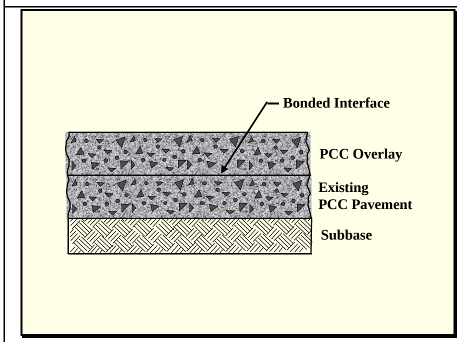
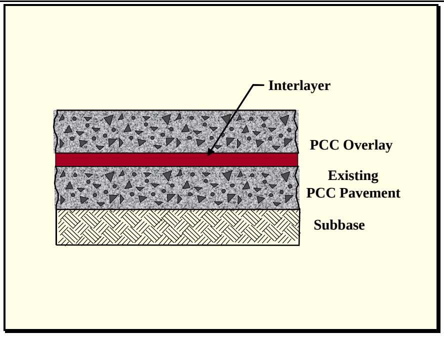
<tr><td>
</td><td></td></tr>
<tr><td>
</td><td></td></tr>
</table>


Interlayer
PCC Overlay
Existing
PCC Pavement
Subbase

ABOUT TEACHING

Over the years, a number of observations have been made about the successful presentation of a NHI course. While all of this information is undoubtedly familiar to the course instructors, it is repeated here.

1. Try to make frequent eye contact with course participants. Refrain from reading from notes, slides, or other visuals. Make points that add to the slide, not just recounting the information on the slide.

2. Admit what you don't know or what you're not exactly sure of. Maybe the other instructors or a participant might know. This would spark great interaction for the class.

3. Encourage classroom participation. Ask open ended questions to those who participate and those who seem "shy"; such as:

   - "What experiences have you had with this?"
   - "What are the barriers to making this happen?"
   - "What has to change in order for this to happen?"
   - "What can WE do to make this happen?"

4. Encourage participants to speak loudly. Involve the back of the room as much as the front of the room.

5. Encourage participants to follow along in their book. Since most of the presentation is visuals, participants can spend more of their time taking notes rather than redrawing what is already supplied to them in the manual.

6. Keep the classroom atmosphere informal so that the participants feel comfortable asking questions, participating, and sharing concerns.

7. Establish program ground rules: punctuality, interruptions, number of breaks, and other "housekeeping duties".

8. During exercises and activities be sure to clarify key points, guide problem solving, reinforce ideas on flipcharts and emphasize application & utilization of what they have learned. Always maintain and enhance self-esteem.

9. Participants' comments should always be addressed, expanded upon and summarized. If you're not sure of the correct answer one of the other instructors or participants might be able to help.

10. Be sure to guide and lead, not direct and control (unless needed).

11. Reward and thank everyone for his or her participation.

12. Use the participant's own experiences to help them solve problems, rather than telling them how it should be solved.

13. Keep the war stories short; don't let things get out of control or off track.

14. Discuss those things that they can make an effect on, don't let it become a gripe session.

15. Stick to the facts. Your personal opinions don't count here and will only get in the way.

16. Put yourself in the class' place. No one likes to sit for long periods; it's hard to stay awake, and even harder to pay attention. Do what you can to minimize this.

17. Remember to ask several students at the end of each day:

- ***What did you learn today?***
- ***How will you apply this in you job?***

LOCAL COORDINATOR CHECKLIST
for NHI Training Courses

TO: Local Coordinators

Training is an essential ingredient to the long-term success of just about every program. The training may be on-the-job, correspondence study, night school, etc. Regardless of what form the training may take there are certain expenses involved. There is usually a fee charged for presenting the course, plus the course sponsor has the additional expense of furnishing training facilities, projection equipment and some incidental items. Probably the greatest expense of all is the time course participants must take away from their regular jobs.

We have all attended training sessions where the instructor could not find the chalk, or the eraser, or the light switch when it came time to show the slides, or the room was too hot, or…,or…,or…. Since there are so many details to remember when preparing for the presenting a successful training course, we have compiled a few simple suggestions and reminders that will hopefully prevent some last minute scurrying around before the training starts, and may mean the difference between a good course and a great course.

