NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 160

COLD-RECYCLED BITUMINOUS CONCRETE USING BITUMINOUS MATERIALS

TRANSPORTATION RESEARCH BOARD
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JON A. EPPS
University of Nevada-Reno
Reno, Nevada

Topic Panel

DALE D. ALLEN, *Oregon Department of Transportation*
TOMMY L. BEATTY, *Federal Highway Administration*
JOHN J. CARROLL, *Federal Highway Administration*
WILLIAM G. GUNDERMAN, *Transportation Research Board*
G.P. JAYAPRAKASH, *Transportation Research Board*
PRITHVI S. KANDHAL, *National Center for Asphalt Technology*
PETE F. PRADERE, *Nevada Department of Transportation*
JAMES H. STOKES, *New Mexico State Highway and Transportation Department*
KEVIN STUART, *Federal Highway Administration*

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NATIONAL RESEARCH COUNCIL
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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to pavement designers, construction engineers, and others interested in economical methods for reconstructing or rehabilitating bituminous pavements. Information is provided on the processes and procedures used by a number of states to recycle asphalt pavements in place without application of heat.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

Since 1975 a growing number of state highway agencies have reconstructed or rehabilitated asphalt pavements by recycling the old pavement in place. This report of the Transportation Research Board describes the processes used for cold in-place recycling, including construction procedures, mix designs, mixture properties, performance, and specifications.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

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Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

COLD-RECYCLED BITUMINOUS CONCRETE USING BITUMINOUS MATERIALS

SUMMARY

Recycling of existing asphalt pavements offers reduced costs, preservation of geometrics, conservation of aggregates and binders, and energy conservation. Although recycling existed as early as 1915, most asphalt recycling has taken place since 1975. Asphalt concrete recycling falls into three general types: surface, cold, and hot. This synthesis is limited to cold in-place recycling with bituminous binders.

Cold in-place recycling benefits include structural improvements without changes in roadway geometry, treatment of all types of pavement distress, elimination of reflection cracking, improvement of ride quality, minimal hauling costs, high production rates, low engineering costs, conservation of aggregates and energy, minimal environmental problems, and cost-effectiveness. Problem areas include greater construction variation than central-plant recycling, curing needed for strength gain, strength gain and construction susceptible to climatic conditions, greater traffic disruption, and need for a wearing surface. Cold in-place recycling has been used primarily on highways with medium and low traffic volumes. It has been used in at least 24 states, including several that have constructed numerous projects.

Construction of cold in-place recycling consists of pavement sizing, addition of new aggregate, addition of new asphalt or recycling agent, mixing, laydown, aeration, compaction, curing, and application of wearing surface. Some of these operations may be combined and others may not be used on some projects. The exact equipment and methods used depend on the agency's specifications, the contractor's experience, and whether the recycling is full- or partial-depth.

Most agencies analyze the recycled pavement for asphalt content and aggregate gradation. New aggregate is added to the mix to provide additional thickness, to correct gradation, or to allow for acceptance of new binder. New binder is usually a slow- or medium-setting asphalt emulsion, although some agencies use a high-float emulsion.

Several state agencies and other organizations have developed mix design procedures for cold in-place recycling of asphalt pavements. A standard national method is not available, but certain basic steps are normally included in the mix design process. These include obtaining samples from the field; processing of samples; evaluation of samples for asphalt content, asphalt physical properties, aggregate gradation, and recycled pavement gradation; selection of amount and type of new aggregate; estimation of asphalt demand; selection of type and amount of recycling agent; testing of trial mixture; establishment of job mix formula; and adjustment in the field.

Few thickness design guides have been published specifically for cold in-place recycling. Most agencies assume that the structural capacity of the recycled material is

equal to that of conventional materials; they replace conventional material with an equal thickness of recycled material without a formal structural design.

Comprehensive national data on performance of cold in-place recycling are not available. Although reports on performance are in the literature, they do not use a common method of defining performance nor do they provide an equal amount of project detail. The general performance data reported by states that have constructed a number of projects indicate that performance has been mostly good or very good, particularly with respect to cracking.

Economic evaluation of pavement rehabilitation strategies should consider initial and recurring costs to the agency (initial capital cost, future capital costs for reconstruction or rehabilitation, maintenance costs, salvage value, engineering) and to users (travel time, vehicle operation, accidents, discomfort, delay during maintenance or rehabilitation). Detailed performance histories and thus life-cycle costs are not available for cold in-place recycling. However, preliminary information indicates that there will be significant life-cycle cost savings compared with conventional overlay techniques. The main savings is in material costs and particularly in the cost of asphalt binder.

Specifications for cold-mix recycling have evolved from soil stabilization and from other cold-mix specifications. Because there is a lack of performance data, users should remain flexible and allow for as many alternatives as possible in order to produce the desired product at the least cost. Currently, the experience and knowledge of the user agency as well as local contractors, equipment manufacturers, and materials suppliers must be relied on to set the standards for cold-recycling operations.

Cold in-place recycling is a viable engineering and economic rehabilitation alternative for asphalt-surfaced pavements with moderate to low traffic volumes. It can be used to strengthen a roadway with minimal change in the vertical cross section. Physical properties of cold in-place recycled materials are typically between those of an asphalt concrete mixture and a cold, asphalt-stabilized base material. Because properties vary from project to project, laboratory tests should be used to establish strength coefficients. Surfacing materials should be placed on all cold in-place recycled projects.

Research is needed to better define structural coefficients, life-cycle costs, field density control techniques, laboratory mixture design techniques, equipment that offers better control of gradation, effects of different diluents in recycling agents, and use of cold-recycled bituminous materials as a base on high-volume highways.

CHAPTER ONE

INTRODUCTION

BACKGROUND

Recycling or reuse of existing pavement materials for pavement rehabilitation, reconstruction, and maintenance is not a new concept; literature indicates that pavement recycling existed as early as 1915 (*1*). However, the quantity of pavement materials recycled from 1915 to 1975 is small in comparison to the amount of recycling that has taken place since 1975.

The engineering community's interest in recycling starting in 1975 was largely based on economics, with some interest in energy conservation. During the mid and late 1970s in the United States there were problems related to (a) reduced funding for transportation facilities, (b) materials supply, (c) equipment availability, (d) trained manpower availability, and (e) energy awareness and availability. Recycling of existing pavement materials for construction, rehabilitation, and maintenance purposes offered a partial solution to these problems. Specifically, recycling offered the following major potential benefits compared with conventional techniques:

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

Because recycling appeared promising from a wide variety of viewpoints, a number of agencies, including the National Cooperative Highway Research Program (NCHRP) (*2, 3*), Federal Highway Administration (FHWA) (*4–10*), Corps of Engineers (for the Air Force) (*11*), and U.S. Navy (*12*), sponsored recycling research and implementation studies. Associations and institutes also contributed to the development of recycling in the United States. These groups include The Asphalt Institute (*13*), National Asphalt Pavement Association (NAPA) (*14, 15*), Portland Cement Association (PCA) (*16*), Pacific Coast User-Producer Group on Asphalt Specifications (*17*), American Society for Testing and Materials (*18*), American Concrete Pavement Association (ACPA), Asphalt Emulsion Manufacturers Association (AEMA), and the Asphalt Recycling and Reclaiming Association (ARRA). Major research and implementation efforts were conducted by various state departments of transportation.

Early research, development, and implementation efforts led to the categorization of four types of pavement recycling:

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

These forms of recycling are addressed in a comprehensive manner in several publications (*2, 3, 10, 19–23*).

Cold recycling may be performed in-place or at a central plant (*24, 25*). The scope of this synthesis is limited to cold in-place recycling (CIR) with bituminous binders. Cold recycling at a central plant and cold in-place recycling with other than bituminous binders are not discussed.

COLD RECYCLING

Cold recycling is a process that consists of combining without heat a processed salvaged material, a stabilizing agent, and perhaps new aggregate. The material produced is expected to meet the specifications for its end use.

Cold-recycled materials have been used for subbases, bases, and surfaces. The most common use to date has been for base courses. Although stabilization with bituminous materials is the most popular process, literature indicates that lime (*26*), portland cement (*16, 27–29*), and calcium chloride (*30*) have been used. Guidelines for selecting the appropriate stabilizer type are contained in Reference *31*. Flow charts of the basic construction operations for cold in-place recycling are shown in Figures 1 and 2.

COLD IN-PLACE RECYCLING

Two forms of cold in-place recycling with bituminous binders have evolved in the United States: full-depth and partial-depth. Full-depth (reclamation/stabilization) cold in-place recycling is a rehabilitation technique in which the full flexible pavement structure and predetermined portions of the base material are uniformly crushed, pulverized, and mixed with a bituminous binder, resulting in a stabilized base course. Additional aggregate may be transported to the site and incorporated in the processing. This process is normally performed to a depth of 4 to 12 in.

Partial-depth cold in-place recycling is a rehabilitation technique that reuses a portion of the existing asphalt-bound materials. Normal recycling depths are 2 to 4 in. The resulting bituminous-bound recycled material is often used as a base course but can be used as a surface course on low-to-medium-traffic-volume highways. When this form of cold in-place recycling is performed on an old uniform pavement, a uniform, higher-quality end product is expected.

The use of full-depth cold in-place recycling with bituminous binders probably dates to the 1910s, although available references indicate 1966 (*32, 33*). States with extensive experience with full-depth cold in-place recycling include California, Indi-

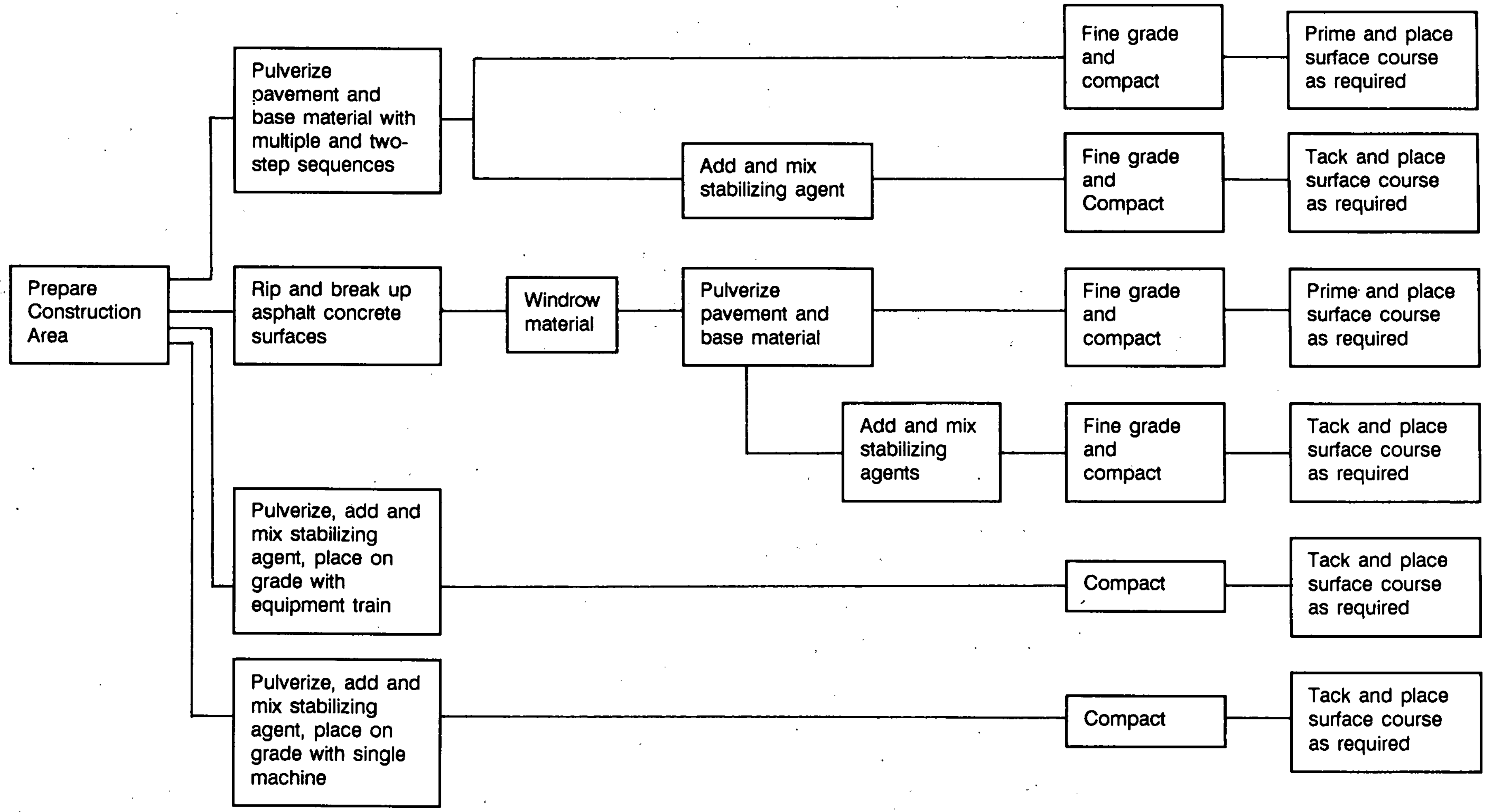


FIGURE 1 Full-depth cold in-place recycling (after *22*).

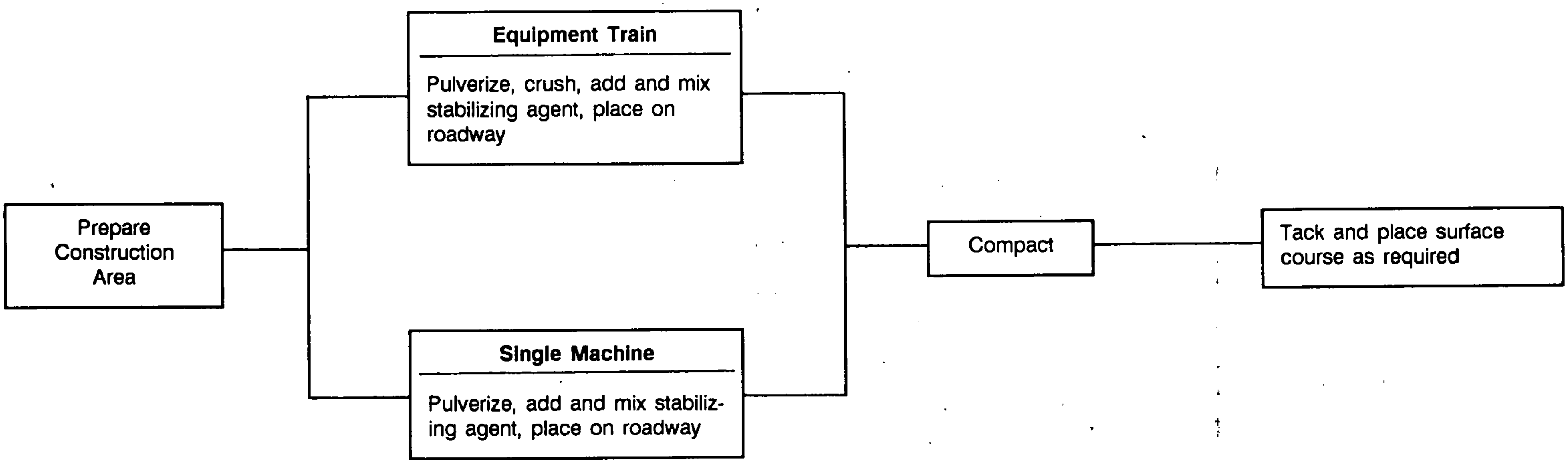


FIGURE 2 Partial-depth cold in-place recycling.

ana, Kansas, Michigan, Nevada, and New Mexico. A number of other states have completed numerous projects as identified later.

Partial-depth cold in-place recycling dates to 1980 with contract-size projects. The states of California, Kansas, Maine, Nevada, New Mexico, Oregon, and Pennsylvania have experience with this form of cold in-place recycling. Oregon has placed numerous projects.

The benefits most often cited by those using cold in-place recycling, regardless of the form (full-depth or partial-depth), include (*3, 22, 32, 34*):

- Significant pavement structural improvements may be achieved without changes in horizontal and vertical geometry and without shoulder reconstruction.
- All types and degrees of pavement distress can be treated.
- Reflection cracking normally is eliminated if the depth of pulverization and reprocessing is adequate.
- Pavement ride quality can be improved.
- Hauling costs can be minimized.
- Old pavement profile, crown, and cross slope may be improved.
- Production rate is high.
- Only thin overlay or chip seal surfacing is required on most projects.
- Engineering costs are low.
- Aggregate and asphalt binder are conserved.
- Energy is conserved.
- Air quality problems resulting from dust, fumes, and smoke are minimized.
- It is a cost-effective solution for a number of situations.
- Frost susceptibility may be improved.
- Pavement widening operations can be accommodated.
- It is environmentally desirable, because disposal problems are eliminated.

Identified problem areas with cold in-place recycling include (*3, 22*):

- Construction variation is larger for in-place versus central plant operations. (Partial-depth cold in-place recycling can result in a uniform pavement layer.)
- Curing is required for strength gain.
- Strength gain and construction are susceptible to climatic conditions, including temperature and moisture.
- Traffic disruption can be greater relative to other rehabilitation alternatives. (The use of the recycling train greatly reduces traffic disruption.)
- Placement of a wearing surface is required.

TABLE 1
STATE USE OF FULL- AND PARTIAL-DEPTH COLD IN-PLACE RECYCLING (after 32)[a]

Agency	Yes	No	Comments	Agency	Yes	No	Comments
Alabama		•		Missouri		•	
Alaska	•			Montana	•		
Arizona	•		Some concern over low stability	Nebraska		•	
				Nevada	•		
Arkansas		•	Used for shoulder	New Hampshire	•		
California	•			New Jersey	x(1)		
Colorado	•			New Mexico	•		Wide variety of projects
Connecticut	x(1)			New York	•		
Delaware		•		North Carolina		•	
Florida	x(2)			North Dakota	•		Very limited experience
Georgia		•	Used milled mat'l for shoulders	Ohio	•		Coal haul road; base
				Oklahoma	•		
Hawaii		•	Hot mix available	Oregon	•		
Idaho		•	Used some planed mat'l. for shoulders	Pennsylvania	•		
				Rhode Island		•	
Illinois	•			South Carolina		•	
Indiana	•			South Dakota		•	Cost not justified
Iowa		•	Hot mix available	Tennessee	x(1)		Good base available
Kansas	•			Texas	•		Prefer hot mix
Kentucky		•		Utah		•	
Louisiana		•		Vermont	•		
Maine	•			Virginia		•	
Maryland		•	Use hot mix	Washington		•	
Massachusetts	•			West Virginia	•		
Michigan	•			Wisconsin	•		
Minnesota	x			Wyoming		•	Used cold plant recycling
Mississippi		•		Dist. of Columbia		•	

x( ) = experimental (no. of projects)

[a]The survey did not distinguish between full-depth and partial-depth cold recycling.

Considering the above identified benefits and problem areas, cold in-place recycling has largely been used on medium-to-lower-traffic-volume highways as a base course. A listing of the more comprehensive references on cold in-place recycling is given below. Those references dealing with full-depth cold in-place recycling are:

- NCHRP Synthesis 54 (1978) (*2*)
- NCHRP Recycling Guidelines (1980) (*3, 35*)
- TRB National Seminar (1980) (*19*)
- *Chevron Cold Mix Recycling Manual* (1982) (*36*)
- The Asphalt Institute (1983) (*37*)
- Scherocman (1983) (*38*)
- FHWA (1987) (*22*)
- Wood et al. (1988) (*32*)

References dealing with partial-depth cold in-place recycling are primarily those based on Oregon research and field experience (*36, 39–43*).

EXTENT OF USE

A nationwide survey of cold in-place recycling was conducted in early 1987 for ARRA (*32*). This survey did not differentiate between full-depth and partial-depth cold in-place recycling. Responses from all state highway agencies as well as numerous counties, cities, and private contractors were received. Twenty-four states indicated use of cold in-place recycling, 5 states indicated that they have placed only experimental test sections, and the remaining 21 states do not use cold recycling (Table 1). Several states, including California, Kansas, New Mexico, Oregon, and Pennsylvania, indicated that they have constructed numerous projects. Table 2 provides references for cold in-place recycling projects in various states based on the literature review conducted for this synthesis (*26, 28, 33, 34, 36, 39, 40, 42, 44–124*). Several of the projects referred to in this table were performed by local government agencies. Based on the ARRA survey (*32*), county roads and secondary highways composed equal proportions of cold in-place recycling projects (31 percent of responses each). City street projects account for 19 percent and primary and Interstate highways compose 12 and 7 percent shares respectively (*32*).

The literature indicates the use of cold in-place recycling for all types of roads and structural section components. However, some agencies restrict its use. Twenty percent of the ARRA reporting agencies restrict cold in-place recycling to rural areas; an additional 20 percent limit use to roads with low traffic volumes. Most agencies limit the use of cold in-place recycling to base courses (95 percent). Of these base course projects, 12 percent placed fog, sand, or slurry seals as surfaces; 33 percent of the projects were surfaced with aggregate chip seals; and 50 percent were surfaced with an asphalt concrete. Three states use cold in-place recycling for shoulder reconstruction on Interstate highways (*32*).

TABLE 2
LITERATURE ASSOCIATED WITH COLD IN-PLACE RECYCLING PROJECTS

Agency	References	Agency	References
Arizona	*39, 44*	New Hampshire	*89*
California	*26, 40, 45-50*	New Mexico	*40*
Colorado	*51*	New York	*90*
Connecticut	*36, 52-54*	Ohio	*91*
Florida	*34*	Oklahoma	*92*
Georgia	*55*	Oregon	*36, 39-42*
Illinois	*56, 57*	Pennsylvania	*93-100*
Indiana	*58-64*	Texas	*101-104*
Iowa	*65*	Vermont	*105-108*
Kansas	*66-72*	Washington	*36, 109*
Maine	*73-75*	Wisconsin	*110-111*
Michigan	*33, 76-80*	Wyoming	*34*
Minnesota	*81-83*	FHWA	*112-114*
Mississippi	*84*	Canada	*115, 116*
Missouri	*85*	England	*117-121*
Montana	*86*	Italy	*122*
Nevada	*28, 39, 87, 88*	Sweden	*123, 124*

CHAPTER TWO

CONSTRUCTION METHODS

The literature indicates that a wide variety of equipment and sequence of operations has been used for cold in-place recycling. The type of equipment and the sequence of operations is largely dictated by the specifications, the contractor's experience, and the type of cold in-place recycling (full- or partial-depth).

Cold in-place recycling consists of nine identifiable operations:

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

Many of these operations are combined with a single machine or operation, whereas others, such as "addition of new aggregate," may not be necessary on some projects. For convenience of discussion, several of these operations have been combined.

SIZING AND MIXING OPERATIONS

The methods acceptable for in-place sizing and mixing for cold-recycling operations can be conveniently separated into four techniques:

- Multiple-step sequence
- Two-step sequence
- Single machine
- Single-pass equipment train

All of these methods are used for full-depth cold in-place recycling; only the single machine and equipment train are used for partial-depth cold in-place recycling. These methods are briefly discussed below.

Multiple-Step Sequence

This method consists of breaking the existing pavement, pulverizing the broken pavement, and adding and mixing the stabilizer. Numerous methods are available for breaking up the existing pavement. Some require simple modifications or additions to conventional equipment, whereas others make use of specialized and sometimes sophisticated machines designed specifically for this purpose.

The simplest procedure for pavement removal is scarifying or ripping by means of a motor grader or dozer with front- or rear-mounted ripper teeth (Figure 3). This is efficient with thin asphalt concrete layers but tends to dig deeper than desired and to produce large chunks of reclaimed material that need additional size reduction (*38*).

Equipment used for size reduction or pulverizing after initial scarification includes the following (*22*):

- Sheepsfoot, grid, or similar roller. Can also be used for initial scarifying and crushing of thin seal-coat roads (Figure 4).
- Cutter-crusher-compactor attached to rear of a motor grader with ripper teeth. Combines the scarifying and size-reduction operation (Figure 5).
- Hammermill (or impact breaker or preparator). Can be towed or self-propelled (Figure 6).
- Rotary mixer. Self-propelled, single-pass mixer with single or multiple transverse rotary shafts, each containing multiple mixing tines or paddles. Can be used for removal, crushing, and mixing (Figure 7).

The disadvantages of using these types of equipment include the need for multiple passes of the machine to achieve required size reduction, limited widths (generally 4 to 5 ft), lack of uniformity in depth of cut, slow production rates, and limitations on depth of cut.

Methods of mixing for this type of operation include the use of a blade mixer (Figure 8) and transverse-shaft mixers (Figure 9).

Two-Step Sequence

This method combines the breaking and pulverizing or sizing steps as described above into a single operation using a cold-milling machine (Figure 10) or large pulverizing machine (Figure 11). The stabilizer is then added and mixed in the second step. Common methods of adding stabilizers in this cold-recycling approach include the use of soil stabilization mixing equipment (Figure 12) and traveling mixers (Figures 13 and 14).

Cold-milling machines have a rotating drum lined with a variable number (depending on width) of replaceable, tungsten-carbide-tipped cutting teeth to grind the old pavement. The advantages of cold-milling machines for breaking and pulverization include:

- Accurate control of depth and profile
- Ability to pulverize and size in a single pass, resulting in less interference with traffic

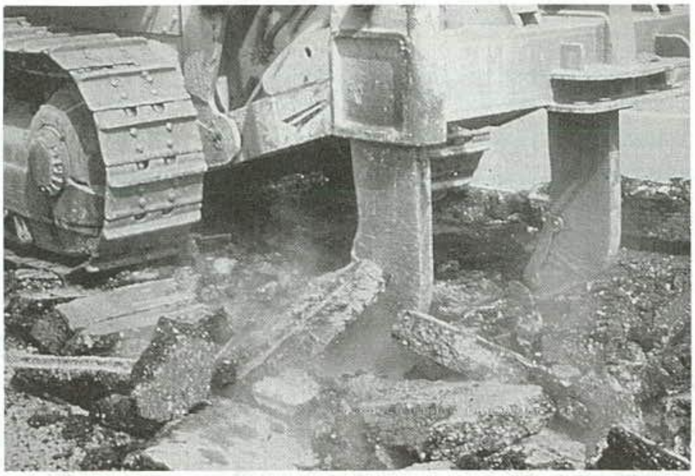


FIGURE 3 Dozer with ripper teeth.

FIGURE 4 Roller for size reduction.

FIGURE 5 Motor grader with cutter-crusher-compactor.

FIGURE 6 Traveling hammermill.

FIGURE 7 Single-shaft rotary mixer for size reduction.

FIGURE 8 Blade mixing.

FIGURE 9 Transverse-shaft mixer for mixing.

FIGURE 10 Cold-milling machine for pavement removal and sizing.