We in the National Highway Institute (NHI) appreciate the behind-the-scenes effort Local Coordinators must provide assistance to assure the requested training matches their agencies' needs and that course participants maximize their learning experience. We realize that many times the responsibility for coordinating a course is taken on in addition to a regular full-time job. Our suggestions are offered in hopes of making the job of coordinating NHI courses easier and that the sponsors of NHI courses will get the maximum benefit from their training dollars.

Best of luck with your training programs.

SUGGESTED CHECKLIST

REQUEST FOR TRAINING

Has the COURSE REQUEST AND CONFIRMATION form (Form GHWA 1530) been completed and sent to the local FHWA division office? The FHWA division office is responsible for forwarding the form to the FHWA regional office and then to NHI.

Has NHI provided at least verbal approval of the requested dates?

TRAINING SITE

Selection of a training room is critical to the success of any course. Great care should be taken to selection a room that will not be overcrowded, hot/cold, or subject to outside distractions.

Has the instructor been contacted to determine specific requirements for the training facilities?

Have a training room been reserved?

Is the training room reserved for the duration of the course?
Will anyone else be using the room for nighttime functions?
Can all books and equipment be left in the room? Training courses requiring special equipment or computers must have after-hours security.

Have you personally visited the classroom to make certain it meets all requirements?

Other considerations for a training room:

Heat or air-conditioning - are controls accessible?
Adequate size and shape. No poles or obstructions.
Special arrangements for demonstrations, labs, and experiments.
Seating arrangements.
Away from kitchen, construction area or other noise distractions.
Electrical outlets.
Lighting controls - Almost every training course uses visual aids that require a projection screen. It is very important to have a room where lighting can be controlled to prevent glare on the screen while not placing the room in total darkness.

Will shades completely darken all windows?
Can the lights be selectively dimmed when showing slides or viewgraphs?
Will overhead lights shine directly on the screen?
Could a bulb be removed above the screen or will the blackboard be too dark?

PARTICIPANTS AND INSTRUCTORS

Has a block of hotel/motel rooms been reserved for the course participants and instructors? Some hotels will provide a free meeting room if a minimum number of participants stay at the hotel.

Have the participants and instructors been:
- Informed of course starting and ending times?
- Advised on hotel accommodations and room rates?
- Furnished with maps?
- Advised on parking arrangements?

EQUIPMENT NEEDS

Nothing is more frustrating to the instructor and annoying to the participants than a slide projector that will not advance, a VCR that will not play, a computer that is not connected properly, or a movie projector that starts spilling film all over the floor. Everything should be checked out thoroughly to make certain that it functions properly.

The instructor should be contacted to determine which of the following items of equipment will be needed:

- Slide projector with spare bulb and remote control extension
- Overhead projector with spare bulb
  - Blank transparencies
  - Marking pens in various colors
- Computers
- LCD projection equipment with cables
- Screen - 6' x 6' or larger
- Videotape player - VHS or Beta cassette
- Blackboard with chalk and eraser
- Whiteboard with dri-mark pens and eraser
- Easel with flip chart paper and various colored markers
- Pointer
- Lectern
- Public address system
- Extension cords
- Masking tape

Does all equipment work satisfactorily?

FINAL ARRANGEMENTS

<u>2 Weeks Before The Course</u>

- Has an approved copy of COURSE REQUEST AND CONFIRMATION (Form FHWA 1530) been received from NHI?
- Have training materials arrived?
- Have the boxes been opened and all items inventoried?
  - Participant notebooks

Tent Cards (Large felt tip markers will be needed.)
Evaluation forms
Class roster form
Certificates

Other Checks:

Reconfirm the training facilities.
Discuss the seating arrangements and who will set up the room.
Discuss what time the room is unlocked/locked.
Will a technician be available in case of problems setting up the room or if something goes wrong during the course?

<u>1 Week Before The Course</u>

- Direction signs to classroom
- Smoking policy
  - Experience has shown that the best policy is no smoking in the classroom.
  - Signs should be posted or written on the blackboard
- Water and glasses
- Refreshments
  - Morning and Afternoon
  - Donuts, fresh fruit, regular and decaffeinated coffee, tea, etc.
  - Who will pay?
- Telephones
  - For outgoing calls
  - For telephone messages
- Eating places for lunch
- Should a list of eating places and addresses be passed out? Map?
- Will someone welcome the participants and introduce the instructors?
- Check-out time from the hotel.
  - Can special check-out arrangements be made to coincide with the course completion time?
- Who will sign the certificates of training?
- Who will pass out the certificates at the end of the course?