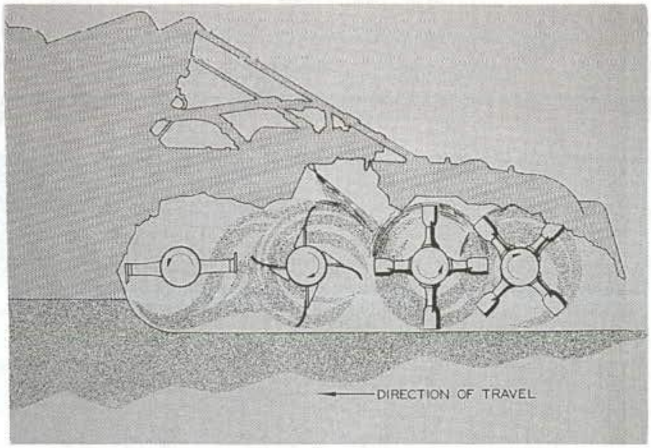


FIGURE 11 Large pulverizing machine for pavement removal and sizing.

FIGURE 12 Soil stabilization mixing equipment for adding stabilizer.

FIGURE 13 Traveling mixer adding stabilizer to recycled asphalt pavement from cold-milling machine.

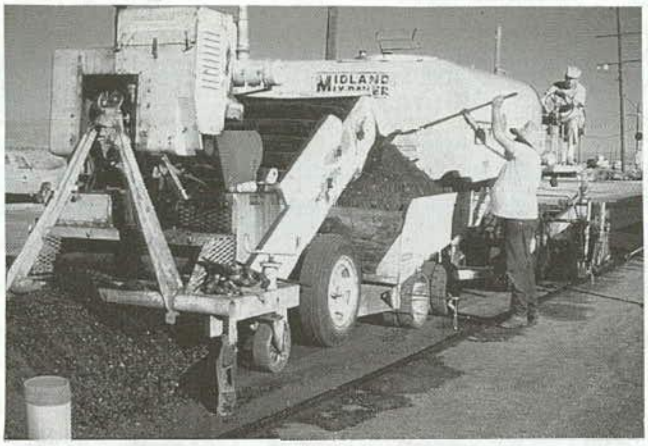


FIGURE 14 Traveling mixer using windrow elevator for recycled asphalt pavement pickup.

FIGURE 15 Cold-milling machine (RayGo).

- Handling of conventional curb-reveal and other cold-planing work (i.e., use is not restricted to recycling)
- Use for mixing when fitted with pump and metering system
- High productivity in almost any weather

The disadvantages of cold-milling machines include the need for trained personnel to operate them and their relatively high cost of operation, which can make them uneconomical for use on seal-coat or thin plant-mixed asphalt roads (*125*). Care must be taken to ensure that all the pavement is reduced to the proper size and that the mix design takes into account the increase in the number of fines.

The drum of the cold-milling machine may be set to operate in an upcutting mode, in which the teeth cut from the bottom of the pavement layers upward as the machine moves forward, or in a downcutting mode, in which the teeth strike the top of the pavement surface in a downward direction as the machine travels ahead. For partial-depth cuts, the upcutting mode generally offers the most accurate cutting depth, with lower cost, greater speed, less tooth wear, less power to operate, and less damage to the underlying surface. However, upcutting can result in the production of significant amounts of oversized material. With downcutting, the reclaimed materials are pinched against the underlying layers, resulting in proper sizing.

The productivity of a milling machine is a function of the resistance of the pavement material to the penetration of the cutting teeth. Three of the most important factors affecting this resistance are material quality, aggregate characteristics, and depth of cut.

Single Machine

Single-pass equipment capable of breaking, pulverizing, and adding stabilizers has been developed and is used for both full-depth and partial-depth cold in-place recycling. Figures 15 to 17 show large cold-milling machines capable of sizing and mixing in a single pass. These operations have the same advantages and disadvantages as cold-milling machines used for pavement removal only.

Single-Pass Equipment Train

Several contractors have developed a single-pass equipment train capable of full-depth and partial-depth cold in-place recycling. Large quantities of pavement can be recycled daily. Figure 18 shows an overall view of the equipment. The equipment train usually consists of a cold-milling machine (Figure 19), portable crusher (Figure 20), travel-plant mixer (Figure 21), and laydown machine (Figure 22). The oversized material from the milling operation is sized by the small portable screen and crusher unit. The cold-milling machine's conveyor discharges the recycled asphalt pavement (RAP) into the crusher unit, which passes it over a screen with large sieve sizes (e.g., $1\frac{1}{2}$ in.). The particular sieve size will depend on the job specifications. The material retained on the screen is rerouted to the roll unit for crushing and then back to the screen. Eventually, 100 percent of the RAP will pass through the screen and onto another conveyor where it can be weighed before being deposited into the pugmill or a paver (*126*). The screen and crusher unit can also be fitted with a pugmill and asphalt feeder system for mixing. The recycled mix can then be windrowed directly behind or to either side of the mixer or, in some cases, directly into the hopper of a self-propelled asphalt laydown machine.

Comparison of Sizing and Mixing Operations

A partial list of advantages and disadvantages associated with each category of breaking, sizing, and mixing operation is given below:

- Multiple-step sequence
  Readily available equipment can be used
  Depth-control problems
  Removal of entire AC layer is necessary
  Mixing of AC and base
  Limited width operations
  Slow production rates
  Traffic control problems
  Construction coordination
  Aggregate oversize

FIGURE 16 Cold-milling machine (Barber-Greene Co.).

FIGURE 17 Cold-milling machine with portable crusher (CMI).

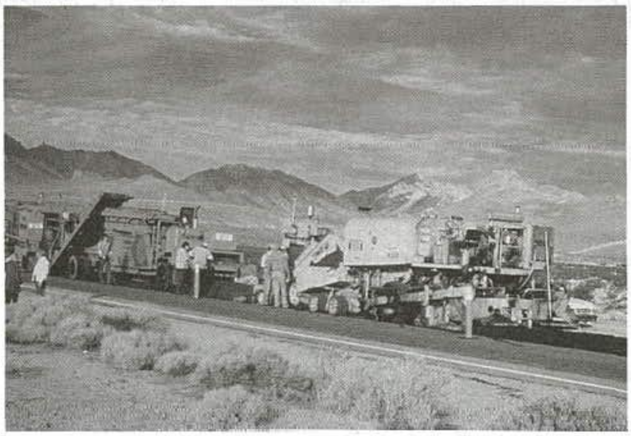


FIGURE 18 Single-pass equipment train.

- Two-step sequence
  Depth limitations
  Partial-depth removal of AC possible
  Aggregate oversize
  Specialized equipment
  High production capacities
- Single machine
  Depth limitations
  Partial-depth removal of AC possible
  Aggregate oversize
  Specialized equipment
  High production capacities
- Single-pass equipment train
  Depth limitations
  Partial-depth removal of AC possible
  Aggregate gradation control
  Specialized equipment
  High production capacities

MIXING OPERATIONS

Asphalt products used as modifiers in cold recycling include emulsified asphalts (usually either slow-setting or medium-set-

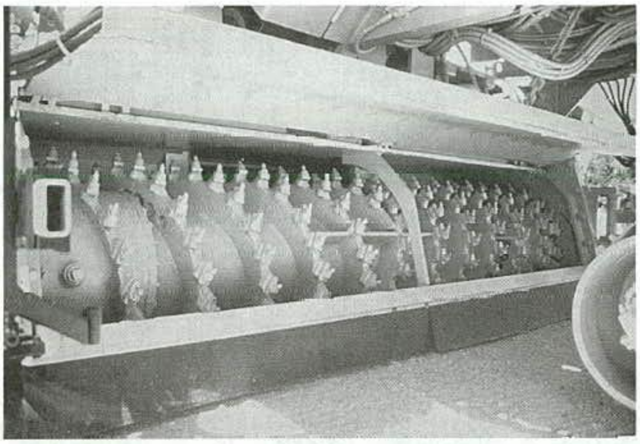


FIGURE 19 Teeth on drum of cold-milling machine.

FIGURE 20 Portable crusher attached to cold-milling machine.

FIGURE 21 Travel-plant mixer.

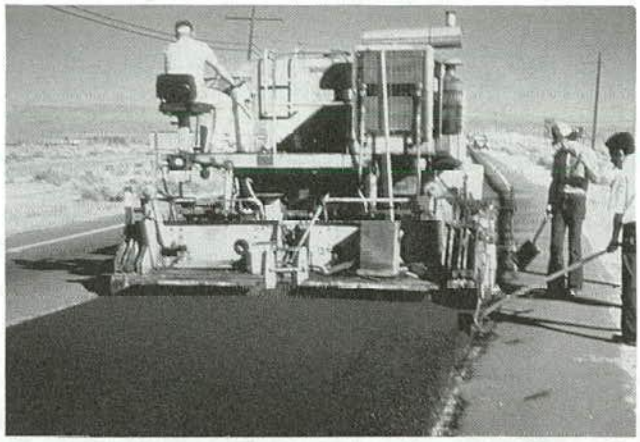


FIGURE 22 Laydown machine.

ting), cutback asphalts, high-penetration asphalt cements (heated to a minimum temperature of 330°F for in-place recycling), and emulsified versions of commercial recycling agents. In addition, water may be added initially to help in the dispersion of the asphalt modifier during the mixing process. A small percentage of portland cement may also be added with emulsified asphalts to help stabilize the recycled mix and reduce curing time. The percentages of any added modifiers should be established in a laboratory mix design as discussed in a later section.

As with pavement removal and size reduction, there are several alternatives for mixing. There are four general types of soil-stabilization construction equipment that can be used for in-place cold recycling:

- Blade
- Flat type
- Windrow type
- Hopper type

All of these equipment types are used for full-depth cold in-place recycling; however, the hopper-type mixer is most often used for partial-depth cold in-place recycling.

Blade Mixing

Blade mixing is the simplest method, but it usually is slow and inefficient (Figure 23). The basic sequence involves (*22*):

- Using a motor grader to windrow the pulverized reclaimed material.
- Adding the prescribed amount of water (if required) to the windrow, preferably using a pressurized water truck rather than gravity flow for reasons of accuracy of application.
- Blading of the windrow across the road with a rolling action to blend in the water.
- Reshaping into a windrow and adding the prescribed amount of asphalt modifier, normally in two or three passes, using an asphalt distributor.
- Using the grader to fold the material around the applied asphalt modifier, followed by working the mixture back and

FIGURE 23 Blade mixing.

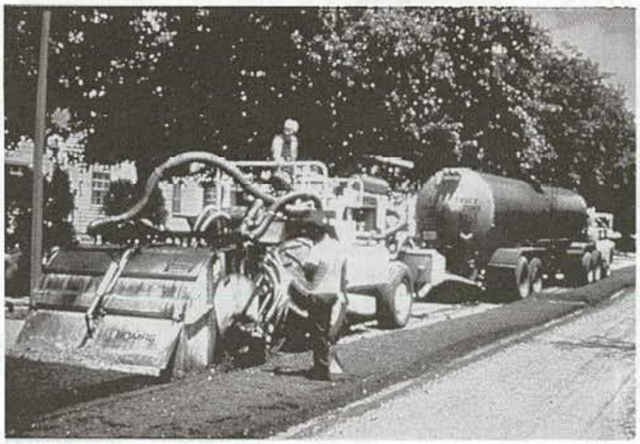


FIGURE 25 Single-shaft rotary mixer with asphalt supply tank.

forth across the roadway surface until the modifier is uniformly distributed and proper fluids content is achieved.

If new aggregate is to be added, it should be windrowed next to the existing pulverized material and mixed in with the motor grader before water or modifier is added.

Flat Type

Mixing operations are often performed with single (Figures 24 and 25) and multiple (Figure 26) transverse-shaft rotary (flat type) mixers. The asphalt modifier can either be applied to the windrowed material by an asphalt distributor before mixing, or it can be added directly by the mixer by means of a spray-bar in the cutting chamber fed by an asphalt supply tanker. With the spray-bar system, mixing can be combined with pulverization in a single-pass operation provided the recycled pavement is sufficiently reduced in size with one pass of the mixer. However, several passes of the machine are normally required to add the proper amount of asphalt and to achieve uniform mix quality. Typically, pulverizing and mixing are completed in separate passes (*22, 31, 127*).

Windrow Type

Windrow mixers can pick up the material from the grade and mix with parallel shafts (Figure 27). These types of mixers are not commonly available today. Windrow, transverse-shaft mixers that do not elevate the material above grade are available. Improved quality control is normally obtained from those mixers that elevate the material above grade.

FIGURE 24 Single transverse-shaft rotary mixer.

FIGURE 26 Multiple transverse-shaft rotary mixer.

Hopper Type

Hopper type or travel-plant mixers are pugmill plants that can mix recycled pavement with liquid modifier, applied at a controlled rate, as they move along the road (Figure 28). There are several options when using these mixer-pavers for in-place recycling. One is to have a windrow pickup attachment for loading the pulverized recycled pavement directly from the roadway

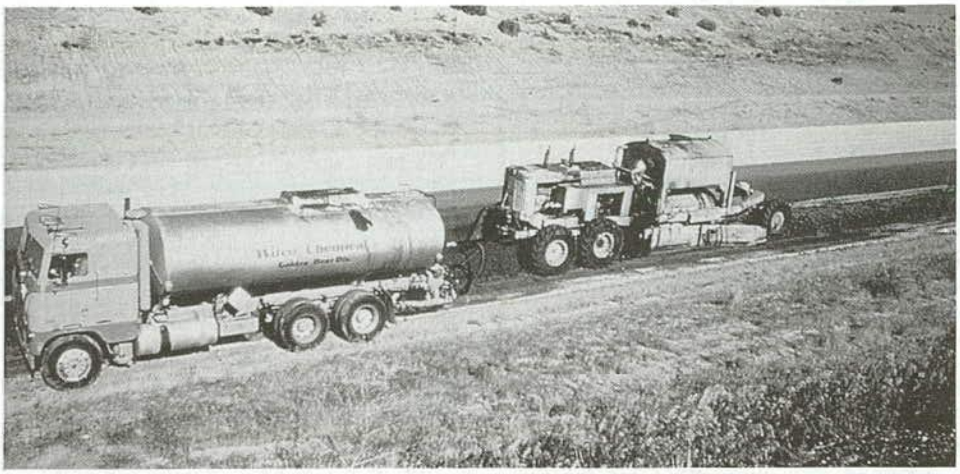


FIGURE 27 Parallel-shaft windrow mixer.

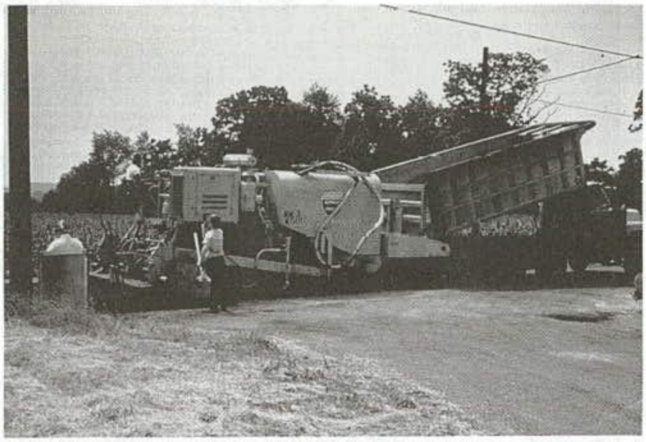


FIGURE 28 Hopper of mixer-paver receiving cold-recycled mix.

FIGURE 29 Laydown of cold-recycled base using Midland Motopaver.

FIGURE 30 Pneumatic-tired roller for compaction.

FIGURE 31 Hopper type paver for laydown of surface course over cold-recycled base.

surface into the pugmill. The windrow type of equipment can use either parallel or transverse shafts. Another option is to feed the recycled pavement, new aggregate, or both, into the plant's aggregate receiving hopper. This requires an intermediate step of loading the recycled pavement into trucks by conveyor or other means. A third option, when using cold-milling machines, is to load the receiving hopper directly by means of a truck-loading conveyor set at the proper angle (*22, 31*).

If water is required in addition to the asphalt modifier, a separate water-delivery system is required. Difficulties may arise if the recycled mix requires variable water contents.

LAYDOWN, AERATION, COMPACTION, CURING, AND SURFACING

Construction techniques for in-place cold recycling laydown, compaction, and surfacing are the same as those used for conventional stabilization operations. Figures 29–31 show typical operations.

The above discussion presents only a brief summary of construction operations currently in use. The reader is referred to those references shown in Table 2 and References *8, 18, 25, 38, 76,* and *128–144* for additional detail.

CHAPTER THREE

MIX DESIGN

INTRODUCTION

The ARRA questionnaire (*32*) addressed the mix design process for cold in-place recycling, although it did not differentiate between full-depth and partial-depth processes. Block, core, and loose-milled samples are obtained by the public agencies for mix design purposes. Sixteen percent of the agencies obtained block samples, 42 percent core samples, and 42 percent obtained samples from the milling operation. Sample location and frequency is based more on judgment than statistical procedures.

New Aggregate

The addition of new aggregate to the recycled pavement appears to be a widespread standard practice. Approximately two-thirds of the reporting agencies allowed for the addition of aggregate. The reasons cited for adding aggregate include providing additional thickness, correcting gradation, and providing for acceptance of additional binder. The new aggregate can be added in front of the pulverizing or milling machine or after partial pulverization; or the existing base course can be used with the pulverized asphalt concrete. The amount of new aggregate ranges from 15 to 50 percent and the amount of salvaged base ranges from 33 to 50 percent (*32*).

Binder

Slow-setting and medium-setting asphalt emulsions are most often used for cold in-place recycling. Almost one-third of the respondents to the ARRA questionnaire use CMS-2 and CSS-1h. In general, the full-depth cold in-place recycling operations use the slow-setting emulsions, whereas the partial-depth operations have used medium-setting emulsions. High-float emulsions have also been used on several projects—full-depth and partial-depth. The New Mexico State Highway Department has used a high-float emulsion with a polymer additive to reduce thermal cracking and resist rutting and provide improved early strength. The western United States uses emulsified recycling agents proposed by the Pacific Coast User-Producer Group, among other types of binders (Table 3) (*43*). Cutbacks and soft asphalt cements are used by some agencies (*32*). The type and amount of diluent should be known by the engineer before any of these liquid asphalts is used.

Amount of Binder

The amount of binder for cold in-place recycling generally ranges from 0.5 to 3 percent emulsion, with 0.5 to 1.8 percent suggested by Oregon and 1.2 to 1.5 percent in Pennsylvania as starting points for mixture design. This is equated to 0.3 to 2 percent residual asphalt for emulsions. States using full-depth cold in-place recycling operations usually require binder contents at the upper end of this range, whereas the partial-depth operations usually use less than 2 percent emulsions. Laboratory mix design procedures are used to determine binder and additive content by one-third of the respondents to the ARRA questionnaire.

Mix Design

The Marshall mix design procedure was used by 20 of 30 agencies using mix design procedures. The Hveem resilient modulus and indirect tensile test were used by the other agencies. One-fourth of responding agencies reported relying on field workability or experience for determining binder content (*32*).

Eighty percent of reporting agencies analyze the recycled pavement for asphalt content and aggregate gradation. Sample preparation was performed by processing or crushing in the laboratory (47 percent), heating and breaking of bulk samples (22 percent), and use of samples from field pulverized or milling operations (31 percent) (*32*).

Marshall compaction (50 and 75 blows), kneading, and gyratory methods of compaction have been used. Curing after compaction varies among agencies and ranges from 1 hr to seven days. Curing temperatures among agencies range from 73°F to 250°F. Density, stability, and air voids are frequently used to select binder contents (*32*).

Agencies and groups that appear to have the most developed mix design procedures for cold in-place recycling include:

- California (*50, 145*)
- Chevron (*36, 146*)
- Corps of Engineers (*20*)
- Nevada (*147*)
- New Mexico (*148*)
- Oregon (*42, 149–153*)
- Pennsylvania (*100, 154*)
- Purdue (*155, 156*)
- Texas (*157, 158*)
- The Asphalt Institute (*37*)

Methods most applicable to the full-depth process include those developed by Chevron, Corps of Engineers, Pennsylvania, Purdue, Texas, and the Asphalt Institute. The procedure developed by Oregon is for partial-depth recycling, whereas those developed by California, Chevron, Nevada, New Mexico, and

TABLE 3

GUIDE SPECIFICATION FOR PARTIAL-DEPTH COLD IN-PLACE RECYCLING (*43*)

Test ID	Test	ERA 5	ERA 25	ERA 75	CMS-2RA	HFE-200
T-59	Viscosity at 77°F	15-100	15-100	15-100		
T-59	Viscosity at 122°F				50-450	50 min
T-59	Sieve	0.1 max	0.1 max	0.1 max	0.1 max	0.1 max
T-59	One-day storage stability (%)	1 max	1 max	1 max	1 max	1 max
T-59	Residue at 500°F (%)	60 min	60 min	60 min	60 min	65 min
T-59	Oil Distillate (%)				5-15	0-7
T-59	Charge	+ Pass	+ Pass	+ Pass	+ Pass	- Pass
	Residue Tests					
T-202	Viscosity at 60°C	200-800	1,000-4,000	4,000-10,000		
T-49	Pen				100-250	200-350
ASTM D4124	Saturate (%)	30 max	30 max	30 max		
T-50	Float Sec 140°F					1200 min
T-44	Solubility (%)	97.5 min	97.5 min	97.5 min	97.5 min	97.5 min
T-240	RFTO Ratio	2.5 max	2.5 max	2.5 max		

Pennsylvania can be used for partial-depth cold in-place recycling. In addition, experience gained by Canessa (*159, 160*) has proved to be of value. Other references on mix design are *29, 99,* and *161*. A standard national method is not available; however, certain basic steps are normally included in the mix design process. These include:

- Obtaining representative field samples from the pavement or from stockpiles of reclaimed materials,
- Processing of field samples for use in mix design,
- Evaluation of recycled pavement,
  Asphalt content
  Asphalt physical properties (penetration, viscosity)
  Aggregate gradation
  Recycled pavement gradation
- Selection of amount and gradation of new aggregate,
- Estimate of asphalt demand,
- Selection of type and amount of recycling agent,
- Mixture, compaction, and testing of trial mixture,
  Initial cure properties
  Final cure properties
  Water sensitivity
- Establishment of job mix formula, and
- Adjustment in field.

Methods proposed by California, Chevron, Oregon, Pennsylvania, and the Asphalt Institute are reviewed below.

CALIFORNIA (*145*)

The California method of mixture design uses the Hveem stabilometer, air voids, and visual condition of samples to establish the optimum binder content (Appendix A).

Field Sample Preparation

Pavement cores or chunks are crushed in the laboratory or pulverized field samples are obtained for mix design purposes.

Evaluation of RAP

Asphalt content, aggregate gradation, and asphalt viscosity are determined.

New Aggregate

The amount and gradation of the aggregate is not directly addressed in the method.

Recycling Agent

The approximate total bitumen requirement (ABR) is determined using an aggregate surface area formula applied to the RAP aggregate after extraction of the asphalt. The amount of recycling agent is obtained by subtracting the asphalt content of the RAP from the approximate bitumen requirement.

The viscosity of the RAP asphalt is used together with the viscosity of the base asphalt in the recycling agent to determine the grade of recycling agent. The desired viscosity of the blend (RAP asphalt and base asphalt from emulsion) is 4000 poises at 140°F.

Lab Sample Preparation and Testing

Six samples are prepared for testing. One sample is used to determine the "Rice Specific Gravity" (ASTM D 2041). Four samples are dried to constant weight, 2 percent water is added, and each is mixed with a different emulsion content. The samples are loose cured at 140°F for 16 hr and compacted with a kneading compactor at 140°F. Hveem stability values at 140°F and air voids are calculated.

Job Mix Formula

The recommended bitumen content is the highest emulsion content that provides a specimen with no evidence of surface flushing or bleeding, a minimum of 4 percent voids, and minimum stability values of (a) 30 for traveled ways or (b) 25 for shoulders.

CHEVRON (*36*)

The Chevron USA, Inc. method of mixture design uses the resilient modulus, Hveem stabilometer and cohesiometer, and mix workability to establish the optimum binder content (Appendix B).

Field Sample Preparation

A method is not identified.

Evaluation of RAP

Asphalt content, aggregate gradation, and viscosity at 140°F or penetration at 77°F and viscosity at 275°F are determined.

New Aggregate

The gradation of the RAP aggregate is examined and, if necessary, new aggregate is added to adjust the gradation to match that shown in Table 4. New aggregate may also be needed to accommodate new binder or to increase the stability of the recycled mix.

Recycling Agent

One of two methods can be used to determine asphalt demand of the recycled mixture: CKE (centrifuge kerosene equivalent) and aggregate surface area formula. The amount of recycling agent is obtained by subtracting the asphalt content of the RAP from the asphalt demand of the recycled mixture. No less than 2 percent emulsified recycling agent is recommended for use. If the design calls for less than 2 percent, additional untreated aggregate is added.

Table 5 is used as a guide for selecting emulsified asphalt or recycling agents. Low-viscosity residue emulsions are recommended for reclaimed asphalt pavements that contain high-viscosity (low-penetration) asphalts. Standard emulsified asphalts recommended for cold-mix recycling include soft-residue, slow- and medium-setting, cationic and anionic emulsions. Certain high-float emulsions are also recommended. Soft-residue quick-set emulsions have been successfully used. Typical requirements for these emulsions are shown in Tables 6 and 7.

Lab Sample Preparation

Trial mixes are prepared at 1 percent below the estimated emulsified recycling agent content, at the estimated content, and at 1 percent and 2 percent above the estimated content. The mixing and testing schedule is illustrated in Appendix B. Coating tests are performed and samples are compacted with the kneading compactor at 73°F. Hveem resistance and cohesiometer and resilient modulus values are obtained after initial, final, and water-soak cure conditions. Initial cure is performed in the compactor mold at 73°F for 72 hr followed by four days of vacuum desiccation. Water soak is performed under vacuum.

Job Mix Formula

The recommended bitumen content is based on the criteria shown in Appendix B, Table 6, which include a final cure resilient modulus in the range of 150,000 to 600,000 (73°F), stability of 30 minimum, and cohesiometer values of 100 minimum (140°F).

TABLE 4

AGGREGATES SUITABLE FOR COLD-MIX RECYCLING (*36*)

Category		ASTM Designation	Process Dense Graded						Sands	Silty Sands	Semi-Processed Crusher, Pit or Bank Run
Gradation and Passing by Weight	1-1/2"	C-136	100								100
	1		90-100	100							80-100
	3/4		-	90-100	100						-
	1/2		60-80	-	90-100	100			100	100	-
	3/8		-	60-80	-	90-100	100		-	-	-
	No. 4		25-60	35-65	45-70	60-80	80-100	100	75-100	75-100	25-85
	8		15-45	20-50	25-55	35-65	65-100	95-100	-	-	-
	16		-	-	-	-	40-80	85-100	-	-	-
	30		-	-	-	-	20-65	70-95	-	-	-
	50		3-18	3-20	5-20	6-25	7-40	45-75	-	-	-
	100		-	-	-	-	3-20	20-40	-	15-65	-
	200		1-7	2-8	2-9	2-10	2-10	9-20	0-12	12-25	3-15
Sand Equivalent, %		D-2419	45 Min	45 Min	45 Min	45 Min	45 Min	45 Min	25 Min	25 Min	30 Min
Los Angeles Rattler @ 500 Revolutions		C-131	40 Max	40 Max	40 Max	40 Max	-	-	-	-	50 Max
% Crushed Faces		Calif[1] 205-E	65 Min	65 Min	65 Min	65 Min	65 Min	65 Min	-	-	-
Soundness 5 Cycles		C-88	12 Max	12 Max	12 Max	12 Max	12 Max	12 Max	-	-	-
Acid Resistance[2]		D-3042	10 Max	10 Max	10 Max	10 Max	10 Max	10 Max	-	-	-

[1]State of California Test Method.
[2]Applicable to limestone surface mixes.

TABLE 5

SELECTION OF EMULSIFIED RECYCLING AGENT (*36*)

Type	Grade Designation	PREFERRED USAGE		
		Aggregate	Rain Resistance	Construction Method
Slow Setting	SS-1 EMA-1	Damp to wet, dense-graded aggregates, high sand content gravels, poorly or well-graded sands.	Dependent on dehydration and absorption.	Central Mix or Travel Plant.
	CSS-1 CEMA-1			
Medium Setting	CMS-2S	Dry or damp, low sand content gravels, well-graded or silty sands.	Resistant to early rainfall.	Travel Plant or In-Place mixing.
	MS-1 MS-2 HFMS-1 HFMS-2 HFMS-2S	Dry or damp low fines processed aggregates.	Resistant to early rainfall.	Central Mix or Travel Plant.
	CMS-2			
Quick Setting	QS-1	Damp to wet dense-graded aggregates, high sand content gravels, or well-graded silty sands.	Dependent on amount and type of additive.	Travel Plant or In-Place mixing.
	CQS-1			

TABLE 6

REQUIREMENTS FOR CATIONIC EMULSIFIED RECYCLING AGENTS* (*36*)

TYPE	SLOW-SETTING				MEDIUM-SETTING				QUICK-SETTING	
GRADE	CSS-1		CEMA-1		CMS-2S		CMS-2		CQS-1	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
TESTS ON EMULSIONS:										
Viscosity SSF @ 77°F sec.	20	100	–	100	–	–	–	–	–	100
Viscosity SSF @ 122°F sec.	–	–	–	–	50	450	50	450	–	–
Storage Stability test, 1 day	–	1	–	1	–	1	–	1	1	1
Coating ability & water resistance:										
Coating, dry aggregate					Good		Good			
Coating, after spraying					Fair		Fair			
Coating, wet aggregate					Fair		Fair			
Coating, after spraying					Fair		Fair			
Particle Charge Test	Positive (a)		Positive (a)		Positive		Positive		Positive	
Sieve Test, %	–	0.10	–	0.10	–	0.10	–	0.10	–	0.10
Cement Mixing Test, %	–	2.0	–	–	–	–	–	–	–	–
Distillation:										
–Oil distillate by volume of emulsion, %	–	–	–	–	–	20	–	12	–	–
–Residue, %	57	–	57	–	60	–	65	–	57	–
TESTS ON RESIDUE FROM DISTILLATION TEST:										
Penetration, 77°F	100	250	–	–	100	250	100	250	100	250
Ductility, 77°F, 5 cm/min., cm	40	–	–	–	40	–	40	–	40	–
Solubility in trichloroethylene, %	97.5	–	97.5	–	97.5	–	97.5	–	97.5	–
Viscosity @ 140°F, poise	–	–	50	200	–	–	–	–	–	–
Viscosity Aging Ratio	–	–	–	5.0	–	–	–	–	–	–
Saturates, %	–	–	–	30	–	–	–	–	–	–

(a) Must meet a pH requirement of 6.7 maximum (ASTM E-70) if the Particle Charge Test is inconclusive.

(b) Viscosity Aging Ratio = $\frac{\text{RTFC Viscosity @ 140°F (60°C)}}{\text{Original Viscosity @ 140°F (60°C)}}$

* These specification requirements may vary in different locations dependent on local construction practices, aggregates, and climatic conditions. Please check with your nearest Chevron U.S.A. District Office for grades available in your area.

TABLE 7

REQUIREMENTS FOR ANIONIC EMULSIFIED RECYCLING AGENTS* (*36*)

TYPE	SLOW-SETTING				MEDIUM-SETTING										QUICK-SETTING	
GRADE	SS-1		EMA-1		MS-1		MS-2		HFMS-1		HFMS-2		HFMS2s		QS-1	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
TESTS ON EMULSIONS:																
Viscosity SSF @ 77°F (25°C) sec.	20	100	–	100	20	100	100	–	20	100	100	–	50	–	–	100
Viscosity SSF @ 122°F (50°C) sec.	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Storage Stability test, 1 day	–	1	–	1	–	1	–	1	–	1	–	1	–	1	–	1
Coating ability & water resistance:																
Coating, dry aggregate	–	–	–	–	Good		Good		Good		Good		Good		–	–
Coating, after spraying	–	–	–	–	Fair		Fair		Good		Fair		Fair		–	–
Coating, wet aggregate	–	–	–	–	Fair		Fair		Fair		Fair		Fair		–	–
Coating, after spraying	–	–	–	–	Fair		Fair		Fair		Fair		Fair		–	–
Cement Mixing Test, %	–	2.0	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Sieve Test, %	–	0.10	–	0.10	–	0.10	–	0.10	–	0.10	–	0.10	–	0.10	–	0.10
Residue by distillation, %	57	–	57	–	65	–	65	–	55	–	65	–	65	–	57	–
TESTS ON RESIDUE FROM DISTILLATION TEST:																
Penetration, 77°F (25°C), 100 g. 5 sec.	100	200	–	–	100	200	100	200	100	200	100	200	200	–	100	250
Ductility, 77°F (25°C), 5 cm/min., cm	40	–	–	–	40	–	40	–	40	–	40	–	40	–	40	–
Solubility in trichloroethylene, %	97.5	–	97.5	–	97.5	–	97.5	–	97.5	–	97.5	–	97.5	–	97.5	–
Float Test, 140°F (60°C), sec.	–	–	–	–	–	–	–	–	1200	–	1200	–	1200	–		–
Viscosity @ 140°F, poises	–	–	50	200	–	–	–	–	–	–	–	–	–			
Viscosity Aging Ratio (a)	–	–	–	5.0	–	–	–	–	–	–	–	–	–			
Saturates, %	–	–	–	30	–	–	–	–	–	–	–	–	–	–	–	–

(a) Viscosity Aging Ratio $= \dfrac{\text{RTFC Viscosity @ 140°F (60°C)}}{\text{Original Viscosity @ 140°F (60°C)}}$

* These specification requirements may vary in different locations dependent on local construction practices, aggregates, and climatic conditions. Please check with your nearest Chevron U.S.A. District Office for grades available in your area.

OREGON (*150*)

The Oregon method of mixture design uses Hveem stability, resilient modulus, and fatigue test results to establish the optimum binder content (Appendix C). This method is applicable only to partial-depth cold in-place recycled mixes. It has been used only experimentally in Oregon and only to estimate the starting point for emulsion content. The emulsion content is adjusted by as much as 0.4 percent, based on field observations.

Field Sample Preparation

Millings are obtained from a 16-in. mill and reduced to 100 percent passing the 25.0 mm (1 in.) sieve by use of a hammer.

Evaluation of RAP

Asphalt content, aggregate gradation, RAP gradation, and asphalt viscosity and penetration are determined. The estimated emulsion content is obtained from Figure 1 of Appendix C or by using the following equation:

$$EC_{EST} = 1.2 + A_G + A_{A/C} + A_{P/V}$$

where:

EC_{EST} = Estimated emulsion content, percent
A_G = Adjustment for gradation, percent
$A_{A/C}$ = Adjustment for asphalt content, percent
$A_{P/V}$ = Adjustment for penetration or viscosity, percent

This formula is based on field experience from 1984 to 1988 and is scaled based on asphalt physical properties, aggregate gradation, and asphalt content from actual field projects in Oregon.

New Aggregate

New aggregate is typically not used on Oregon projects and not directly considered in design.

Recycling Agent

Before the 1988 construction season, CMS-2S was used for all projects except one experimental project. Most 1988 cold in-place recycling used HFE-150 because of the following:

- Improved performance was noted for sealing and oil mats.
- Sensitivity to small changes in emulsion content was improved.
- There was less thermal cracking.
- The cost of emulsion was reduced.

The emulsions shown in Table 3 will be used in the future. Experience has indicated that the final estimated design emulsion content for CMS-2S can be as low as 0.4 percent and as high as 2.6 percent, and for HFE-150 within the range of 0.6 to 1.8 percent.

Lab Sample Preparation and Testing

The estimated total fluids content is determined by using Oregon's Test Method TM-126. Typical water contents of 0.5, 1.0, and 1.5 percent are used with the "estimated design emulsion content." Samples are prepared at the estimated emulsion content and the estimated content ± 0.3, ± 0.6, and ± 0.9 percentage points. These samples are placed in molds and static compaction is applied. Liquid loss is used to determine the design total fluids content.

Samples for Hveem stability and resilient modulus are compacted by the kneading compactor. Sample preparation steps are outlined in detail in Appendix C and summarized below:

- Add water to the RAP.
- Add emulsion to the RAP and mix. Emulsion is preheated to 140°F.
- Cure for 1 hr in pan.
- Compact with Hveem compactor at 140°F.
- Cure at 140°F overnight and recompact using the kneading compactor.
- Cure at 140°F for 24 hr in molds.
- Extract samples from molds and cure for 72 hr at 73°F.
- Test samples for stability and resilient modulus at 77°F.
- Record the emulsion content at the peak of the Hveem and resilient modulus curve.

Job Mix Formula

Selection of the final estimated emulsion content is based on the laboratory test results with allowances for field change. Field adjustments are made to the final estimated emulsion content based on consideration for RAP gradation, moisture content, isolated fat spots or unstable mixtures, and visual appearance of the mat 2 or 3 hr after rolling. Corrections (reductions) for isolated fat spots are 0.2 percent in slightly fat areas and 0.4 percent in areas that are obviously unstable or rutted. Adjustments of 0.1 to 0.2 percent are made based on visual appearance of the mat 2 to 3 hr after initial compaction. Emulsion is added if the mat remains brown and is prone to raveling. Emulsion is reduced if the mat is very black and shiny and raveling is not apparent.

PENNSYLVANIA (*100, 154*)

The Pennsylvania method of mixture design primarily uses the resilient modulus test. This method is based on experience gained on more than 90 cold-mix projects in the state (Appendix D). Marshall test data are obtained for information only.

Field Sample Preparation

Pavement cores (6-in. diameter) or pulverized field samples are obtained. A laboratory jaw crusher is used to size cores for mix design purposes.

Evaluate RAP

Asphalt content, aggregate gradation, and asphalt viscosity at 140°F and penetration at 77°F are determined.

New Aggregate

As much as 50 percent new aggregate can be added to the RAP. New aggregate is desired to allow for the emulsion added to exceed 2 to 3 percent. Emulsion contents on the order of 2 to 3 percent are often inadequate for achieving adhesion and cohesion of the recycled mix. New aggregate is also added to sand RAP, RAP with excessive binder, and RAP that needs gradation adjustments.

Recycling Agent

The approximate total asphalt needed is determined using aggregate surface area formulas applied to the RAP aggregate after extraction of asphalt. Surface area formulas proposed by Chevron, the Asphalt Institute, Witco Chemical, and Illinois are used as a guide for establishing the range of emulsion contents to be used in the mix design.

Emulsions used by Pennsylvania include CMS-2 and CSS-1h. A CMS-2 emulsion with an asphalt residue of 100 to 250 penetration is used when the penetration of the RAP asphalt is in the 15 to 20 range. These ranges of penetration are common when old asphalt concrete pavements are recycled. For roads built over the years with surface treatments, seal coats, and cold mixes, relatively soft asphalts have been identified in the RAP. The use of CSS-1h emulsions with 40 to 90 penetration asphalt residues are recommended.

Lab Sample Preparation and Testing

The optimum moisture content is first determined by fixing the emulsion content at 2.5 percent (100 percent RAP mix) and varying the water content in increments of 1 percent starting at 3 percent. After 2 min of hand mixing, 90+ percent coating is required for acceptability. Mixes are unacceptable if they strip or stiffen excessively on mixing, break prematurely, or become excessively soupy and segregate on standing. For mixing, the RAP is maintained at 73°F and the emulsion is heated to 140°F.

The optimum emulsion content is determined by preparing three mixtures each at four emulsion contents using the established optimum moisture content. If 100 percent RAP is used, these percentages are 2.0, 2.5, 3.0, and 3.5 percent emulsion. When RAP and new aggregates are used in combination, higher emulsion contents are used.

After mixing, the loose samples are cured in an oven at 105°F for 45 min and remixed. Compaction is performed at 73°F by the 75-blow Marshall procedure. The compacted samples are cured in the mold at 73°F for 15 to 24 hr and extruded. The extruded samples are cured at 104°F for three days. After curing, the resilient modulus at 77°F and the bulk specific gravity are determined. Samples are then vacuum saturated and soaked for 30 min followed by determination of resilient modulus and Marshall stability and flow values.

Job Mix Formula

The optimum emulsion content is selected considering the bulk specific gravity, initial resilient modulus, soaked resilient modulus, and percent-retained resilient modulus. Usually the initial resilient modulus decreases as the emulsion content is increased. The rate of decrease of the resilient modulus and the absolute value of the resilient modulus after vacuum saturation are considered to establish the optimum emulsion content. Peak Marshall stability or stability at 10 flow (if there is no peak) is reported. The laboratory-determined emulsion contents are adjusted in the field as required.

THE ASPHALT INSTITUTE *(37)*

The Asphalt Institute method uses surface area calculations to establish a target binder content, which is adjusted based on field trials. The procedure is detailed in Appendix E.

Field Sample Preparation

A random-sampling procedure is used to obtain a minimum of five samples.

Evaluation of RAP

Asphalt content and aggregate gradation are determined.

New Aggregate

New aggregate may be needed to correct gradation of the RAP or to increase the thickness of the recycled pavement. Combined gradations of RAP and new aggregate are given in Appendix E.

Recycling Agent

Selection of the type and grade of asphalt cement or emulsified asphalt should be based on historic use of materials and the broad engineering consideration of the properties of the asphalt, consistency, and curing or setting rate. In general, the use of the heaviest asphalt that can readily be worked is recommended.

When asphalt cements are used, mixing water contents of 4 to 6 percent will be required, to cause the hot asphalt cement to foam and aid coating. Lower-viscosity asphalt cements should be used in mixes with relatively high fines (minus No. 200). Higher-viscosity asphalts can be used in mixes with lower fines contents.

Medium-setting emulsions are designed for mixing with coarse aggregate. These emulsions do not break immediately upon contact with the aggregate, and mixing is possible for a short period of time. High-float medium-setting emulsions may give better coating and asphalt retention under extreme temperature conditions and can be used with coarse- or dense-graded aggregates.

Slow-setting emulsions are designed for maximum mixing stability and can be used for high-fines-content, dense-graded aggregates.

The asphalt demand in the recycled mixture is determined using an aggregate surface area formula. The amount of recycling agent is obtained by subtracting the asphalt content of the RAP from the asphalt demand.

Lab Sample Preparation and Testing

A specific procedure is not recommended. The Asphalt Institute does have cold-mix procedures.

Job Mix Formula

The job mix formula is based on the surface area formula and associated calculations. Field adjustments are made.

DISCUSSION

All methods provide approaches for selecting the type and amount of binder and the amount of water. Methods of compaction, curing, and testing differ. Most methods define mix property measurements soon after compaction, at or near a final cure condition, and after exposure to water. These are desirable properties from a rational mixture design approach.

A good cold in-place recycling binder is recognized as one that (a) produces initial softening of the RAP asphalt, (b) has good initial coating of RAP and new aggregate at low fluids contents, (c) allows for early compaction and traffic, (d) is relatively insensitive to binder content, and (e) does not continue to soften for several months to create rutting and bleeding problems. The grade of binder is chosen to soften the RAP asphalt to a selected level. Depending on environmental conditions, complete mixing of the new binder and the RAP binder may or may not occur in a timely manner. If complete mixing does not occur, it is possible that the new binder or recycling agent will remain on the surface of the hard RAP aggregate and create an unstable mixture. In selecting recycling agents it is better to err on the hard side of the residual asphalt (high viscosity or low penetration) in the emulsified and asphalt cements.

CHAPTER FOUR

PROPERTIES OF MIXTURES

Research conducted in Indiana (*59, 60, 155, 162–168*), Michigan (*80*), Nevada (*87, 88*), Oregon (*41, 150*), and Texas (*169*) and by Chevron (*146*) and U.S. Navy (*29*) has produced basic mechanical property data on cold-recycled materials. Results from selected studies are presented below.

MARSHALL STABILITY AND FLOW

Marshall properties for cold in-place recycling projects have been reported by a number of agencies, including Michigan, Oregon, and Purdue University.

Michigan (*80*) reported data obtained from both preconstruction and construction samples. Typical Marshall properties as a function of new binder residue are shown in Figure 32. A comparison of Marshall properties for cutback and emulsion binders in a pulverized bituminous material is shown in Figures 33 and 34. These figures illustrate strength gain with time and the importance of curing as well as potential strength losses associated with water in partially cured mixtures. The influence of binder residue properties on Marshall properties and density is shown in Figures 35 and 36.

Relationships among Marshall properties, curing time, soaking, type of binder, and binder residue content are shown in Figures 37 and 38. Stability increases with time. Soaking for 24 hr causes a substantial loss in strength until sufficient curing is obtained. A minimum of one week of curing is usually required for adequate strength gain and resistance to water damage.

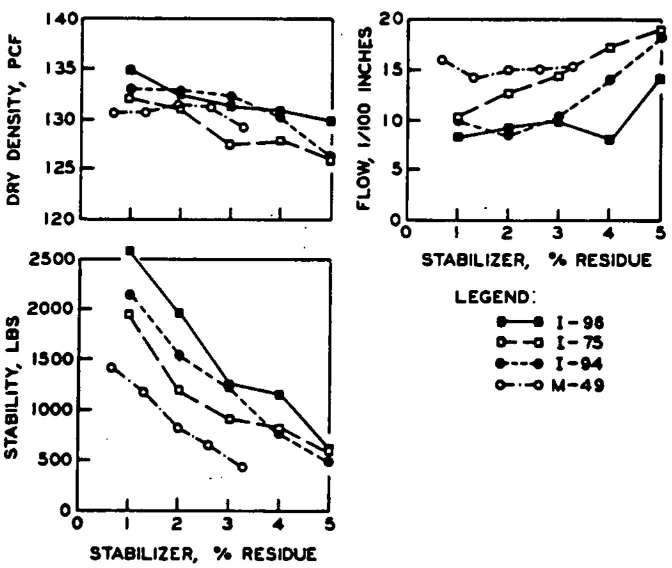


FIGURE 32 Preconstruction Marshall test results. All samples were prepared at 3 percent moisture content with aggregates obtained from the projects and stabilized with MS-2S (*80*).

Figure 39 shows the freeze-thaw durability of recycled materials as a function of residue content and binder type. No significant effects of freeze-thaw exposure are noted. The asphalt cements produced improved stability compared with the liquid asphalts. Freeze-thaw damage to partially cured mixes can occur.

Figure 40 indicates that for Marshall compaction efforts the amount of asphalt does not greatly influence the maximum density. Asphalt type influences the maximum density as shown in Figure 41. The significant influence of compaction moisture content on Marshall density is shown in Figure 42. Variations of these relationships that may occur on a single project are shown in Figure 43.

Field and laboratory density comparisons are given in Table 8. Effects of remixing and delayed compaction on stability are shown in Figure 44. Stability of samples taken from seven projects during construction are given in Table 9.

Michigan has developed a hydraulically operated penetration device to measure in-place properties of stabilized bases. This test can be used to investigate construction variation and the influences of curing, binder type, binder quantity, moisture content, and density on strength.

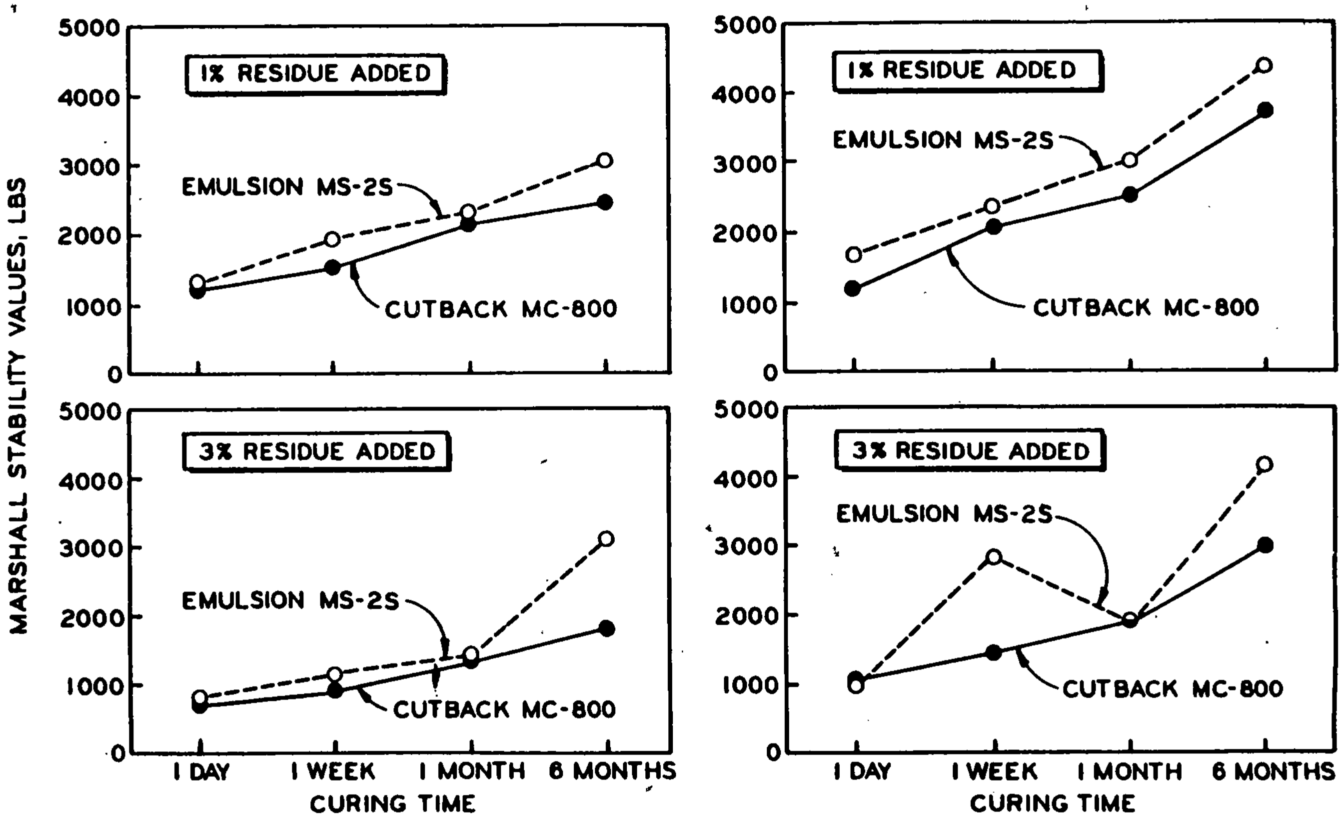
Marshall properties of core samples obtained from seven Oregon projects are shown in Figure 45 (*150*).

Purdue University examined influences of compactive effort, binder residue, and cure conditions on Marshall stability (*163*). Maximum Marshall stability was noted at about 0.5 percent residue. There was little difference between curing for 28 days and "ultimate" cure. Stability was influenced by the percent asphalt residue.

HVEEM STABILITY

Hveem stability data for cold in-place recycling projects have been reported by a number of agencies including California, Nevada, Oregon, Chevron, and Purdue University.

Preconstruction Hveem properties for two Nevada projects are shown in Figures 46–48 (*87, 88*). Hveem stability values are shown to decrease with an increase in binder. Note that the recycled mixtures reported in Figure 46 are more sensitive to binder content than the mixtures shown in Figures 47 and 48. As expected, air voids decrease and density increases with binder



Ratio of base aggregate to pulverized surfacing = 1 : 1

Ratio of base aggregate to pulverized surfacing = 3 : 1

FIGURE 33 Comparison of cutback and emulsion for stabilizing base aggregates blended with pulverized bituminous surfacing (*80*).

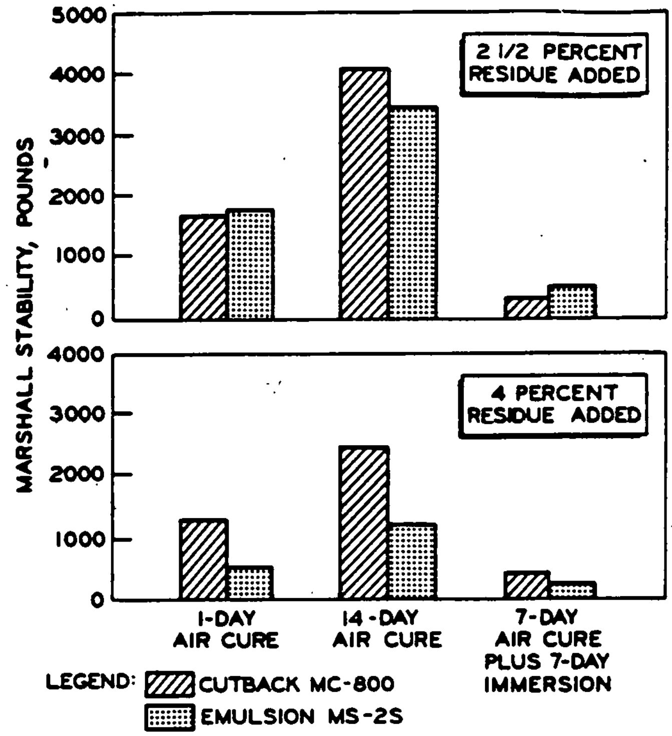


FIGURE 34 Influence of curing and immersion on cutback- and emulsion-treated aggregate at 3 percent moisture content (*80*).

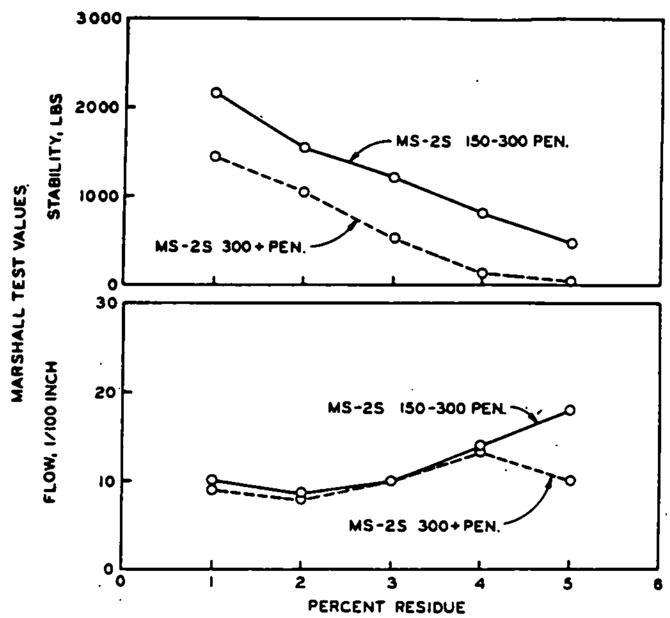


FIGURE 35 Comparison of two asphalt emulsions of different penetration ranges when used to stabilize shoulder and base aggregates (*80*).