<u>1 Day Before The Course</u>

- Set up classroom
- Organize the participant material
- Post direction signs
- Test all equipment

<u>During The Course</u>

Let the instructor know where you will be or how you can be reached at all times during the course in case he/she needs assistance.

Provide a copy of the Class Roster to all course participants.

Prepare Certificates of Training. The time needed to prepare the Certificates of Training may be reduced and the appearance improved by using a computer with a graphics program and a laser printer.

After The Course

Make certain the instructor has the Class Roster, Course Evaluation forms, and Application for CEU's forms. The instructor is responsible for sending these items to NHI.

MULTIMEDIA MODULES

5.1 INSTALLATION

Before you install the tutorial, please check the following list to determine if your hardware can run the Multimedia Modules.

Minimum System Requirement

- Windows 95 Operating System
- 16 megs (MB) of ram
- Pentium processor
- 14” monitor
- printer
- CD-ROM drive

If your hardware meets these requirements, you can safely install the software.

Software Installation

The software is a “runtime” version of the program. This means that the program was created with a rather large (200 MB) software program and condensed so that all is needed is the actual tutorial program and some runtime files. To install the program onto your computer, follow these easy steps:

1. Place the CD-ROM in your CD-ROM drive.
2. Open Microsoft Windows Explorer
3. Select your CD-ROM drive.
4. Highlight the “RehabMM” folder.
5. Use the Edit pulldown menu and choose “copy”.
6. Select your hard drive (usually C:).
7. Use the Edit pulldown menu and choose “paste”

5.2 USER INSTRUCTIONS

These modules are designed to supplement the "Techniques for Pavement Rehabilitation" training course. With questions, content screens, and menus, the program is an interactive tool designed to give the user an overview of several of the course modules. These can run at the convenience and preferred pace of the user.

Starting the Program

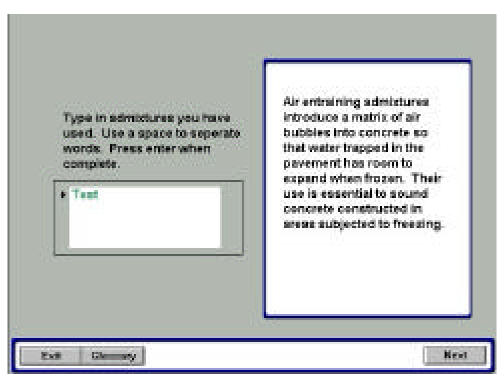
- Open the directory where the files have been stored during installation.
- Click on the "TFPR.EXE" program.
- Follow the instructions on the screen.
- Have fun!!!

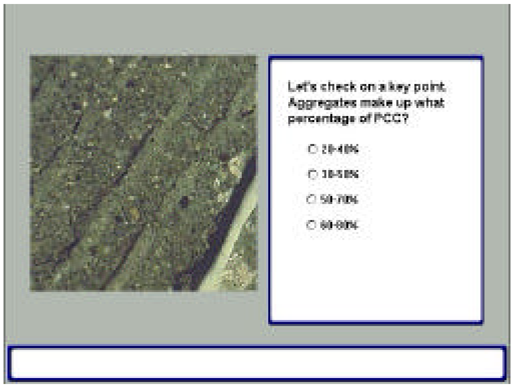
Program Interface

The program interface is simple to use. Areas have been designed for consistent use. For example, content and graphics will always appear in the middle of the screen. The user can navigate through the program using the buttons at the bottom. These allow the user to exit, use the glossary, and continue. Users will also receive feedback on their answers in the lower left hand corner. Moving through the program is just a simple click!!!

Questions

During the program, you will be asked to input a variety of information. Most will have buttons to click, but some will ask for keyboard information. This will include your name, occupation, and other bits of information. When entering your name, please limit it to five characters. This information will be very helpful to us in developing new programs and updating the course.





As you go through the program, your answers to the questions will determine if you can continue. If you give the correct answer, you will receive the appropriate feedback and move forward. If you answer incorrectly, you will be given some remediation in order to answer the question correctly. Your scores for each module will be kept and displayed for you at the end of each module.

Ending the Program

You will be able to end the program at any time. By pressing exit, you will go to the main menu. From there, you will be able to exit. When you return to the program, you will be asked to log on. You will then go to the main menu. It is suggested that you finish a module before starting a new one. The modules take ten minutes on average to complete. If you quit in the middle of a module, the program will restart the module from the beginning.

Please remember the program is a supplement to the course. It is intended to present selected concepts. It will not replace the course.