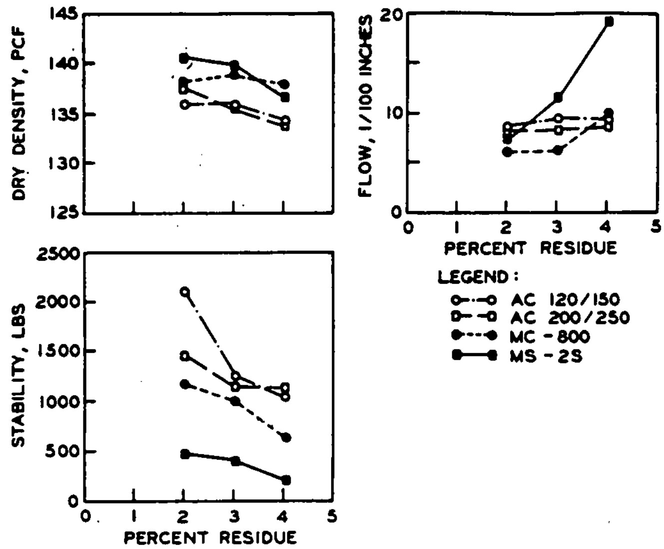


FIGURE 36 Marshall test results comparing four ashpalts used for stabilizing aggregate. Samples were mixed at 3 percent moisture and air cured for one day before testing (*80*).

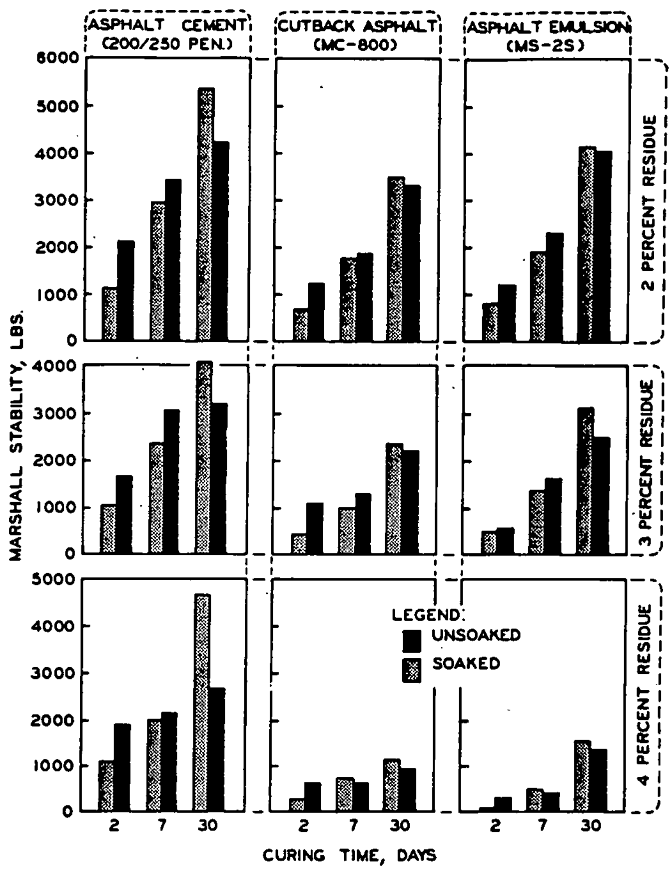


FIGURE 37 Relationship of stability and curing time for soaked and unsoaked samples (*80*).

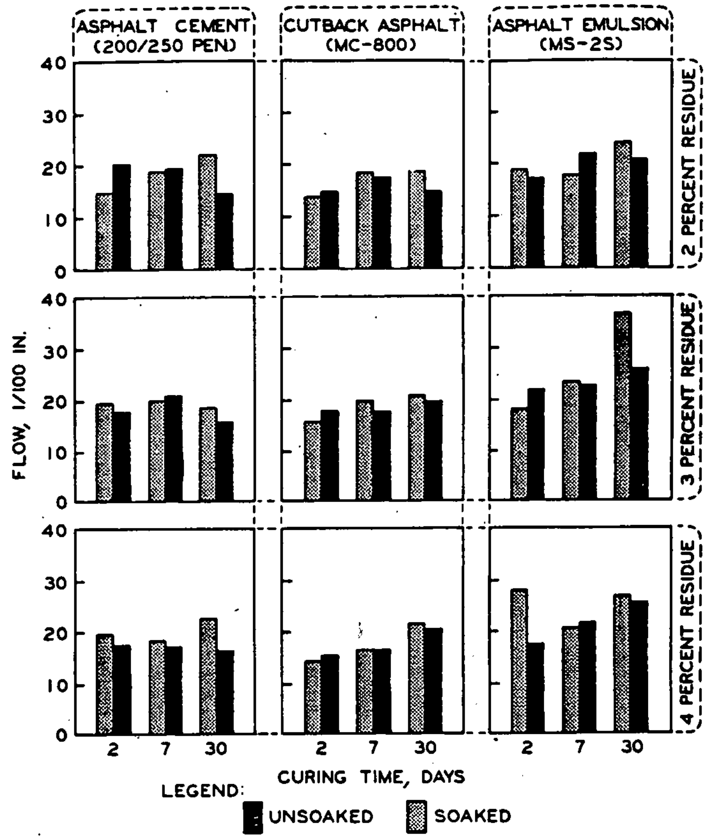


FIGURE 38 Relationship of Marshall flow and curing time for soaked and unsoaked samples (*80*).

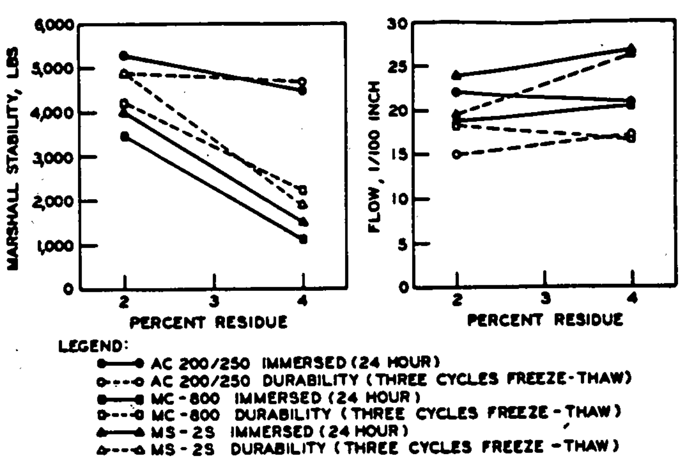


FIGURE 39 Freeze-thaw durability of three asphalts used for stabilizing recycled bituminous surfacing mixed with aggregate from I-75 (*80*).

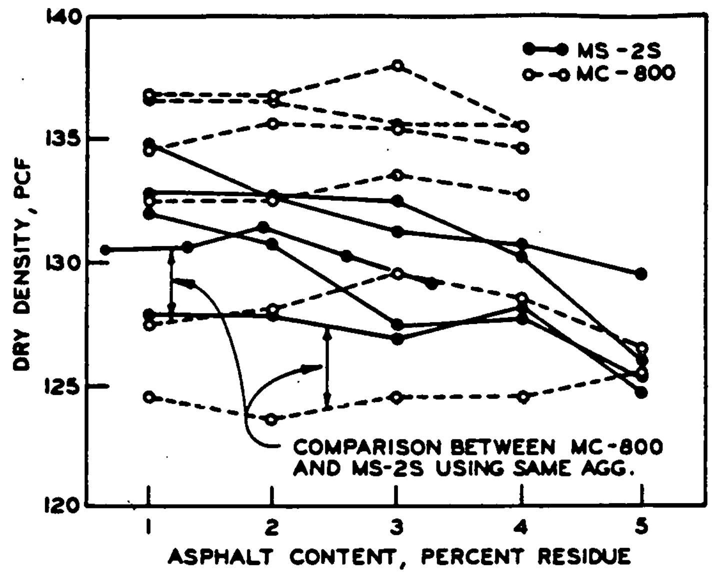


FIGURE 40 Effect of asphalt content on density of stabilized mixtures sampled from shoulder construction projects (*80*).

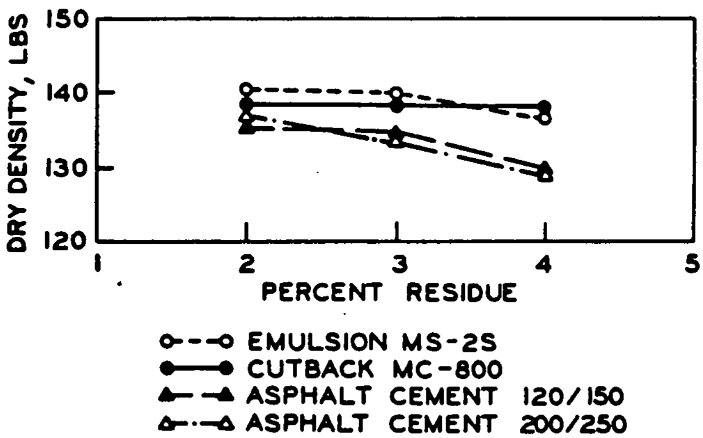


FIGURE 41 Comparison of densities obtained with different asphalt types used for stabilizing 22A aggregate at 3 percent moisture content (*80*).

content (Figure 46). Nevada's water sensitivity test (dynamic strip) is also shown to decrease with an increase in binder content. Proprietary recycling agents and CMS-2S were used in these tests.

Hveem stability and air voids were determined on core samples obtained shortly after construction and three years after construction. Air void contents decreased with time. Initial values ranged from about 10 to 15 percent. Hveem stabilities have decreased with time.

The curing conditions (28 days and ultimate cure) used in a Purdue University study (*163*) had little effect on the R value and only small changes were noted with an increase in compactive effort. A decrease in R value was noted with an increase in binder content.

RESILIENT MODULUS, FATIGUE, AND TENSILE STRENGTH

Resilient modulus data have been reported by Oregon, Nevada, Chevron, and Purdue University, among others. Fatigue test results have been obtained in Oregon.

Resilient modulus and fatigue test results were obtained on cores from seven projects in Oregon (*149,150*). These results are shown in Figure 49. Resilient modulus values in the range of 150,000 to 600,000 psi were obtained. Fatigue life was determined at an initial tensile strain level of 100 x 10^{-6}, 1 cycle per second, and under controlled load conditions.

Resilient modulus values for laboratory prepared samples in Nevada are shown in Figures 50–52. Resilient modulus cure time relationships in Figure 50 show that high strengths are

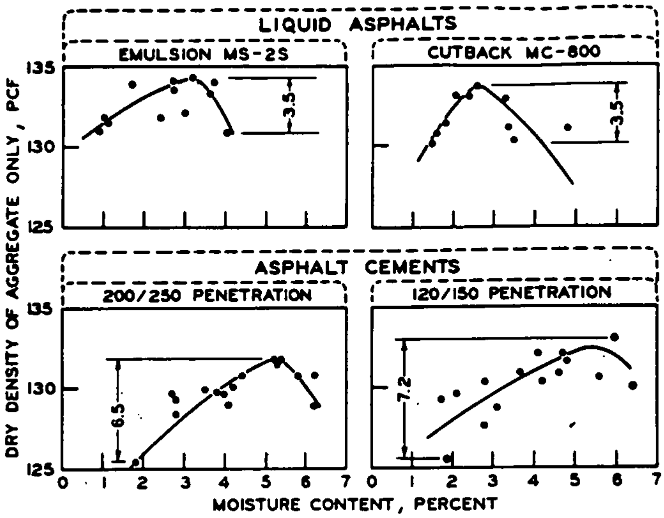


FIGURE 42 Moisture-density relationships for stabilized base aggregates blended with pulverized bituminous surfacing (*80*).

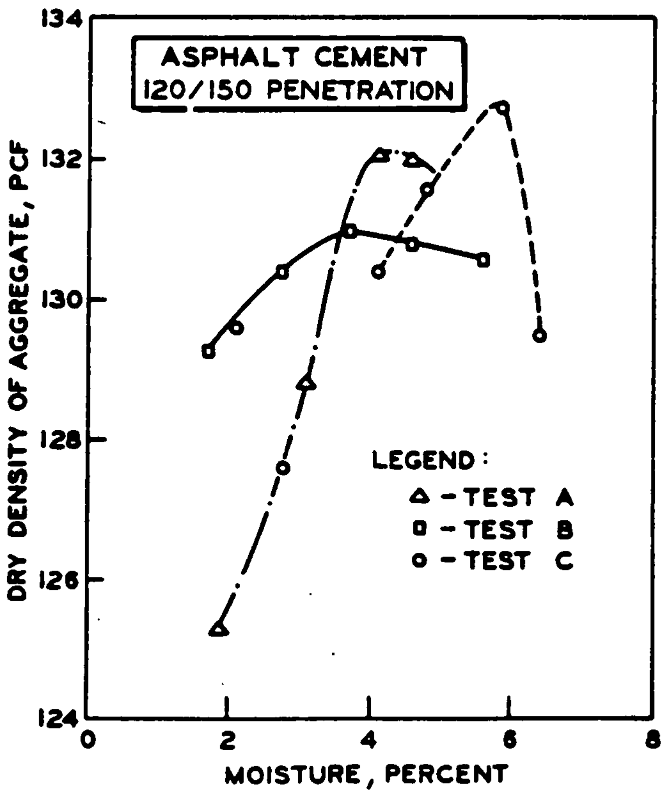


FIGURE 43 Variation of individual moisture-density curves for stabilized base aggregates blended with pulverized bituminous surfacing (*80*).

TABLE 8

FIELD AND LABORATORY DENSITY COMPARISONS (*80*)

Project No.	Laboratory Density, dry[a]	In-Place Density, dry[b]	Job-Mixed Laboratory Density, dry[c]
2	127.4	128.6	130.5
4	134.8	125.4	131.1
6	128.1	132.5	131.3

[a] Marshall density at 50 blows per face with 3 percent residue added.

[b] In-place nuclear density.

[c] Marshall density at 50 blows per face at field moisture content.

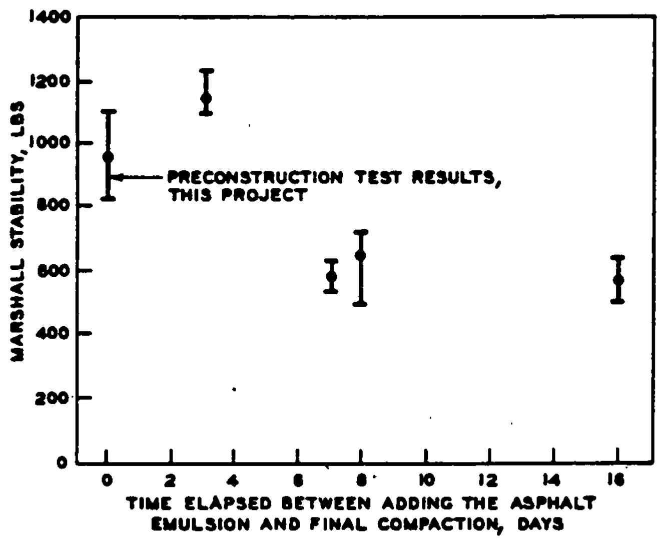


FIGURE 44 Effect of remixing and delayed compaction on stability (*80*).

TABLE 9

TEST RESULTS OBTAINED FROM SEVEN PROJECTS DURING CONSTRUCTION (*80*)

Project No.	Dry Density, pcf	Moisture Content, percent	Asphalt Content, percent residue	Laboratory Test Value					
				Marshall			Triaxial		
				Stability, lb	Flow, 1/100-in.	Dry Density	C, psi	ϕ deg	E*, psi
1	121.3	4.50	2.19	2,069	7.94	130.8	6.53	41.6	16,600
2	128.6	3.21	3.00	1,423	9.75	130.5	5.83	34.1	15,000
3	132.5	2.80	3.56						
4	125.4	3.46	3.45	2,111	12.24	131.1	7.00	45.9	18,300
5									
6	132.5	3.11	4.46	1,288	10.50	131.3	5.00	40.0	12,600
7		2.90	2.50						

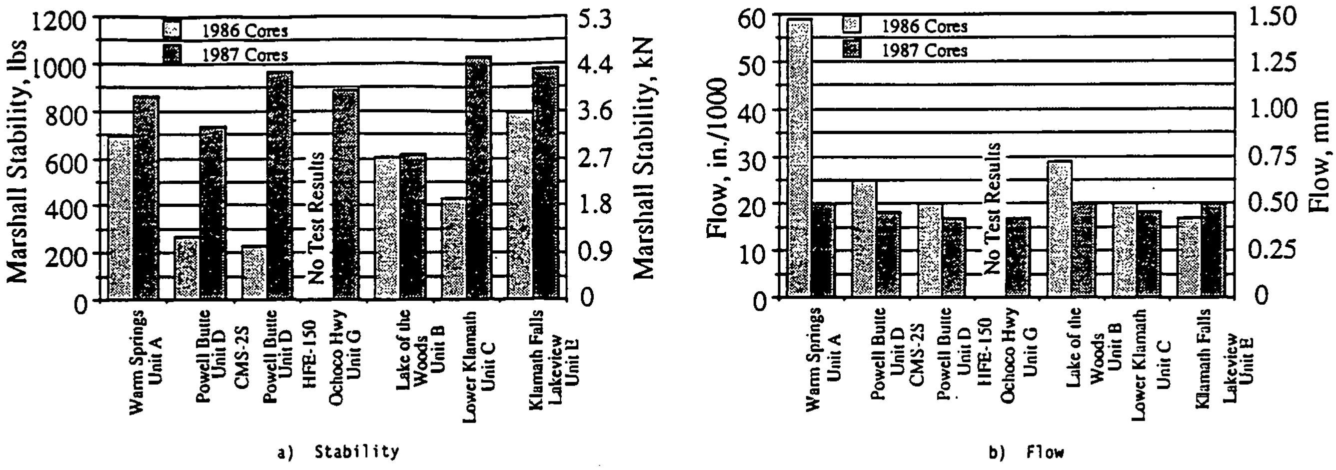


FIGURE 45 Marshall stability test results (selected 1986 projects) (*150*).

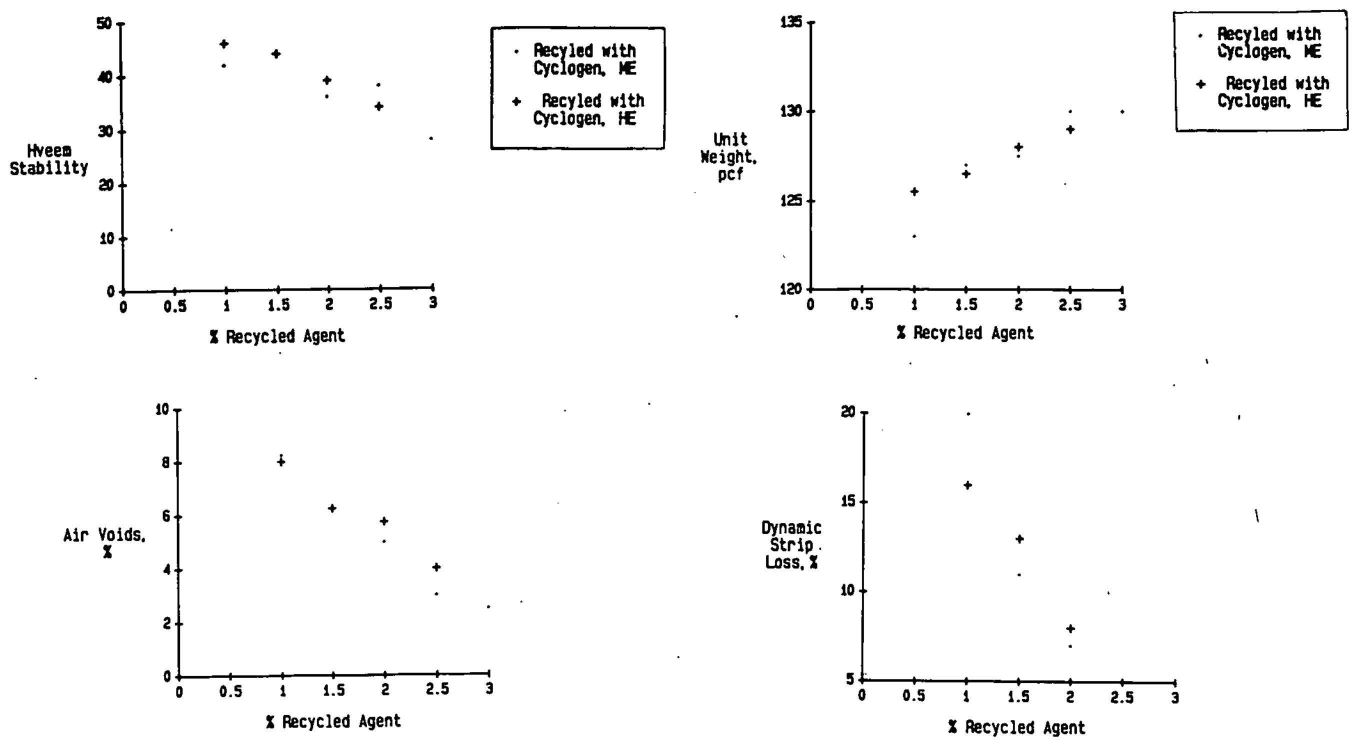


FIGURE 46 Properties of cold-recycled mixtures during mix design (*87*).

reached after about 14 days. Resilient modulus versus temperature relationships are shown in Figure 51. Saturation and a freeze-thaw cycle is damaging, whereas the saturation and 2-hr soak procedure is not damaging. Tensile strength relationships are shown in Figure 53.

Results from core samples are shown in Figures 54–58. Resilient modulus at various locations and as a function of temperature is shown in Figures 54 and 55. Values less than 200,000 psi were obtained at 77°F. These values did not increase with time in the field (Figure 55). Resilient modulus and tensile strength are shown after saturation and soaking (Figure 56) and after Lottman (1-cycle freeze-thaw) conditioning (Figures 57 and 58). Retained resilient modulus and tensile strengths of 10 to 35 percent are evident.

Chevron investigated the increase in resilient modulus with cure time (Figure 59) (*146*). Resilient modulus increased with

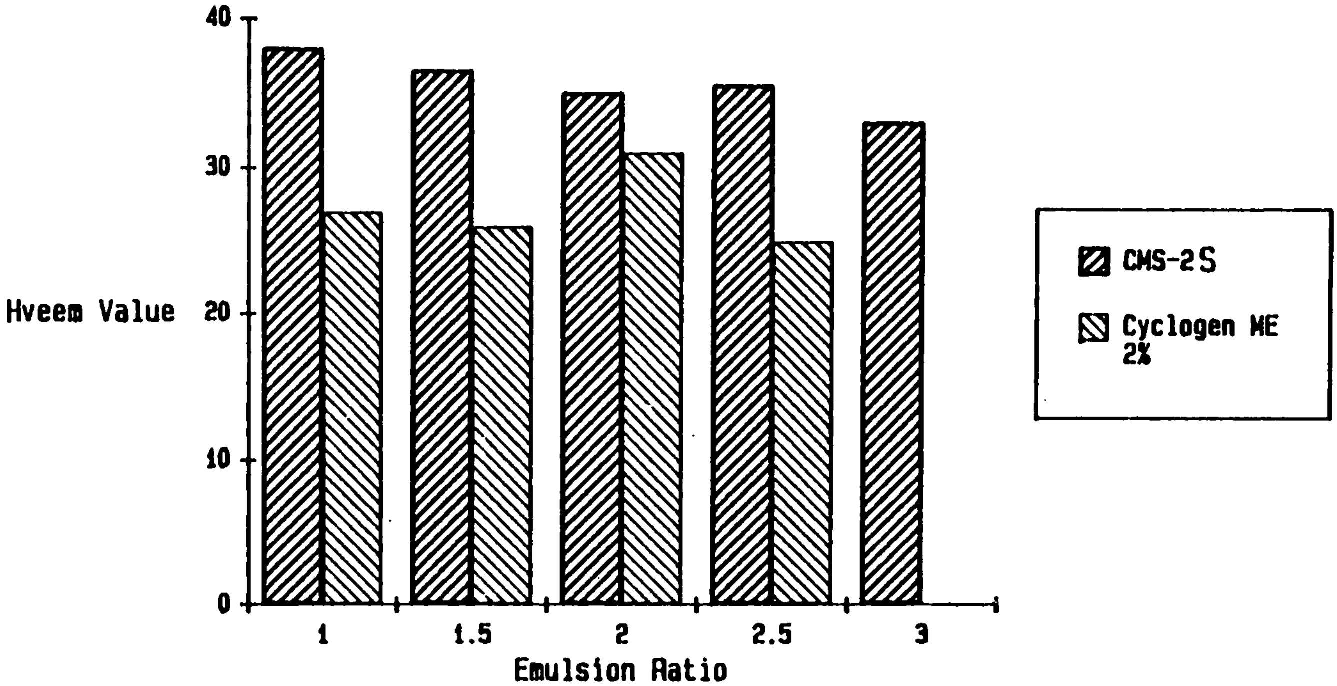


FIGURE 47 Results of Hveem testing on preconstruction samples (*88*).

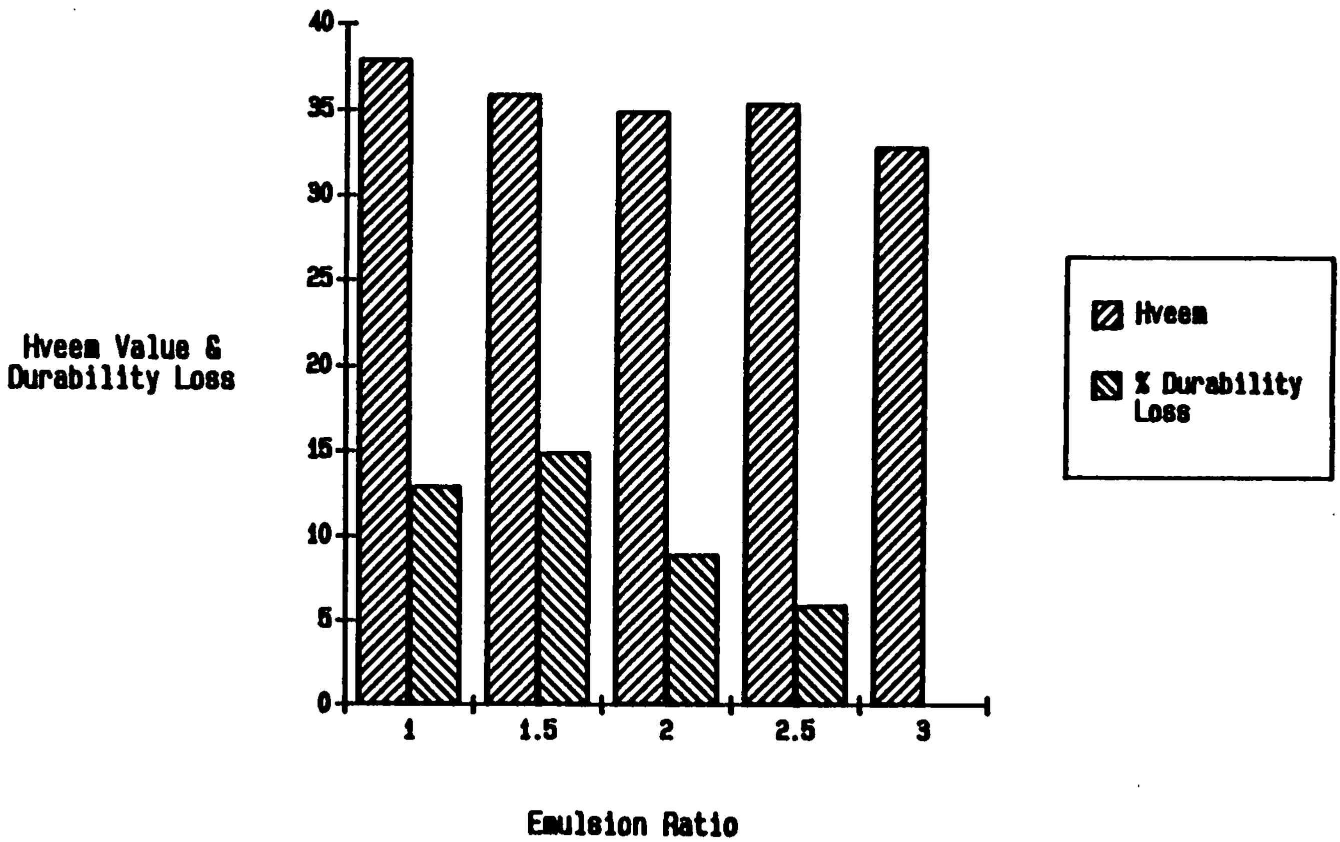


FIGURE 48 Preconstruction results of Hveem and durability testing on CMS-2S emulsion (*88*).

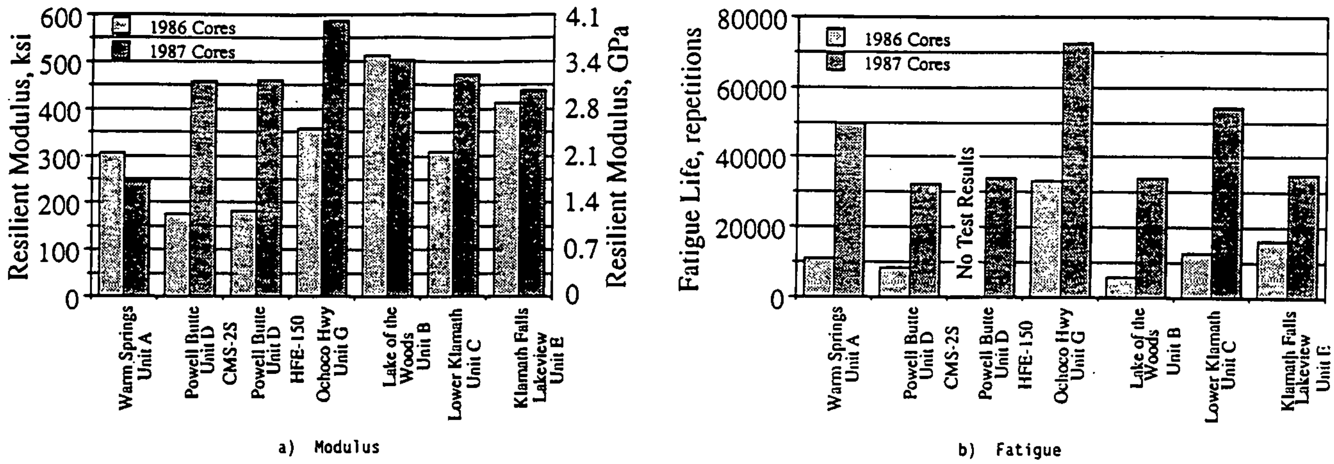


FIGURE 49 Resilient modulus and fatigue life test results (selected 1986 projects) (*150*).

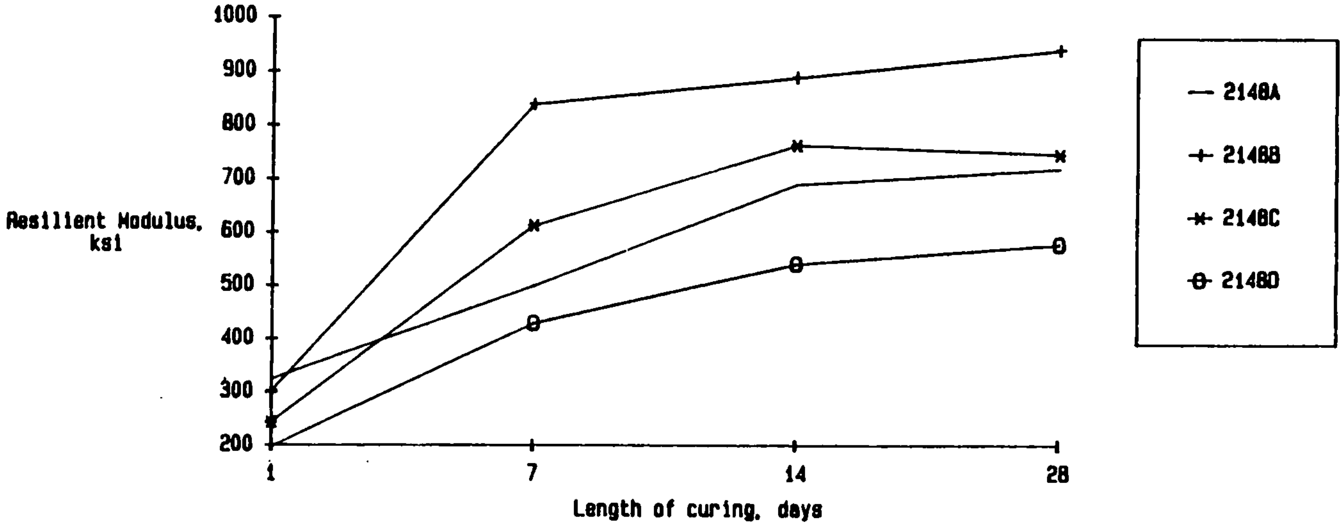


FIGURE 50 Relationship of curing times on resilient modulus for cold-mix recycling material (*88*).

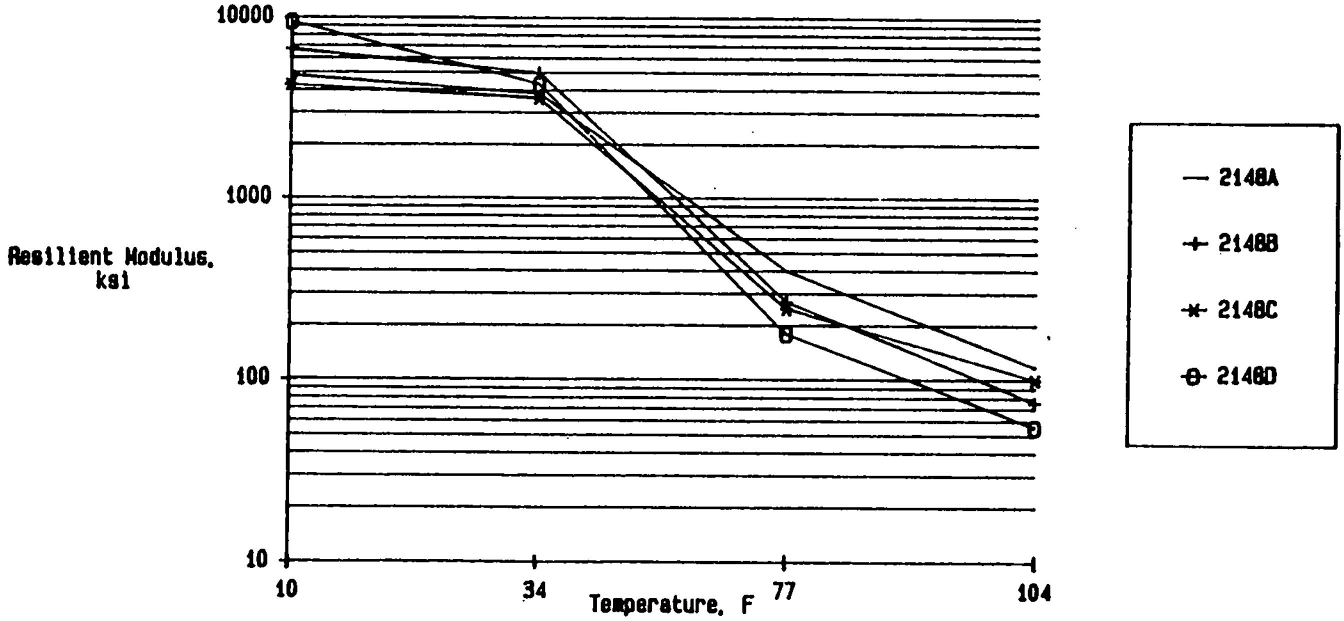


FIGURE 51 Relationship of test temperatures on resilient modulus for cold-mix recycling material (*88*).

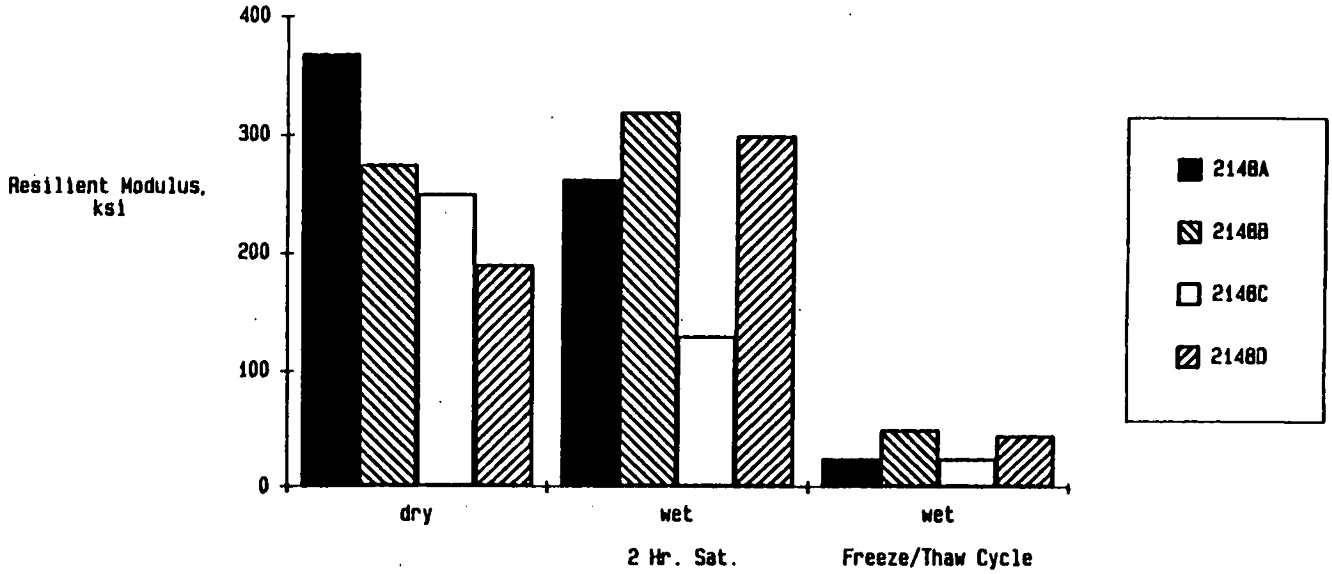


FIGURE 52 Relationship for the resilient modulus of the Lottman Accelerated Conditioning Procedure for cold-mix recycling materials (*88*).

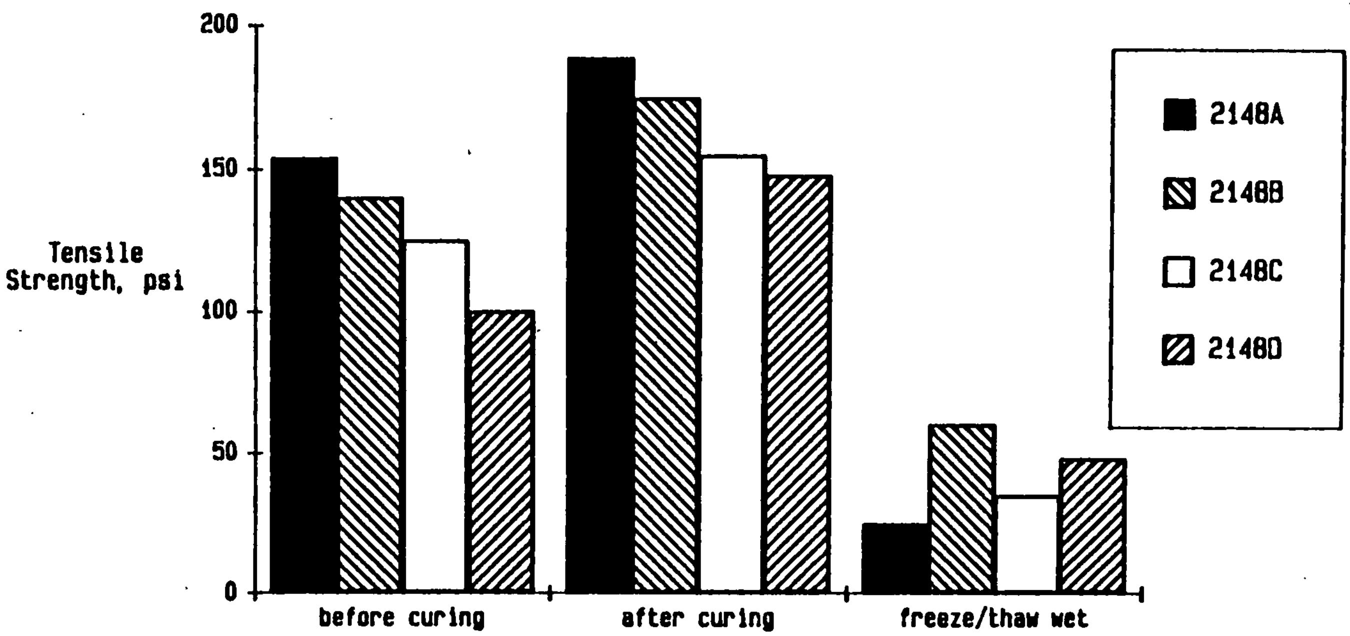


FIGURE 53 Relationship for the tensile strength, ratio values, of the Lottman Accelerated Conditioning Procedure for cold-mix recycling materials (*88*).

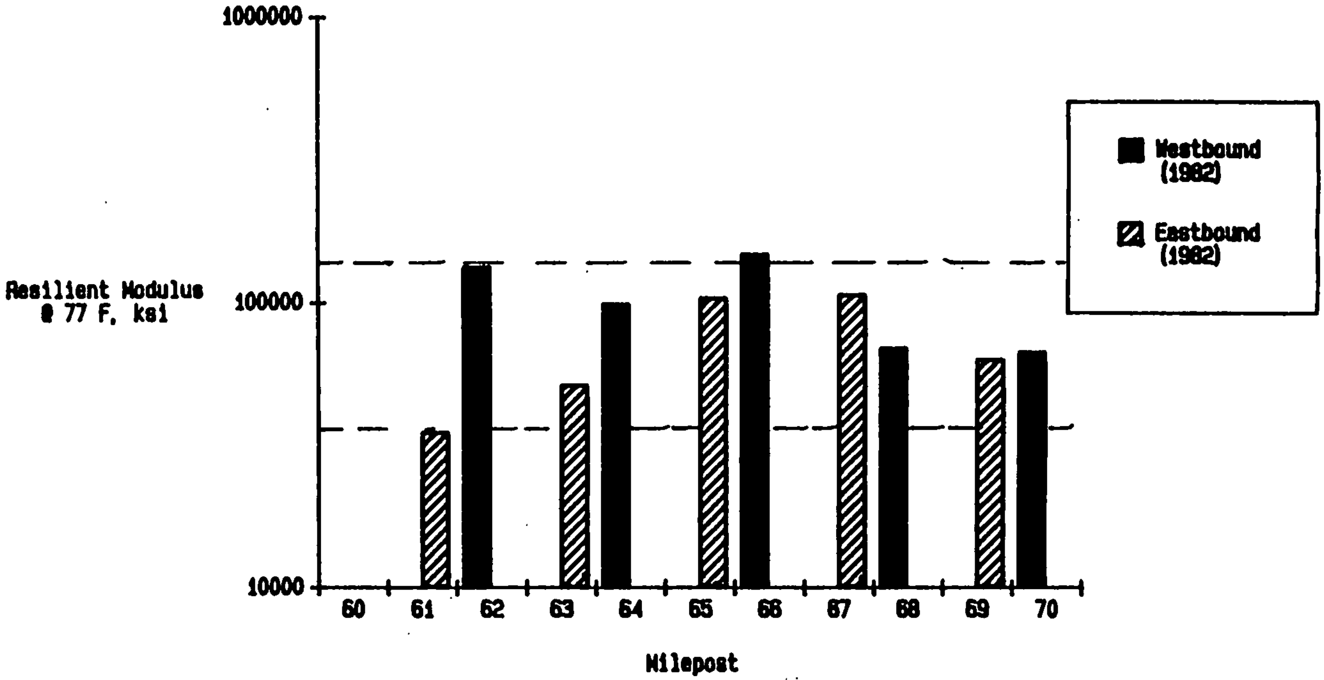


FIGURE 54 Resilient modulus at various locations within project (*87*).

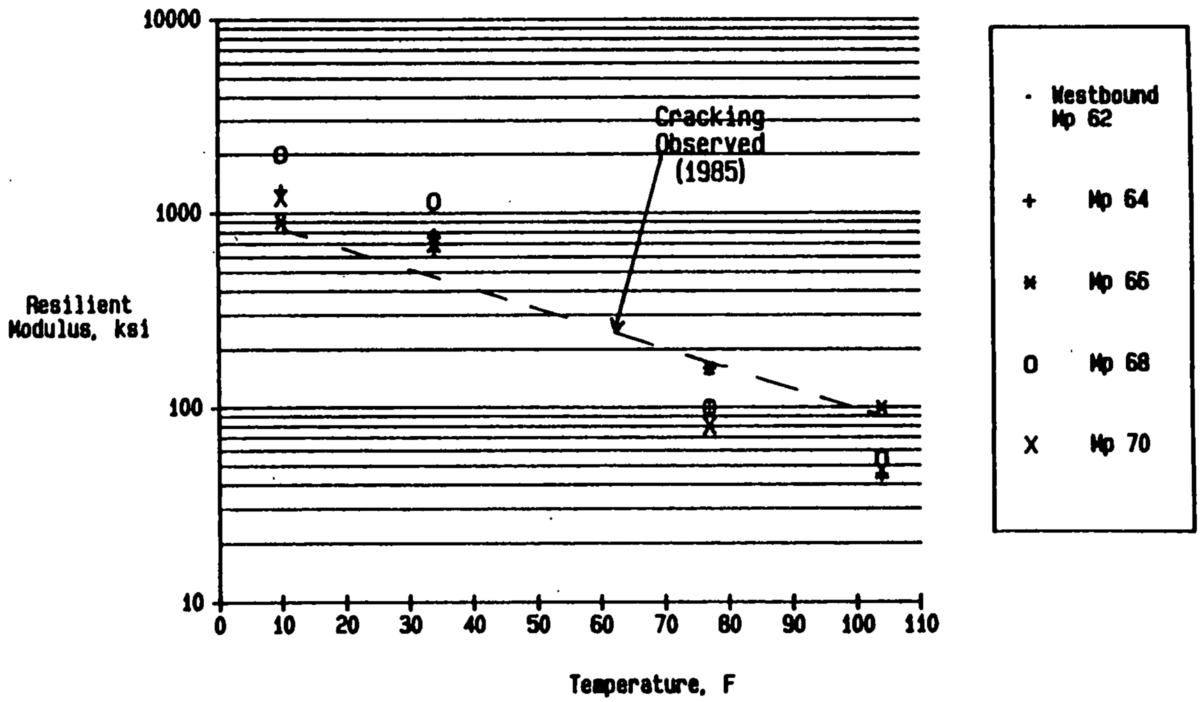


FIGURE 55 Resilient modulus versus temperature for 1985 cores samples (*87*).

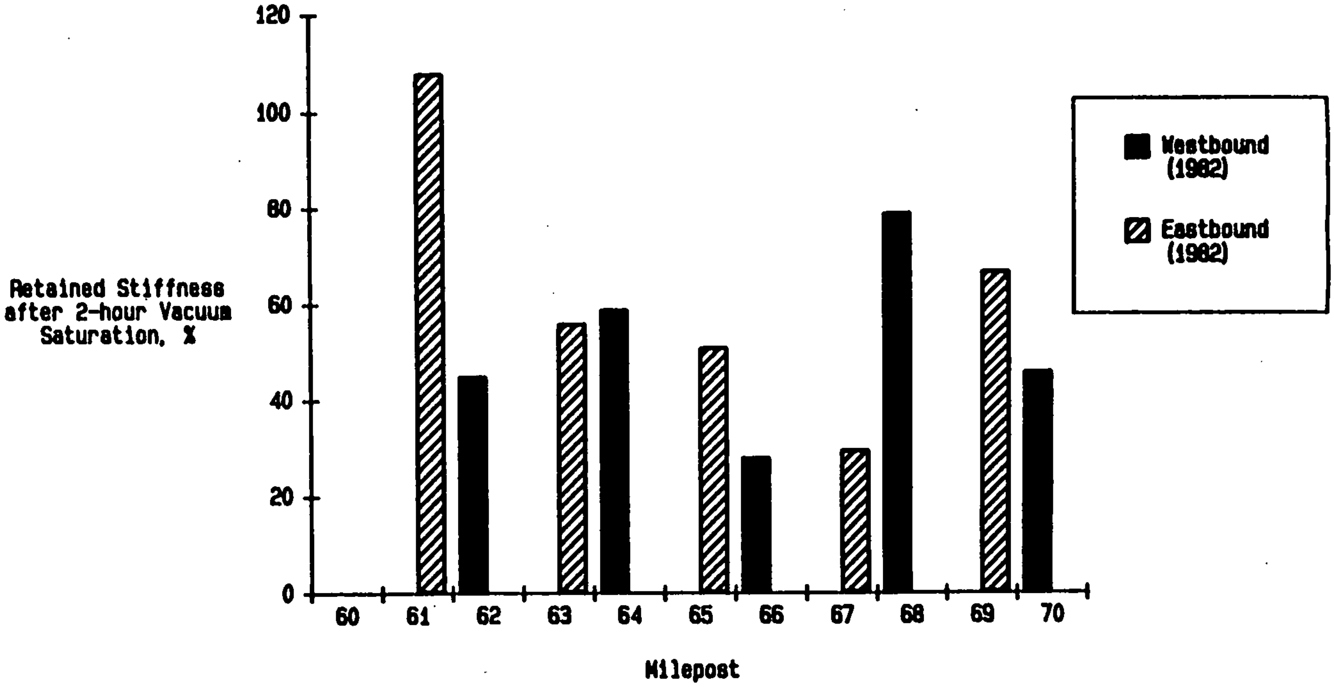


FIGURE 56 Retained resilient modulus after 2-hr vacuum saturation (*87*).

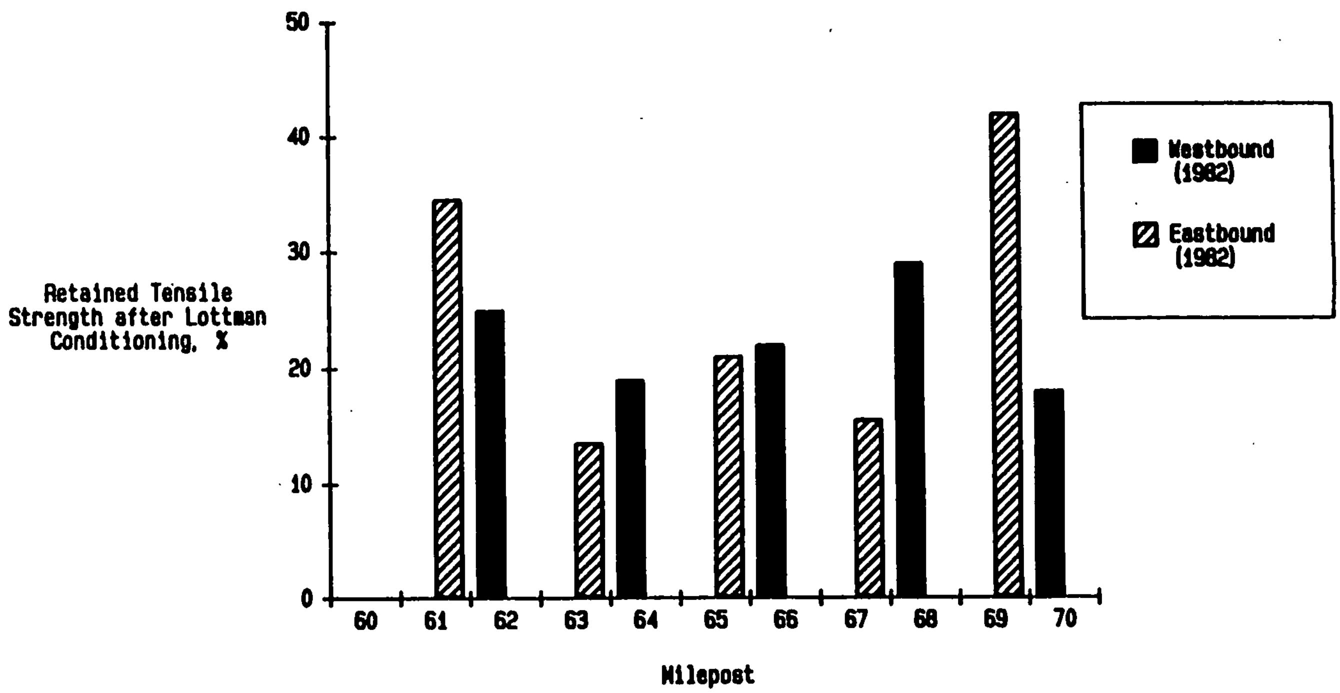


FIGURE 57 Retained resilient modulus after Lottman conditioning (*87*).

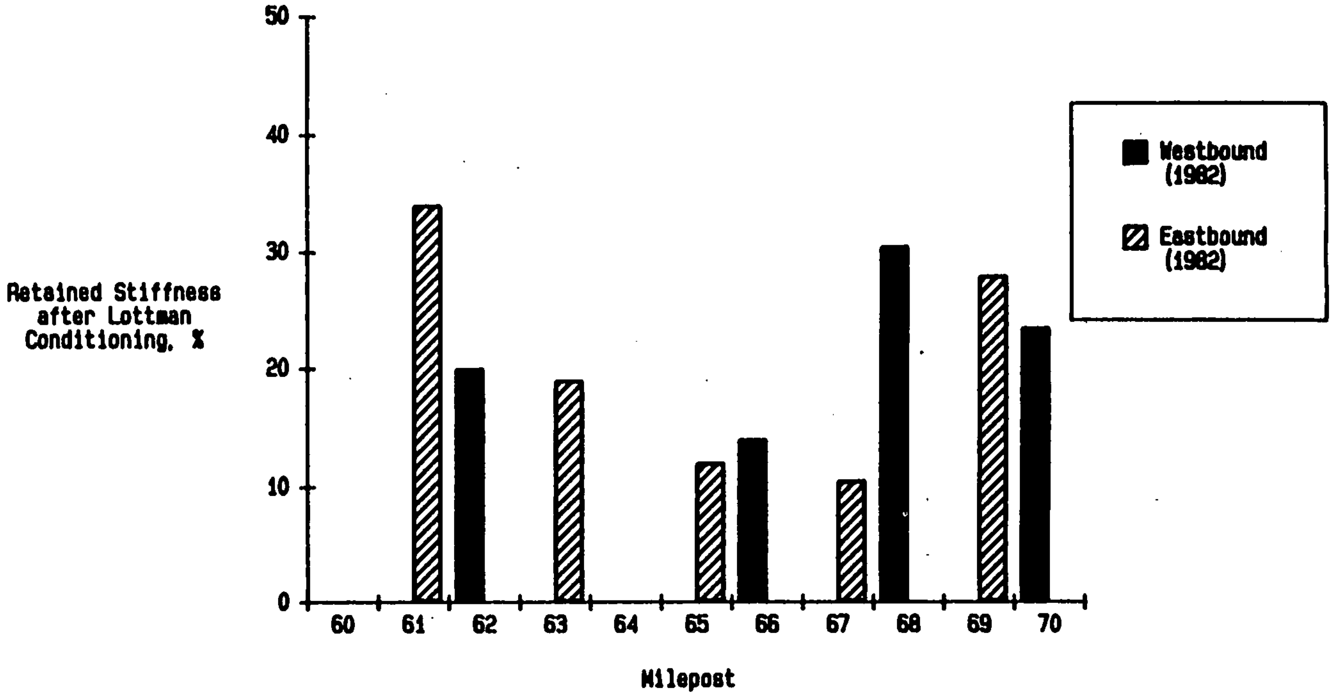


FIGURE 58 Retained tensile strength after Lottman conditioning (*87*).

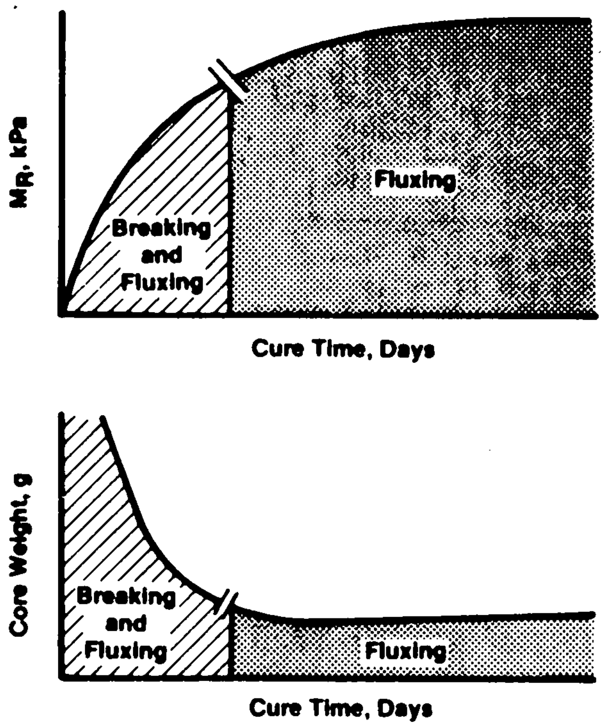


FIGURE 59 Development of modulus with cure time of cold-recycled mixes (*146*).

TABLE 10
WATER SENSITIVITY OF COLD-RECYCLED MIXES (*146*)

Recycling Agent	Dry Tensile Strength (psi, 73°F)			Wet Tensile Strength (psi, 73°F)			Retained Strength (%)		
	40°F[a]	73°F[a]	100°F[a]	40°F[a]	73°F[a]	100°F[a]	40°F	73°F	100°F
2% Recycling Agent									
Recycling Agent A	69.6	90.5	104.4	0[b]	18.2	27.6	0	20.1	26.4
Recycling Agent B	89.3	114.3	169.9	31.8	30.1	56.3	35.6	26.5	33.1
CMS-2S	92.7	130.4	191.7	28.7	39.8	92.2	31.0	30.5	48.1
CSS-1	159.8	164.9	210.8	29.2	44.6	92.7	18.3	27.0	44.0
3% Recycling Agent									
Recycling Agent B	65.7	80.8	128.4	14.6	29.9	63.7	22.2	37.0	49.6
Recycling Agent C	98.7	129.4	187.9	34.8	66.9	107.8	35.3	51.7	57.4
CMS-2S	76.4	132.7	194.2	41.3	61.1	123.5	54.1	46.0	63.6
CSS-1	138.8	171.3	226.0	53.9	76.7	129.1	38.8	44.8	57.1
4% Recycling Agent									
Recycling Agent C	87.8	104.6	144.7	48.8	66.2	104.8	55.6	63.3	72.4
CSS-1	144.3	167.1	211.5	52.6	90.0	144.3	36.5	53.9	68.2

[a] Cores cured for six months at indicated temperature.

[b] Sample fell apart during water soak.

cure time, reaching a maximum between 20 and 100 days, depending on cure temperature and recycling agent content. Resilient modulus decreased as the percentage of recycling agent increased. Resilient modulus is also affected by the stiffness of the RAP asphalt. Water-sensitivity test results are shown in Table 10 and are affected by the type and concentration of the binder.

The effect of cure time, binder content, and compaction effort on resilient modulus was studied at Purdue University (*163*). Resilient modulus increased significantly from one to seven days and leveled off after seven days. Optimum percentage of asphalt emulsion binder added increased as testing temperatures decreased.

CHAPTER FIVE

STRUCTURAL DESIGN

California (*170*), the Asphalt Institute (*37*), and Chevron (*36*) have published thickness designs for cold in-place recycled pavements. The California method determines the minimum milling depth needed to prevent reflection cracks and uses a deflection-based overlay design method for calculating required thickness.

TABLE 11

MINIMUM SURFACE COURSE THICKNESS (*36*)

Traffic Level (EAL)	Minimum Surface Course Thickness	
	(mm)	(in.)
10^4	50	2
10^5	50	2
10^6	75	3
10^7	100	4
10^8	130	5

The minimum milling depth for reflection cracking is calculated with the following equation:

$$X = (T\text{-}2Y)/3$$

where:

T = original pavement thickness (ft)
Y = virgin AC cap thickness (ft)
X = milling depth (ft)

A gravel equivalency factor of 1.5 is used by California for cold in-place recycled material.

The Asphalt Institute and Chevron methods are nearly identical, with thickness design charts provided for cold in-place recycled mixtures, depending on gradation. Minimum surface course thicknesses are specified as shown in Table 11. A typical thickness design chart is illustrated in Figure 60.

The ARRA questionnaire (*32*) indicated that most agencies assume that the structural capacity of cold in-place recycled materials is equal to that of conventional materials. In most cases conventional materials are replaced with an equal thickness of RAP without a formal structural design. Only 11 agencies reported characterizing the material for thickness design. Three agencies assign AASHTO layer coefficients between 0.14 and 0.44.

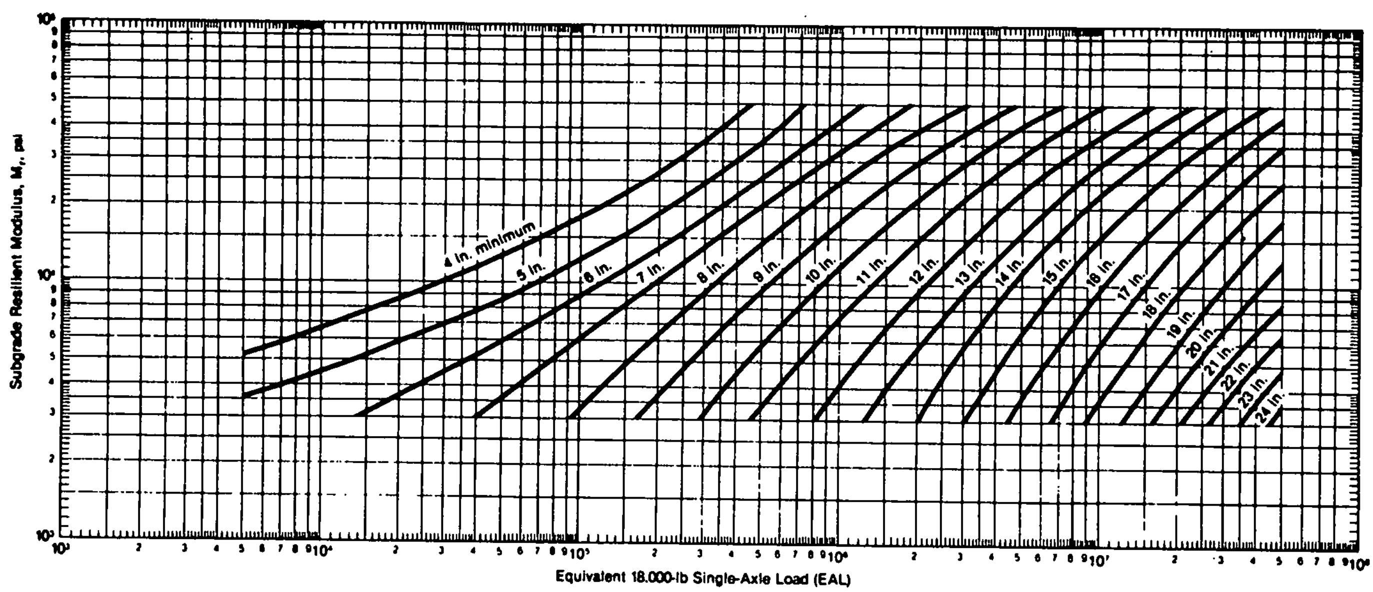


FIGURE 60 Cold-recycled mix Type II.

TABLE 12
STRUCTURAL COEFFICIENTS OF FULL- AND PARTIAL-DEPTH COLD IN-PLACE RECYCLING PROJECTS

	AASHTO Coefficient		Gravel Equivalent		Layer Coefficient		
Agency	Range	Representative Value	Range	Representative Value	Range	Representative Value	Basis of Coefficient
California (*170*)			1.5-2.5	1.5			Pavement deflection
Pennsylvania (*100*)		0.30					
Purdue (*163*)	0.25-0.40						Lab tests and pavement deflection
Texas A & M (*171*)	0.22-0.49	0.39			1.0-3.44		Lab tests and pavement deflection
ARRA (*32*)	0.14-0.44						

Table 12 summarizes available structural coefficients from the literature. The Texas A&M University study is the most extensive to date (*171*). Values appearing in this table should be used with caution because the coefficients are not only dependent on cold in-place recycled material properties but also layer thickness and traffic. The AASHTO method of pavement design can be used together with the appropriate layer coefficient to structurally design pavements with cold in-place recycled layers. AASHTO coefficients from a Purdue University study ranged from 0.25 to 0.40 (*163*).

CHAPTER SIX

PERFORMANCE

Comprehensive nationwide information on performance of cold in-place recycling is not available. The FHWA-sponsored research project to define performance of recycled pavements at Iowa State University and ARE, Inc. is limited in its evaluation of cold in-place recycled pavements. Reports that define performance of cold in-place recycled pavements are available in the literature; however, they do not use a common method of defining performance nor do they provide an equal amount of project detail. A summary of information from California (*50, 99*), Indiana (*132*), Kansas (*172*), Maine (*74*), Nevada (*88*), New Mexico, Oregon (*42, 149, 150, 152*), and Pennsylvania (*100*) is presented below.

CALIFORNIA

California DOT (*50, 99*) mandates the recycling of asphalt concrete materials unless it can be demonstrated that recycling will not result in a significant savings in energy, nonrenewable resources, and cost (*50*). Performance of cold-recycled pavements has been mostly encouraging with stable, performing pavements. California requires 0.15 ft of asphalt concrete to be placed on a surface course on all projects.

Table 13 gives the performance of 13 recycling projects completed during 1979 to 1983 in California. Performance up to five years after construction is provided. One project is reported as failed, two as poor performance, one as fair performance, and nine as good performance. Definitions associated with ratings are shown in Table 14 (*50*).

The 09-KER-178 project failed within three months of construction because of extensive instability and rutting caused by moisture vapor. Four percent moisture was contained in the cold-recycled material at the time of overlay. Moisture vapor was transported together with asphalt to the asphalt concrete overlay from the cold-recycled layer, causing loss of stability. Air temperature reached 120°F during this period. Specifications now limit the moisture content to 1.5 percent in the cold in-place recycled material at the time of overlay (*50*).

Poor performance on the 11-IMP-98 project was associated with nonuniform distribution of the binder. A "mill and mix" unit was used for the first time in California on this project (*50*).

Poor performance has been noted on the Kern County project because of excessive binder content. Incomplete mixture design was performed and the project failed by bleeding and rutting within three weeks of construction (*99*).

INDIANA

Roughness, deflections, and visual inspections are being used to define the performance of 1986 cold in-place recycling projects in Indiana (*132*). After one year of service, the recycled pavement is performing better than the conventional pavement. Transverse reflection cracks and longitudinal cracks where the pavement was widened are beginning to develop in the resurfaced section. Cracks have not appeared in the recycled section.

KANSAS

Kansas (*172*) reports pavements containing cold-recycled asphalt concrete exhibit less reflective cracking if the existing mat is left thin enough so that less mass is available to reflect cracks upward but thick enough to form a solid base for the equipment (Figure 61). Rut depths are larger in cold-recycled pavements compared with conventional and hot-recycled pavement sections (Table 15). Sections that contained "rejuvenations" have slightly more rutting than the other sections. Kansas uses MS-1 HF emulsion to control rutting of the cold in-place recycling sections and allows curing before placing the surface.

MAINE

Deflection, rut depth, ride quality, and a crack study have been performed on recycled pavements in Maine (*74*). Based on three years of performance, cold in-place recycling has virtually eliminated reflective cracking problems and can help solve frost problems. Deflection and rut measurements indicate that cold in-place recycling with and without the addition of binder does not produce the same load-carrying ability as that of conventional black bituminous base. Strength reductions were noted with moisture and frost action. Bituminous binder should be used with cold in-place recycling when excessive fines are present.

NEVADA

Cores have been obtained and visual condition surveys have been conducted on two Nevada projects (*87, 88*). After seven years of service, one project has areas of bleeding and minor cracking. A large portion of the project has no distress. The bleeding is probably caused by improper seal coat quality control or design.

A three-year-old project showed center construction joint raveling the first winter after construction. No other distress is evident on the project.

TABLE 13

CALIFORNIA COLD IN-PLACE RECYCLING PROJECTS (*50*)

Dist,Co,Rte	Date Bids Open/ Fin.	Tons	Contract Number	Status	Salvaged AC Binder		Mix Formula Salv./ Virg.	Recy. Agent		Performance	
					Pen.	Visc(1)		Source	Grade	Date Review	Rating
05-Mon-101 (Chualar)	6/82 9/82	5,500	284604	*	3	$5x10^6$	100%	Witco	25	1/83	Good
05-SB-101 (Goleta)	10/82 5/83	17,000	284804	*	4	$4x10^6$	100%	Witco	25	9/83	Good
06-Ker-204 (Bakersfield)	4/82 7/82	1,800	207304	*	7	$2x10^5$	100%	Witco	75	10/83	Good
06-Kin-6th (Corcoran)	7/80 6/81	11,700	445144	*	2	$10x10^6$	100%	Witco	5	11/82	Good
06-Tul-99 (Kingsburg)	5/82 8/82	1,600	211804	*	4	$5x10^5$	100%	Chev.	5 (CEMA 1)	11/83	Good
06-Fre-41 (Sierra-Herndon)	3/83 6/83	800	236104	*	5	$4x10^6$	100%	Witco	5	8/84	Good
08-SBd-395 (Adelanto)	3/82 8/82	50,000	231304	*	22	$7x10^4$	100%	Koch	25	2/85 4/86	Good FAIR
09-Mno-395 (Crowley Lake)	4/81 8/81	6,400	086204	*	31	$5x10^3$	100%	Witco	25	2/85 12/85	Good(2) POOR
09-Iny-395 (Bishop)	6/79 12/79	17,900	074704	*	8	$2x10^5$	100%	Witco	25	2/85 12/85	Good GOOD
09-Ker-178 (Inyokern)	10/81 2/82	12,000	070904	*	7	$2x10^6$	100%	Witco	5	5/82 12/82	FAILED Failed
11-Riv-10 (Chiriaco)	3/80 6/80	2,000 T	189914	*	?	?	100%	Witco	5	2/85	Good
11-Imp-98 (Ocotillo)	3/83 7/83	4,100	158034	*	22	$9x10^4$	100%	Koch	RH-75	2/85 12/85	FAIR POOR
06-Imp-OCO (FAS)	3/83 8/83	38,000	145684	*	No	Data	IMPERIAL	COUNTY	PROJECT	8/84	Good

TABLE 14
RATING CRITERIA FOR RECYCLED AC (*50*)

Rating	Description
A = Excellent	Minimal amount of cracking - nothing over 1/4" wide; no raveling, rutting, flushing, or potholing.
B = Good	Minimal amount of cracking - nothing over 1/4" wide; and/or slight raveling, or rutting; no flushing or potholes.
C = Fair	Moderate amount of cracking - a few over 1/4" wide; and/or moderate raveling, rutting, and flushing with no potholes.
D = Poor	Considerable cracking and/or raveling, or rutting, or flushing, or occasional potholes, and/or considerable patching.
E = Failed	In immediate need of maintenance work due to - extensive cracking, or rutting, or flushing, or potholing, or raveling, or any combination.

NEW MEXICO

As of February 1987, New Mexico had placed 277 miles of cold in-place recycled pavements on 54 projects (personal correspondence with D. Hanson). Deflection measurements and cores have been obtained on these projects. Only one project shows evidence of distress (rutting). Projects were constructed from 1984 to 1986.

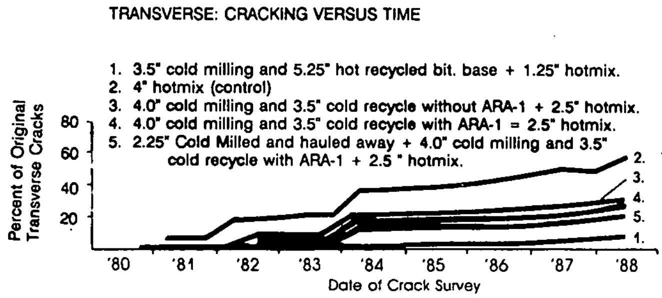


FIGURE 61 Kansas DOT performance information from Scott County (*172*).

OREGON

Extensive performance evaluations of Oregon cold in-place recycled pavements have been conducted (*42, 149, 150, 152*). Of the 52 pavements evaluated, 47 (90 percent) have good or very good performance. Five pavements (10 percent) have poor performance. The projects are divided into "classes of treatment," which are defined as follows:

- Class I—Recycling performed on a uniform pavement built to specifications.
- Class II—Recycling performed on a pavement with significant maintenance patches over a uniform pavement.
- Class III—Recycling performed on low-volume highways where considerable variation in pavement structure exists.

Oregon has used the performance data to revise its mixture design and construction operations as well as selection of binder for the cold in-place recycling operation. More than 450 miles have been placed in Oregon.

TABLE 15
KANSAS FULL-DEPTH COLD IN-PLACE RECYCLING - K-96 TEST PAVEMENT (*172*)

		Rut Depths (in.)				
		Westbound		Eastbound		
Method	Station	Outer Wheelpath	Inner Wheelpath	Inner Wheelpath	Outer Wheelpath	Average
Hot recycle	210 to 230	0.375	0.375	0.188	0.25	
		0.313	0.25	0.125	0.188	0.25
Control	220 to 230	0.125	0.125	0.125	0.125	
		0.063	0.188	0.125	0.250	0.125
		Bleeding spots in this section				
Cold recycle	230 to 235	0.313	0.188	0.188	0.313	
		0.250	0.188	0.188	0.375	0.25
Cold recycle	235 to 243+20	0.563	0.563	0.500	0.688	
		1.000	0.813	0.313	0.438	0.625
		Bleeding spots in this section				
Cold recycle	243+20 to 256+40	0.438	0.250	0.625	0.500	
		0.938	0.625	0.250	0.313	0.500
		Bleeding spots in this section				

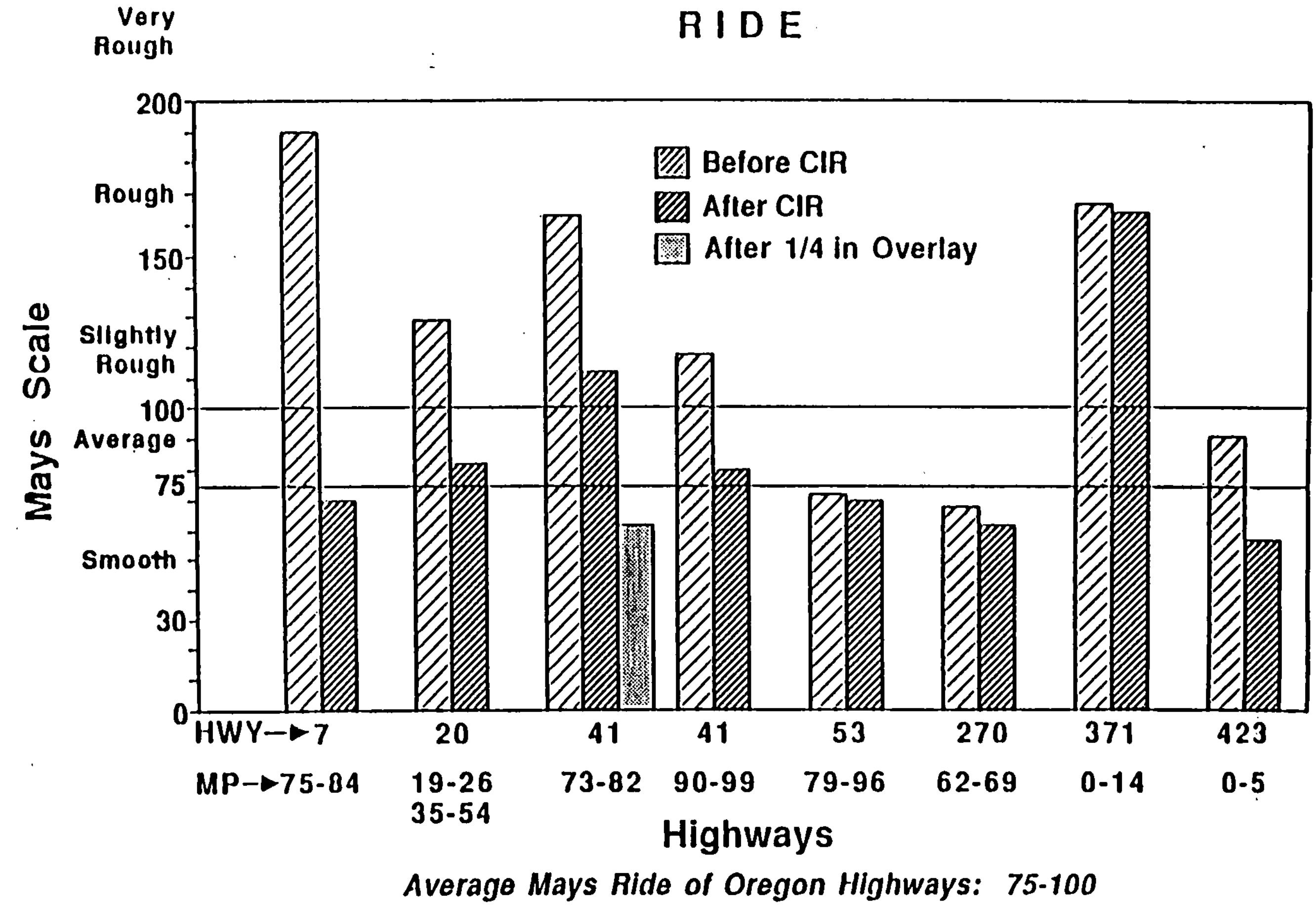


FIGURE 62 Before-and-after ride data, 1986 central Oregon projects (*149*).

Pavements that have shown poor performance can be traced to the following causes:

- Too high a recycle agent content in the early years. Contents more than 2 percent with 7 to 10 percent diluent were shown to create excessive softening.
- Placing a tight seal or dense wearing course too soon, resulting in trapping water and diluent, followed by stripping and rutting.
- Depth of recycle stopped at a delaminated layer of old pavement, resulting in loss of bond.
- Failure to provide some type of seal before freeze/thaw conditions.

Figure 62 illustrates the improvement in ride quality that can be achieved with cold in-place recycling.

PENNSYLVANIA

The Pennsylvania Department of Transportation had completed about 90 cold-mix recycling projects by the end of 1985 (*100*). Experience with these projects indicates a need for obtaining optimum moisture content in the RAP material so that the emulsified asphalt can be dispersed effectively in the mix. Recycled mixtures are usually susceptible to damage from moisture intrusion and abrasion by traffic. The placement of a surface is necessary to avoid raveling and potholing. The guidelines in Table 16 have been recommended in selecting a candidate project for cold recycling. Projects carrying a significant amount of heavy truck traffic should not be selected for cold recycling. Cold recycling should not be attempted if the existing road has inadequate drainage.

TABLE 16
GUIDELINES FOR USE OF COLD RECYCLING IN PENNSYLVANIA

Average Daily Traffic	Wearing Surface
1,500 or less	Surface treatment (double application) as a minimum
1,500 to 3,000	Hot-mix wearing course
More than 3,000	Do not use cold recycling

CHAPTER SEVEN

ECONOMICS

Economic evaluation of alternative pavement rehabilitation strategies should consider initial and recurring costs. These costs include:

- Agency costs
  Initial capital costs of rehabilitation
  Future capital costs of reconstruction or rehabilitation (overlays, seal coats, etc.)
  Maintenance costs recurring throughout the design period
  Salvage return or residual value at the end of the design period
  Engineering and administration
  Costs of investments
- User costs
  Travel time
  Vehicle operation
  Accidents
  Discomfort
  Time delay and extra vehicle operating costs during resurfacing or major maintenance
- Nonuser costs

Definition of many of these costs is difficult, and other costs do not significantly affect the analysis for alternatives for a given roadway segment. Simplistic methods of economic analysis consider only:

- Initial capital costs
- Future costs of reconstruction or rehabilitation
- Maintenance costs
- Salvage values

TABLE 17
FULL- AND PARTIAL-DEPTH COLD IN-PLACE RECYCLING COST DIFFERENCES

		Cost Difference (%)[a]		Cost of Cold In-Place Recycling ($)		
Agency	**Year**	**Range**	**Rep. Value**	**Range**	**Rep. Value**	**Comments**
California (*99*)	1979-83	15-43	31	14.71-24.32/ton	20.16/ton	Relative to conventional mix
California (*40*)			37		22.00/ton	
California (*46*)	1980		21		5.17/sq. yd.	Relative to equivalent section
Illinois (*56, 57*)	1982				3.80/sq. yd.	
Indiana (*64*)	1976			11.95-22.00/ton		
Iowa (*65*)	1988		67		6.90/ton	Relative to asphalt concrete
Kansas (*70*)	1977		53			Relative to equivalent section
Kansas (*172*)	1988					See Table 18
Missouri (*181*)	1978		50			Relative to equivalent section
Montana (*86*)	1978		21		21.59/ton	
New Mexico[b]	1984-86			1.05-2.00/sq. yd.	1.40/sq. yd.	Average 2.6 in. of recycling
N. Carolina (*180*)[c]	1977		6		3.99/sq. yd.	Relative to equivalent section
Oklahoma (*92*)	1979				3.46/sq. yd.	
Oregon (*41*)	1984		24	1.81-2.42/sq. yd.	2.00/sq. yd.	Relative to equivalent section
Pennsylvania (*98*)	1983		16			Relative to equivalent section
Vermont (*107*)	1978		28		7.90/sq. yd.	Relative to equivalent section
Vermont (*108*)	1982		31		1.37/sq. yd.	Relative to equivalent section
Wisconsin (*111*)	1978				0.29/sq. yd.-in.	
FHWA (*114*)					4.72/sq. yd.	

[a] Relative to commonly used rehabilitation alternatives used by identified states.

[b] Personal communication with D. Hanson (1987).

[c] Cost increase on one project.

Initial capital costs of cold in-place recycling operations can be found in References *32, 36, 40, 41, 46, 47, 49, 56, 57, 64, 65, 70, 83, 86, 89, 92, 97–99, 111, 113, 114, 121, 138,* and *173–181.* Table 17 gives a summary of capital costs. Detailed performance histories are not available to allow for the time scheduling of rehabilitation and maintenance operations. Thus, detailed life-cycle cost information does not appear in the literature. However, preliminary performance information obtained from state records indicates that significant life-cycle cost savings will be obtained when comparisons are made between conventional overlay techniques and cold in-place recycling operations. In some instances the first cost of cold in-place recycling will be greater than conventional overlays; however, improved performance and the use of stage construction techniques with the cold in-place recycling option will lower life-cycle costs. First-cost data are discussed below.

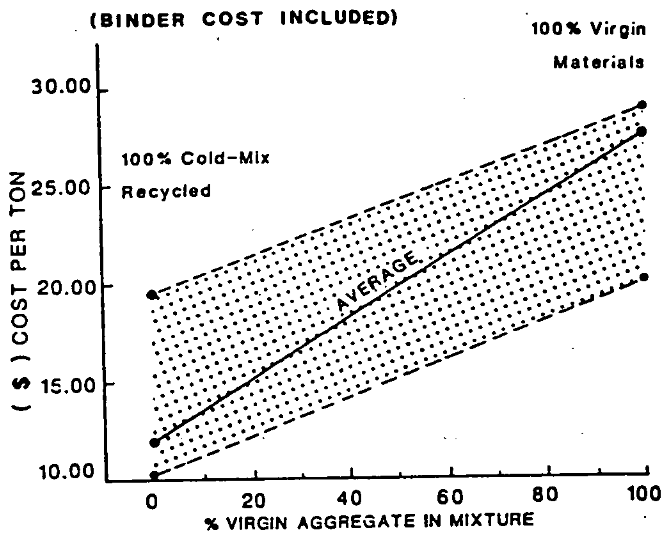


FIGURE 63 Effect of varying amounts of virgin aggregate on the cost of asphalt mixtures (*156*).

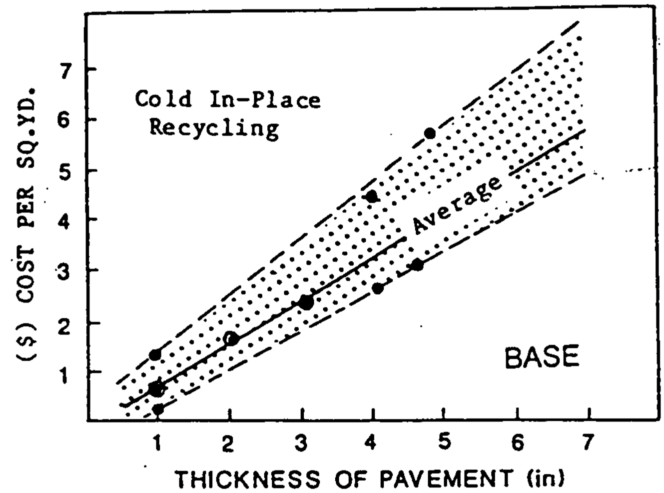


FIGURE 64 Cost of cold in-place recycled material (*156*).

A review of the FHWA Demonstration Project 39 reports, as well as other information, indicates the following component costs for cold in-place recycling operations:

- Materials 46.6 percent
- Equipment 29.7 percent
- Labor 23.7 percent

The main economic advantage that recycling offers is in material cost savings. The majority of the material costs are associated with new binder. Increases in new aggregate will increase recycling costs as shown in Figure 63. Typical square yard costs for cold in-place recycling operations are shown in Figure 64 (*156*).

First costs of cold in-place recycling operations are project dependent, and, hence, generalizations should be used as guides only. First-cost savings of 6 to 67 percent are reported in the literature (Table 17).

CHAPTER EIGHT

SPECIFICATIONS AND QUALITY CONTROL

Specification and quality control procedures for cold in-place recycling operations have been developed by a number of state highway agencies. Appendixes F, G, and H contain the specifications developed by Michigan, Pennsylvania, and the Asphalt Recycling and Reclaiming Association and used primarily for full-depth cold in-place recycling operations. Appendixes I and J contain specifications developed by Oregon and New Mexico for partial-depth cold in-place recycling operations. These specifications contain elements of both method specifications and end-result specifications.

These types of specifications rely on the expertise of the public agency, contractors, material suppliers, and equipment manufacturers to obtain the desired end product at a reasonable cost. A discussion of the general elements of the specification and quality control guidelines follows.

SPECIFICATIONS

Most cold-asphalt recycling specifications tend to focus on the material properties of the reclaimed material and of the recycled mix rather than on the exact methods of construction. Specifications are often written to allow for the use of a wide variety of in-place equipment provided the recycled mix meets the job specification for depth, maximum particle size, and gradation. The typical specification for cold-mix recycling will contain sections on some or all of the following topics:

- Overall description of work
- Materials (RAP, new aggregate, asphalt binder, water)
- Equipment
- Method of construction
  - Scarification and pulverization
  - Addition of asphalt modifier and mixing
  - Aeration
  - Spreading
  - Compaction
- Approval of job-mix formula
- Inspecting, sampling, and testing
- Quantity and basis of payment for each material
- Wearing course (asphalt concrete, chip seal coat, slurry seal, etc.)
- General (weather, traffic control, safety, etc.)

MATERIALS

The primary materials specifications deal with aggregate gradation, asphalt binder type, asphalt binder content, water content (if applicable), and density requirements.

Maximum Size

Most specifications limit the top size of the RAP produced by the pulverization equipment. Some public agencies require 100 percent passing the 25.0-mm (1-in.) sieve. This type of specification can be overly restrictive (and can slow down the recycling process). The top size of milled or pulverized material is a function of (*38*):

- Condition of existing pavement (if alligator cracking is present, oversized pieces will most likely be produced),
- Top size of original aggregate,
- Speed of milling (higher speeds produce larger sizes), and
- Depth of cut (thicker cuts tend to produce chunks of greater size).

The preferred alternative is to allow some oversized material to be present in the recycled mix by specifying a minimum percentage for the nominal maximum size instead of placing restrictions on top size [e.g., 97 percent passing the 38.1-mm (1½-in.) sieve with no chunks larger than 4 in. or with the remaining 3 percent not so large as "to affect adversely the stability and structural integrity of the mixture nor to hamper the shaping operation" (*38, 142*).

Aggregate Gradation

It is not practical to have the aggregate gradation of the RAP specified for all sieve sizes because of the variability associated with the pulverization process. However, consideration should be given to the amount passing the 75-μm (No. 200) sieve because milling tends to increase the filler content by two to three percentage points (a maximum of 12 percent is reasonable). Because of the variability of the material being cold recycled, allowance must be made in the specification (from the viewpoints of both engineering and economics) such that the gradation reflects what is present in the roadway and not what the designer considered to be optimum values (*38*). In addition to meeting RAP gradation requirements, the scarification and pulverization equipment should also be capable of reasonable accuracy in cutting the existing pavement to a specified depth.

Asphalt Binder

The specified asphalt binder should conform to the appropriate standard AASHTO, ASTM, or state specifications for emulsified asphalt, cutback asphalt, emulsified recycling agents, viscosity-graded asphalt cement or penetration-graded asphalt cement. Specifications for emulsified recycling agents have been developed by a committee of the Pacific Coast User-Producer Conference on Asphalt Specifications (Table 3) (*43*).

Binder Content

The equipment for adding the modifier should be capable of an accurate application rate such that the total binder content of the recycled mix is equal to the job-mix formula amount within a specified tolerance, typically ± 0.5 percent. Provision should also be made for the accurate application of any required pre-mix water as specified by the job-mix formula.

Job-Mix Formula

The responsibility for establishing the job-mix formula and required sampling procedures, test methods, and design criteria for the mix design needs to be clearly outlined in the job specifications. The specifications for full-depth cold in-place recycling generally do not place limits on the amount of RAP in the mix, unless additional aggregate material is required to increase the thickness of the stabilized layer. Extraction and recovery tests, which are part of the mix design process, can be used to determine if any new aggregate is needed to improve the quality of the RAP.

New Aggregate

If new aggregate is to be incorporated into the recycled mix, the aggregate should be tested for compliance with standard specifications for virgin aggregate such as sand equivalence, resistance to abrasion, and so forth.

EQUIPMENT

Equipment specifications for the various phases of construction can be either the method or end-result type. The user agency's choice of which to use will depend on factors such as contractor and equipment availability, economics, and the desired quality of work.

DENSITY

A major item in the job specifications is the required density of the compacted mix, which can be specified in one of three ways:

- Percentage of theoretical maximum density
- Percentage of laboratory density
- Percentage of field density

Some agencies recommend the use of percentage of theoretical maximum density instead of percentage of lab density. Agencies citing the problem with variation in the original pavement suggest that a target density (i.e., an actual density in lb/ft^3 or other units) combined with a rolling pattern that can be changed may be the most realistic type of density specification (*139*). This control-strip approach is used in Nevada and Pennsylvania.

The extent of agency experience with cold recycling and environmental factors will probably determine which type of density specification is appropriate. Typical specifications require air void contents in the 12 to 15 percent range.

To summarize, specifications for cold-mix recycling have evolved from soil stabilization and other cold-mix type specifications. There are still insufficient performance data available to develop statistically based quality assurance specifications for recycling (*138*). It is suggested that the user agency remain flexible and allow for as many alternatives as possible to maximize competition in order to produce the desired product at the least cost. Furthermore, the user agency should (*182*):

- Be responsible for the adequacy of design alternatives.
- Write simple, straightforward specifications that clearly state what is expected.
- Permit the contractor to select the materials and methods that will accomplish the end result.
- Use standard specifications familiar to the contractors.
- Modify standard specifications only as necessary to obtain the end result.
- Focus on end results by allowing the contractor flexibility in choosing the most economical methods and procedures to accomplish the work.

QUALITY CONTROL

To achieve a properly constructed cold-recycled pavement, equipment must be selected, operated, and sequenced to provide the following (*138*):

- Pulverization of recycled pavement material
- Proper water content (uniformly mixed)
- Proper binder content (uniformly mixed)
- Attainment of some minimum specified density
- Favorable temperature and moisture conditions for strength development during the curing period
- Protection of the stabilized surface from traffic to prevent abrasion and to ensure adequate time for strength development

Potential quality control problem areas for in-place recycling can include:

- Depth of removal and pulverization
- Blending associated with addition of new aggregate, water, stabilizers, or modifiers
- Degree of pulverization
- Distribution of modifiers, water, or stabilizers
- Variability in the pavement being recycled, including patches, seal coats (full or partial), and crack sealing materials.

As can be seen from these lists of objectives and problem areas, the quality assurance and quality control of cold-recycled mixes are primarily related to equipment type and environmental considerations. The limitations of a laboratory mix design have previously been discussed. Consequently, materials selection can often be a trial-and-error process. During construction, fluids content and asphalt content can be checked, but these are time-

TABLE 18
1988 KANSAS OVERLAY PROGRAM

Type	Miles	Cost/Mile
2 in. Overlay	14,194	40,561
4 in. In-Place Cold Recycle and 3/4 in. Overlay	39,848	31,516
2 in. Hot Recycle	73,061	31,244
1-1/2 in. Overlay	326,475	28,819
4 in. In-Place Cold Recycle and Conventional Seal	48,228	22,548
Mill and 3/4 in. Overlay	7,555	24,750
Hot Surface Recycle and 3/4 in. Overlay	31,322	23,544
Hot Surface Recycle and Conv. Seal	26,916	20,270
1 in. Overlay	31,672	18,525
3/4 in. Overlay	56,908	15,944
1/2 in. Overlay and Conv. Seal	84,805	7,791
Conventional Seal	60,601	6,060
	801,585	
Other Surfacing Combinations	117,484	
Total	919,069	

consuming processes and the commonly used extraction procedures (centrifuge, reflux, and vacuum) have a relatively low degree of precision associated with them (*183*). The number of roller passes required to achieve the specified density can be monitored by means of a nuclear gauge. However, because strength development is a function of curing time and conditions, early coring of the pavement may be difficult or impossible and running stability tests on compacted samples of the mix will have little meaning. Testing by Purdue University (*184*) during a study of cold recycling using central-plant mixing and emulsified asphalt as the modifier found considerable variation in mix properties. The Hveem stability of cores obtained after placement of surface course ranged from 10 to 40 and densities ranged from 133 to 155 lb/ft^3. In spite of these variations, the subject pavement has performed well for more than three years. Of course, long-term performance data, as with most other cold-recycled projects, are still lacking.

Until such time as statistically based quality assurance specifications are developed, the local experience and specialized knowledge of contractors, equipment manufacturers, materials suppliers, and the user agencies will have to be relied on in setting the standards for the various types of cold recycling operations. Typical guidelines from experienced agencies include:

- Cold in-place recycled mixtures should not be placed in depths greater than about 3 to 4 in., because curing can be a problem, nor should depths be less than about 2 in., because segregation may be a problem during construction.
- Softening of the recycled mix may occur within the first two to three days. Some agencies reroll the pavement at this time to obtain additional density.
- An excessive amount of initial compaction can cause problems. However, several states, including New Mexico and Pennsylvania, do not reroll their pavements after construction.
- Traffic should not be allowed on the recycled pavement for a minimum of 2 hr after compaction.
- If the surface starts to ravel under the action of traffic, traffic should be controlled and a finish roller should continue to compact the pavement.
- Rain within 24 hr of construction can create performance problems.
- Before placing the wearing surface, curing should be allowed to reduce the moisture content to the 1 to 1.5 percent range. Summertime curing for 7 to 14 days is typically used. Late-season construction can cause performance problems.
- An asphalt wearing course that is placed over the recycled base should be an open-graded mix to allow curing to continue for an extended period of time. A dense hot mix can trap diluent or water.
- Problems with density control are common. Nuclear density devices provide relative numbers. Cores may not be able to be obtained without proper curing (which may be one year).

The ARRA questionnaire provides a summary of existing specification requirements (*32*). Eighty-three percent of the agencies using cold in-place recycling monitor density. Twenty-seven percent of these agencies measure field density with core samples, 41 percent with nuclear density gauges, and 9 percent with a sand cone. Some agencies specify density (23 percent) by a description of a rolling pattern.

Various density reference standards are used. The 50-blow Marshall procedure is used by 52 percent of the agencies, 32 percent use 75-blow Marshall, 12 percent static compaction, and 4 percent gyratory.

RAP moisture content and asphalt content is tested by 37 percent of the reporting agencies. RAP asphalt physical properties are measured by 18 percent of the agencies. Twenty-five percent test the final recycled material for gradation.

Field adjustment of the binder content is allowed by 66 percent of the agencies. Workability and experience is the basis for adjustment.

CHAPTER NINE

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

- Cold in-place recycling is a viable engineering and economic rehabilitation alternative for asphalt-surfaced pavements with moderate to low traffic volumes.
- Cold in-place recycling is a rehabilitation alternative that can be used to rehabilitate the pavement from the "bottom up" and thus can be used to strengthen a roadway with minimal change in the vertical cross section. This technique also lends itself to stage construction.
- Two forms of cold in-place recycling with asphalt binders have evolved in the United States: full-depth and partial-depth. The full-depth process uses the full flexible pavement structure and/or predetermined portions of base and/or new aggregate in combinations with an asphalt binder. The partial-depth process primarily uses existing asphalt-bound materials and typically recycles 2 to 4 in. in depth. Higher-quality, more uniform paving mixtures are usually produced from the partial-depth process.
- Mixture design methods have been developed for both full-depth and partial-depth cold in-place recycling operations. Emulsion contents of 0.5 to 3 percent are used. Quantities in the range from 0.5 to 1.5 percent are used for the partial-depth operations, whereas quantities in the range from 1.5 to 3 percent are used for the full-depth operations. Medium-setting and high-float emulsions and emulsified recycling agents are typically used with the partial-depth operations. Slow-setting and medium-setting emulsions and soft asphalt cements are typically used with the full-depth operations. Mixing water contents are established as part of the design process.

Physical properties of cold in-place recycled materials are typically between those of an asphalt concrete mixture and a cold, asphalt-stabilized base material. Because properties vary from project to project, laboratory tests should be used to establish strength coefficients.

- Construction equipment and contractor capability are available to perform quality cold in-place recycled projects. Contractors have developed high-capacity, mobile equipment that creates minimum disruption to traffic during construction.
- Surfacing materials should be placed on all cold in-place recycled projects. Chip seals and hot-mixed dense and open-graded mixes are typically used as surface courses. Moisture contents in the recycled material should be reduced to 1 to 1.5 percent before placement of the surface. Summer curing of 7 to 14 days is typically required to achieve these moisture contents, depending on local climate.
- General performance data have been collected by several states. Overall performance has been very good on a large percentage of the projects. Some problems with raveling, rutting, and cracking have been noted. There is a lack of data on long-term performance.
- Adequate specification and quality control guidelines have been developed by state highway agencies.

RECOMMENDATIONS

Research should be conducted to better define the following:

- Structural coefficients of both full- and partial-depth cold in-place recycled materials.
- Life-cycle costs (first costs, life-cycles, needed rehabilitation, and maintenance alternatives).
- Field density control techniques.
- Laboratory mixture design techniques (compaction and curing techniques to simulate field conditions).
- Equipment that will offer better control of the gradation of the mix produced.
- Effects of different diluents in the recycling agents.
- Use of cold-recycled bituminous concrete as a base on high-volume highways.

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CALIFORNIA MIX DESIGN METHOD

STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION
Office of Transportation Laboratory
P. O. Box 19128
Sacramento, California 95819

California Test 378
November 1, 1983

METHOD OF TEST FOR DETERMINING THE PERCENT AND GRADE OF RECYCLING AGENT TO USE FOR COLD RECYCLING OF ASPHALT CONCRETE

A. SCOPE

This procedure is used to determine the percent and grade of recycling agent to use for recycling asphalt concrete when the cold method of recycling is used.

B. APPARATUS

1. A jaw crusher which can be adjusted to produce material passing the No. 4 sieve. A sledge hammer may be used to reduce oversize particles enough to permit the material to be fed into the crusher.
2. Hot asphalt extractor as described in California Test 310.
3. Two ovens, one capable of maintaining a temperature of 140° ± 5°F with provision for free circulation of air through the oven and another capable of maintaining a temperature of 300° ± 9°F. A microwave oven may be used in lieu of the 300°F oven.
4. Balance, 5 kg. capacity; accurate to 1 gram.
5. Sieves, U.S. Standard sizes; 1 in., ¾ in., ½ in., ⅜ in., Nos. 4, 8, 16, 30, 50, 100, 200.
6. Sample splitter for aggregates, 1 in. riffle type or equal.
7. Pans, 10 in. diameter, 2 in. deep.
8. Pans, 11 in. × 7 in. × 1 in. deep.
9. Trowels, small pointed.

C. MATERIALS

1. Emulsified recycling agents.

D. PREPARATION OF SAMPLES

1. Gradation
   a. Pavement Cores or Chunks
      1) Trim samples so that only that portion designated for recycling remains.
      2) Prepare an 800 gram representative sample of the proposed recycling mix.
         a) Determine the asphalt content using Calif. Test 310.
         b) Determine aggregate gradation after extraction using Calif. Test 202.
      3) Crush the remaining material proposed for recycling to conform (approximately) to the following gradation prior to extraction:

Sieve Size	% Passing
1"	100
¾"	*
⅜"	*
#4	70% of the amount passing the #4 sieve for the after-extraction grading.

* Determine by drawing a straight line between plotted points for the 1" and #4 sieves as illustrated on Figure 1.

   b. Pulverized Field Samples
      1) Prepare field samples representative of the material processed by the contractor (milling and/or crushing) and ready for field mixing as follows:
         a) Dry to a constant weight in an oven (maximum temperature 140°F).
         b) Remove from oven and cool to room temperature.
         c) Quarter out 2000 ± 1 grams.
         d) Determine and record the gradation (% passing) by hand sieving through the following sieves:
            1½"
            1" *
            ¾"
            ⅜"
            #4

2. Viscosity of Aged Asphalt
   a. Prepare a 3500 gram sample representative of the material to be recycled and send to TransLab in Sacramento. Request that the asphalt physical properties be determined via the Abson Recovery Test.
3. Recycling Agent—Amount and Grade.
   a. Determine approximate total bitumen requirement (ABR) using the formula:

$$ABR = \frac{4R + 7S + 12F}{100} \times 1.1$$

where, after extraction: R = % retained #8
S = % passing #8 and retained #200
F = % passing #200

Record data on Form No. DH-TL-312

* When preparing the stabilometer test, always scalp so that 100% passes the 1" sieve.

b. Determine the amount of recycling agent to add by subtracting the asphalt content of the old pavement from the ABR. Divide the remainder by .60 to obtain the percent of *emulsified* recycling agent to add.
c. Determine the amount of recycling agent (%) in the final blend (asphalt and recycling agent) by dividing the *residual* amount of recycling agent to be added by the total binder content.
d. Using the nomograph for viscosity (Form 314), plot the viscosity of the aged asphalt (use centipoise) on the left viscosity scale and connect that point with lines extending to points representing the viscosities of the residues for the various emulsified recycling agents on the right vertical scale, thereby creating a family of curves.
e. On the nomograph, locate the percent of recycling agent in the blend on the lower horizontal scale and draw a vertical line from this point.
f. At the intersection of the above established vertical line and the horizontal viscosity line for AR-4000, note the closest recycling agent curve. Select this grade of recycling agent to begin testing.

4. Prepare the test specimens for the stabilometer valuation as follows:

a. Prepare six 1200 gram samples using material prepared in accordance with D 1. a. or D 1. b.
b. Save one sample for determining maximum specific gravity (ASTM D-2041) and one sample for future testing if needed.
c. Dry four samples to a constant weight in a 140°F oven.
d. Remove the four samples from the oven and cool at room temperature for 2 hours ± 30 minutes.
e. Add 2.0% water to each sample by dry weight of the mix and thoroughly hand mix.
f. To one sample, add the amount of emulsion calculated in Paragraph 3b and thoroughly hand mix (aggregate, emulsion and mixing at room temperature, 75 ± 5°F).
g. Add lesser and greater amounts of emulsion in 0.8% increments. General practice is to increase the content on one sample and decrease it on two samples. Mix each sample thoroughly after the addition of the emulsion.

E. CURING

1. Place in standard curing pans (7" × 12" × 1") and cure at 140°F for 16 ± 1 hours.

F. FABRICATION OF THE STABILOMETER TEST SPECIMENS

1. Prepare compaction mold and mold holder by placing in a 140°F oven for 30 minutes prior to use. If several samples will be compacted in succession, the mold holder may be used after the first preheating without additional heating.

2. Place mold in mold holder and this assembly into position in the mechanical spader. (If a mechanical spader is not available, proceed to paragraph "8".) Place a metal shim ¼" thick, approximately ¾" wide and 2½" long under the mold adjacent to the portion of the mold holder that extends up into the mold. Place a 4" diameter cardboard disk into the mold on top of the mold holder base.

3. Weigh out sufficient mix to provide a specimen between 2.40" and 2.60" in height for the stabilometer test.

4. Separate the coarse and fine material by screening the mix through a ½" sieve onto a flat metal scoop.

5. Arrange the separated material into two parallel rows across the width of the scoop with the finer material closest to the scoop handle.

6. Introduce the mix onto the feeder belt of the mechanical spader, exercising care so as not to disturb the size arrangement effected on the metal scoop.

7. Start the mechanical spader and operate until all of the material has been introduced into the compaction mold. Proceed to step 9.

8. In lieu of the mechanical spader described above, a specially constructed feeder trough 4 in. wide and 16 in. long may be used for introducing the mix into the mold. Thoroughly mix and disperse the heated material on the trough (which has also been preheated to approximately the compaction temperature to be used) to insure a uniform sample when transferred to the mold. Place the mold in position in the mold holder and place a 4 in. diameter cardboard disk into the mold on top of the mold holder base.

Use a paddle, shaped to fit the trough, to push one-half of the material into the mold. Rod the material 20 times in the center of the mass and 20 times around the edge with a bullet nosed steel rod ⅝ in. diameter, 16 in. long. Then push the remainder of the sample into the mold and repeat the rodding procedure. Perform these operations as rapidly as possible to prevent cooling of the sample. If two feeder troughs are available, the work can be expedited by preparing another sample while one is being compacted. The extra trough containing the next sample is kept in the oven until ready for compaction.

9. Place mold holder containing the mix and mold into position in the mechanical compactor.

10. Start the compactor and adjust the air pressure so 250 psi will be exerted by the tamper foot. Keep the tamper foot hot enough to prevent the mix from adhering to it.

11. Apply approximately 20 tamping blows at 250 psi pressure to accomplish a semi-compacted condition so the mix will not be unduly disturbed when the full load is applied. The exact number of blows to accomplish the semi-compaction shall be determined by observation. The number of blows may vary between 10 and 50, depending upon the type of material.

12. Remove the ¼ in. shim and release the tightening screw sufficiently to allow approximately ⅛ in. side movement under load. Then raise the compaction pressure to 500 psi and apply 150 tamping blows to complete the compaction in the mechanical compactor.

13. Apply a total static leveling-off load of 1250 lbs. in the testing machine at a head speed of .05 in. per minute with the bottom of the sample in contact with the lower platen of the press. Release the applied load immediately.

14. Measure the height of the test specimen to the nearest 0.01 in. and record for later use.

G. TESTING

1. Stabilometer Test

a. Test for stabilometer value at 140°F in accordance with Calif. Test 366.

2. Specific Gravity and Voids

a. Use the stabilometer test specimen and determine the specific gravity of the briquette using Method A of Calif. Test 308.

b. Place a 1200 gram sample (from D 4. b.) of salvaged AC in a container as required and determine the salvaged AC specific gravity using ASTM Test Procedure D-2041.

c. Calculate the void content of the test specimen as follows:

$$\text{Max.Sp.Gr.} = \frac{100 + \%\ \text{Asphalt Residue}}{\dfrac{100}{\text{Salv.AC Sp. Gr.}} + \dfrac{\%\ \text{Asphalt Residue}}{\text{Sp.Gr.Asph.}}}$$

$$\text{Relative Density} = \frac{\text{Sp.Gr. Briq.}}{\text{Max.Sp.Gr.}}$$

$$\text{Percent Voids} = 100 - \text{Relative Density}$$

H. RECOMMENDATION

1. Optimum Bitumen Content (OBC). Recommend the highest emulsion content that provides a specimen with the desired stabilometer value *, no evidence of surface flushing or bleeding, and a minimum of 4% voids. Slight flushing is considered as no flushing.

* Traveled way stabilometer value = 30 min.
Shoulder stabilometer value = 25 min.

I. CORRECTION OF GRADE OF RECYCLING AGENT

1. Replot the final binder content data on the viscosity nomograph. If this results in the need to use a grade of recycling agent different than the one tested, retest using the recommended amount with the newly designated recycling agent.

J. REPORTING OF RESULTS

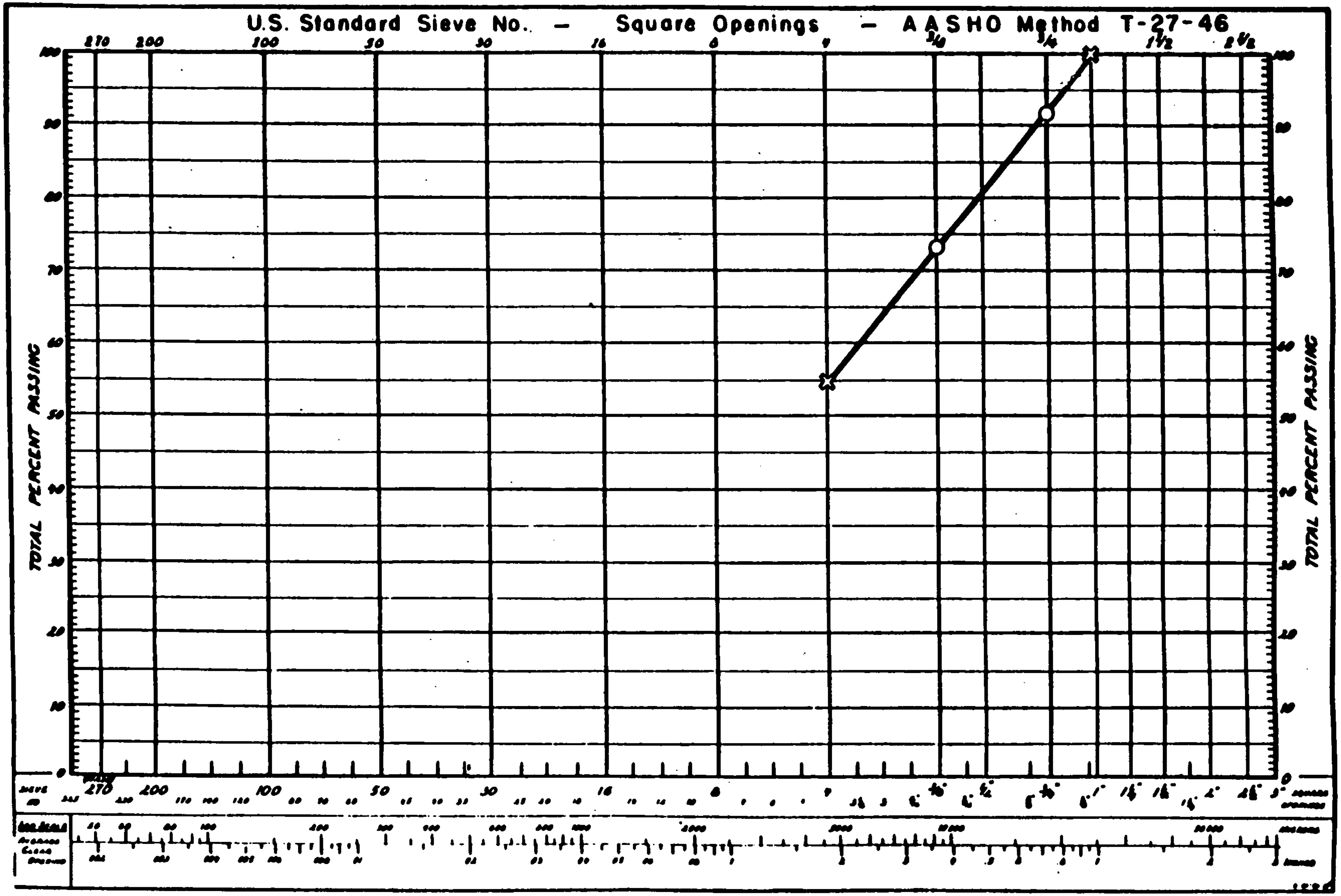
1. Use Form TL 302 for recording and reporting test data.

2. Report:
1) Asphalt extraction
2) Extracted grading
3) Grading prior to extraction
4) Grade of recycling agent to use
5) Amount of recycling agent (OBC)
6) Voids at OBC
7) Viscosity used as a design basis (1000, 2000, 4000 or 8000)

End of Text (3 pages) on Calif. 378

State of California
TRANSPORTATION LABORATORY

SEMI-LOG CHART FOR GRADING CURVES



TL-216 (Rev.4/79)

TEST REPORT NO.______

Location: Dist.______ Co.______ Rte.______ P.M. ____________

Contract No.________

DATA	COLUMN 1: PAV'T. TO BE RECYCLED (MEASURED)	COLUMN 2: DESIGN – CALC.	COLUMN 3: DESIGN – RECOMM.	COLUMN 4: RECYCLED PAVEMENT (MEASURED)
DATE:				
(A) Asphalt Content, %		—	—	
(B) Asphalt Demand (1) O	—			
(B) Asphalt Demand (2) (V) (V_a)	—			
(B) Asphalt Demand (3) (B_1 − A) (T) + B_2	—			
(C) Stab. Value Calif. T.M.366: Compacted @ 230°F, Tested @ 140°F	—	—		
(C) Stab. Value Calif. T.M.366: Compacted @ 140°F, Tested @ 140°F	—	—		
(D) Sp. Gr. Calif. TM 308C (1) Compacted @ 230°F, Tested @ 140°F	—	—		
(D) Sp. Gr. Calif. TM 308C (2) Compacted @ 140°F, Tested @ 140°F	—	—		
(D) Sp. Gr. (3) Theoretical Max. Sp. Gr. (ASTM) D-2041	—	—		
(E) %Voids $\left(100 - \frac{D_1 \text{ or } D_2}{D_3}\right)$	—	—		
(F) Penetration @ 77°F				
(G) Viscosity @ 140°F, P				
(H) Aggregate Gradation: R, retained #8, %				
S, passing #8, retained #200, %				
F, passing #200, %				

NOTES:

Calculate $B^1 = \frac{4R + 7S + 12F}{100} \times 1.1 =$ ________ Emulsion $= \frac{B^1}{.60} =$ ______%

Grade of recycling agent used ______________________________

COMMENTS:

Virgin aggregate asphalt content is based on AR Grade 4000 if a recycling agent is to be used as a binder.

(B) Asphalt Demand

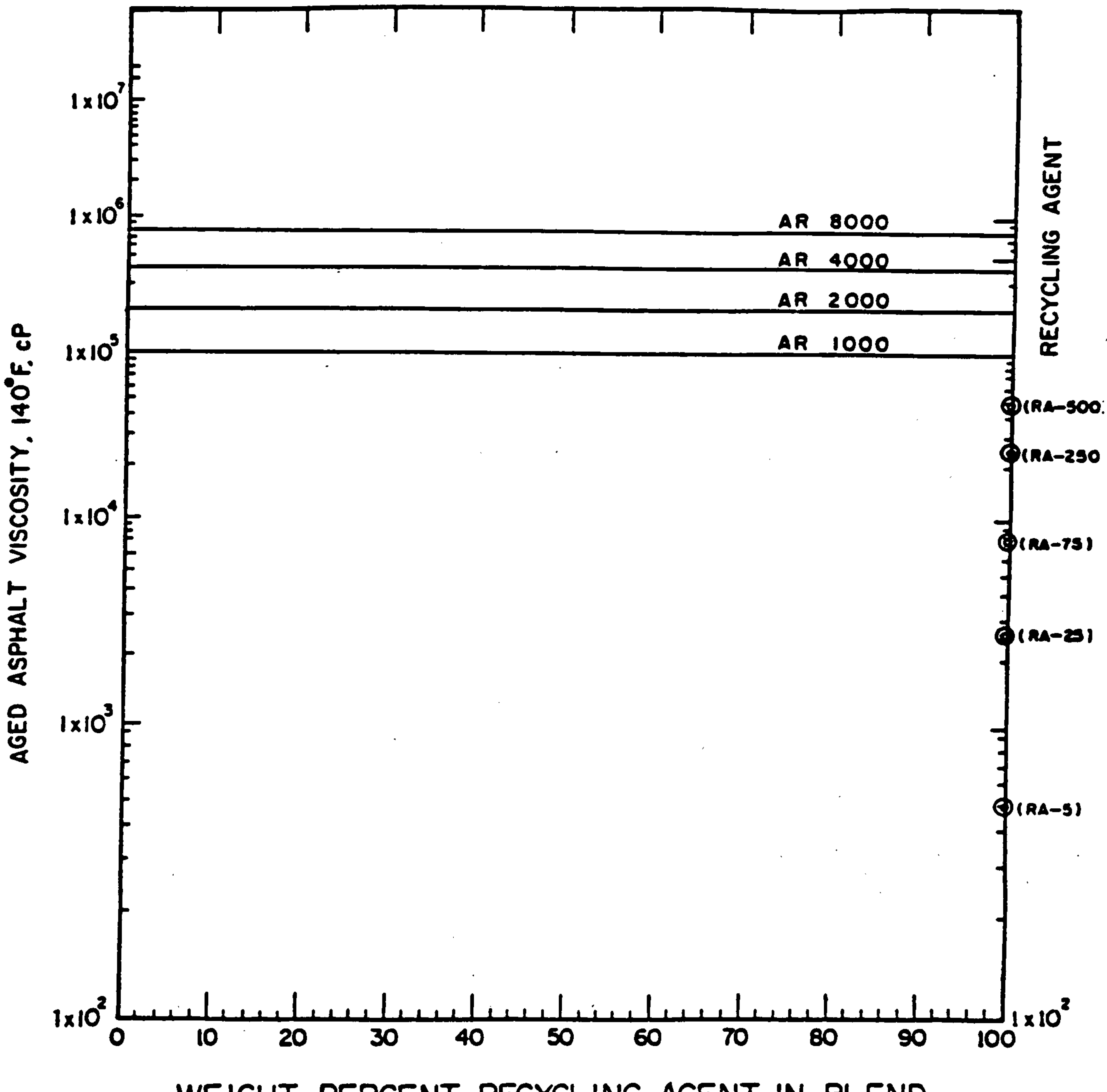
O = 100% Salv. A.C.

V = % of Virgin Agg.

V_a = Binder Content For 100% Virgin Agg.

T = % of Salvaged

Form No. DH-TL-312



TO USE: Draw a straight line connecting viscosity of aged asphalt with viscosity of recycling agent. Draw a vertical line up from the percent recycling agent in blend. The two lines intersect at predicted approximate viscosity of the recycled asphalt.

NOMOGRAPH FOR VISCOSITY

Form No. DH TL-314

MIX DESIGN

The primary objective of the cold mix recycling design procedure is to produce a paving mixture comparable to a cold mix made from all new materials. Laboratory tests, empirical formulas, or past experience with similar jobs are used to establish the initial emulsified recycling agent content. Adjustments to binder content might be made after field construction begins.

The percentage of reclaimed asphalt pavement to be used in the mix is normally specified early in the mix design procedure. Up to 100% reclaimed asphalt pavement can be used in cold mix recycling. The exact percentage depends on the mix characteristics of the reclaimed material and the desired end product. The type and grade of emulsified recycling agent is determined by the properties of the asphalt and aggregate extracted from the reclaimed asphalt pavement.

The Chevron Cold-Mix Recycling Design Procedure is summarized in the flow diagram in Figure 2. The Chevron procedure has 6 major steps:

1. Evaluate the reclaimed asphalt pavement.
2. Select the amount and gradation of untreated aggregate required.
3. Estimate asphalt binder demand.
4. Select type and grade of emulsified recycling agent.
5. Proportion and test trial mixes.
6. Establish job mix formula.

Each of these steps is described below.

STEP 1 - <u>Evaluate Reclaimed Asphalt Pavement</u>
The first step is to extract and recover the asphalt and aggregate from the reclaimed asphalt pavement and determine:

a) The <u>asphalt content</u> of the reclaimed asphalt pavement using ASTM Method D-2172 or equivalent.

b) The <u>consistency</u> of the asphalt in the reclaimed asphalt pavement. If the reclaimed asphalt pavement contains more than one percent asphalt, recover the asphalt by ASTM D-1856. If the reclaimed asphalt pavement contains less than one percent asphalt, assume the asphalt cannot be recovered and treat the reclaimed asphalt pavement as untreated aggregate. Determine the viscosity at 60°C (140°F) of the reclaimed asphalt by ASTM D-2171.
If the viscosity of the reclaimed asphalt is too high to easily measure, estimate the viscosity at 60°C (140°F) using Figure 3 from measurements of penetration at 25°C (77°F) by ASTM 5 and viscosity at 135°C (275°F) by ASTM D-2170.

c) The <u>gradation</u> of the aggregate extracted from the reclaimed asphalt pavement using ASTM C-136. This sieve analysis is used to determine if the reclaimed aggregate is deficient in one or more of the aggregate fractions (coarse aggregate, sand, mineral filler). Any deficiency in the gradation can be corrected with the addition of untreated aggregate of the proper size and gradation.

The quality of the reclaimed aggregate can also be checked and improved, if necessary, by the addition of untreated aggregate. Tests for aggregate quality include:

(1) Wear - Los Angeles Abrasion Test, ASTM C-131

(2) Crushed Faces - State of California Method 205-E

(3) Soundness, ASTM C-88

(4) Acid Resistance (limestone surface mixes), ASTM D-3042

The extracted aggregate should be saved for blending with the untreated aggregate for estimating asphalt binder demand.

FIGURE 2

CHEVRON COLD-MIX RECYCLING DESIGN PROCEDURE

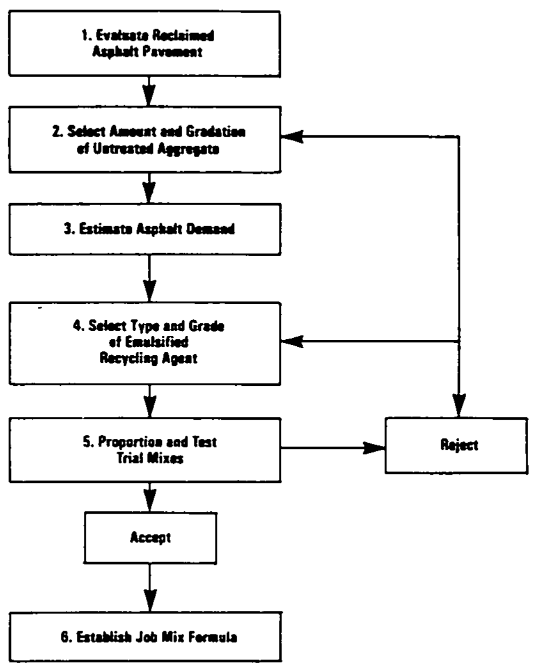
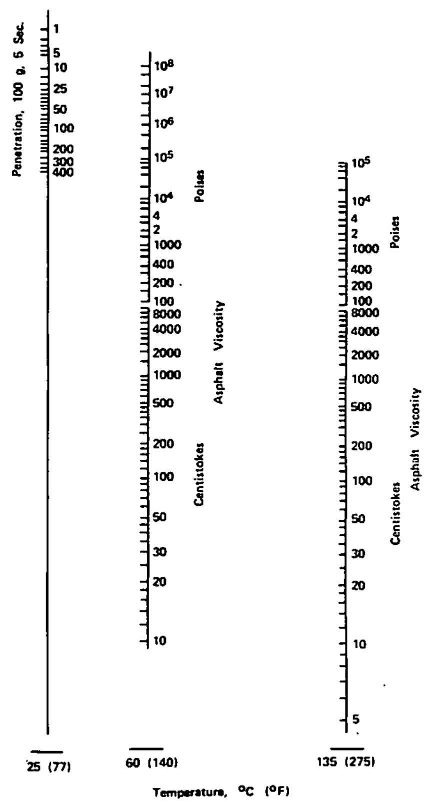


FIGURE 3

ASPHALT CONSISTENCY-TEMPERATURE CHART



STEP 2 - Select the Amount and Gradation of Untreated Aggregate

Aggregate gradations suitable for cold recycled mixes are given in Table 4. Up to 100% reclaimed asphalt pavement can be used in cold mix recycling. The gradation of the aggregate extracted from the reclaimed asphalt is examined and, if necessary, untreated aggregate is added to adjust to the desired gradation. Procedures for analyzing and blending aggregates are found in Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types, MS-2, The Asphalt Institute.

The amount of untreated aggregate used in the recycled mix is determined by the amount present in an untreated base of the pavement to be recycled, the amount of emulsified recycling agent that can be added to the reclaimed asphalt pavement or the adjustment required to give the final aggregate gradation and quality desired.

STEP 3 - Estimate Asphalt Binder Demand

Method A - By CKE method.

The asphalt demand of the reclaimed asphalt pavement or combined reclaimed asphalt pavement and added aggregate can be estimated from the Centrifuge Kerosene Equivalent (CKE) Test as described in MS-2, The Asphalt Institute. The aggregate used in the CKE procedure is the extracted aggregate from the reclaimed asphalt pavement or the blend of extracted aggregate and added aggregate selected in STEP 2.

The percent of emulsified recycling agent required for cold mix recycling, Pc, based on weight of aggregate, is determined from the formula:

Equation 1
$$Pc = \frac{PR - (Pa \times Pp)}{R}$$

Where:
- Pc = percent* emulsified recycling agent**
- PR = percent* asphalt demand** by CKE
- Pa = percent* asphalt** in reclaimed asphalt pavement.
- Pp = decimal percent reclaimed asphalt pavement in the recycled mix
- R = decimal percent emulsion residue, normally 60-65%

* Expressed as a whole number.
** By weight of aggregate.

Method B - By aggregate gradation.

The percent of emulsified recycling agent required for cold mix recycling, Pc, based on weight of aggregate, is determined from the formula:

Equation 2
$$Pc = Pe - Pa\,\frac{(Pp)}{(R)}$$

Where:
- Pc = percent* emulsified recycling agent**
- Pe = 0.05A + 0.1B + 0.5C; total percent* of emulsified binder required, by weight of aggregate (binder includes asphalt extracted from RAP and residue from recycle agent).
  - A = percent* of aggregate retained on the 2.36mm (No. 8) sieve.
  - B = percent* of aggregate passing the 2.35mm (No. 8) sieve, and retained on the 75mm (No. 200) sieve.
  - C = percent* of aggregate passing the 75mm (No. 200) sieve.
- Pa = percent* asphalt** in reclaimed asphalt pavement.
- Pp = decimal percent reclaimed asphalt pavement in the recycled mix.
- R = decimal percent emulsion residue, normally 60-65%.

* Expressed as a whole number.
** By weight of aggregate.

No less than 2% emulsified recycling agent should be used. If the design calls for less than 2% emulsified recycling agent, additional untreated aggregate should be added to the reclaimed asphalt pavement and the binder demand recalculated.

STEP 4 - Select Type and Grade of Emulsified Recycling Agent

A guide to the selection of emulsified asphalt or recycling agents for cold mix recycling is given in Table 3. These low viscosity residue emulsions are recommended for reclaimed asphalt pavements that contain high viscosity (low penetration) asphalts. Standard emulsified asphalts recommended for cold mix recycling include soft residue, slow and medium-setting cationic and anionic emulsions. Certain high float emulsions are also recommended. Soft residue quick-set emulsions have been successfully used in mix-in-place recycling.

STEP 5 - Proportion and Test Trial Mixes

Trial mixes are prepared at 1% below the estimated emulsified recycling agent content, at the estimated content, and 1% and 2% above the estimated content, but in no case, lower than 2%.

Mixing and testing of trial mixes is done in accordance with procedures presented in Appendix A of the Chevron Bitumuls Mix Manual or Method 1 in A Basic Asphalt Emulsion Manual, MS-19, The Asphalt Institute.

Reclaimed asphalt pavement or blends of reclaimed asphalt pavement and untreated aggregate are substituted for new aggregate in the design procedure.

A flow diagram of the testing schedule for cold recycled mixes is given in Figure 4. The recommended design criteria for cold recycled mixes are given in Table 6. Early cure and fully cured conditions are considered.

Resilient modulus provides a valuable guide to the initial proportioning of components (reclaimed asphalt pavement, untreated aggregate, mixing water, and emulsified recycling agent) in the cold recycled mix. Limiting resilient modulus values of 150,000 to 600,000 psi at 73°F on a fully cured core are suggested. Values higher than 600,000 psi indicate a high viscosity (hard) binder that could produce mixes susceptible to low temperature cracking and surface ravelling. Values lower than 150,000 psi indicate a soft binder in the mix that could result in permanent deformation or surface flushing problems.

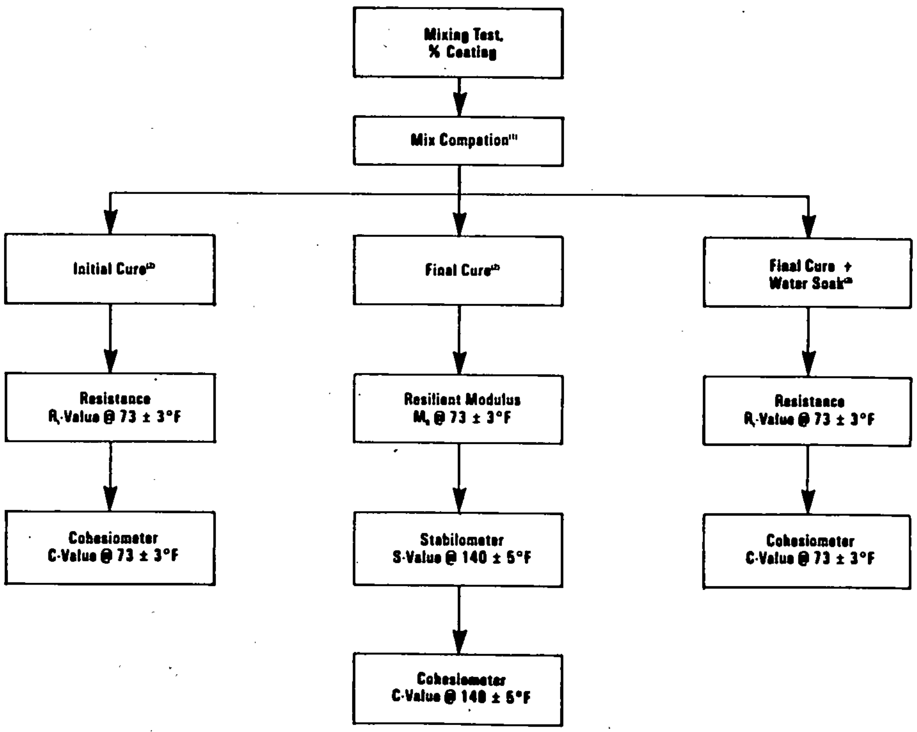
STEP 6 - Establish Job Mix Formula

The lowest emulsified recycling agent content (minimum of 2%) that meets the design criteria in Table 6 is selected as the design binder content. Adjustments to the binder content might take place in the field if construction conditions warrant a change.

The job mix formula consists of the proportions of reclaimed asphalt pavement and untreated aggregate, percentage of mixing water added (if needed), and percentage of emulsified recycling agent added.

FIGURE 4

TESTING SCHEDULE FOR COLD RECYCLED MIXES



(1) Includes 10-50 blows (250 psi) kneading and 40,000 lb. double plunger.
(2) Cure conditions are described in TABLE 6.

DESIGN EXAMPLE #1

A rural roadway is sampled and found to consist of a 2 in. asphalt road mix surface course over 4 in. of untreated gravel base. The surface and top 2" of untreated gravel base are to be recycled with SS-1 emulsified asphalt in a travel plant. A new 2 inch open graded mix will be placed over the recycled mix. Extraction tests indicate the asphalt content of the reclaimed asphalt pavement to be 5.7 percent. The gradation of the aggregates contained in the surface and base courses are as follows:

Sieve Size	Percent Passing Surface Course	Percent Passing Base Course	50/50 Blend	Spec.
19.0mm (3/4 in.)	100	100	100	
12.5mm (1/2 in.)	100	100	100	100
9.5mm (3/8 in.)	93	100	96.5	90-100
4.75mm (No. 4)	76	50	63	60-80
2.36mm (No. 8)	56	30	43	35-65
300 m (No. 50)	20	10	15	6-25
75 m (No. 200)	10	6	8	2-10

The ratio of reclaimed asphalt pavement to total pavement (surface and base) is 2 in./4 in. = 0.50.

Using Method B, the total emulsified asphalt binder demand, Pe, is:

$$Pe = 0.05A + 0.1B + 0.5C$$
$$A = 57\%$$
$$B = 35\%$$
$$C = 8\%$$
$$Pe = 0.05\,(57) + 0.1\,(35) + 0.5\,(8)$$
$$Pe = 2.85 + 3.50 + 4.00$$
$$Pe = 10.35\%$$

From Equation (2), the estimated amount, of SS-1 emulsified asphalt required, Pc, in the recycled mix is:

$$Pc = Pe - Pa\,\frac{(Pp)}{R}$$

Where:

$Pe = 10.35\%$
$Pa = 5.7\%$ (asphalt in reclaimed pavement)
$Pp = 0.50\%$ (reclaimed asphalt mix in trial mix)
$R = 0.60\%$ (adjustment for 60% residue emulsion)

$$Pc = 10.35 - 5.7\,\frac{(0.50)}{(0.60)}$$
$$Pc = 10.35 - 4.75 = 5.6\%$$

Trial mixes containing 50% reclaimed asphalt surface mix and 50% untreated base are prepared with 4.6%, 5.6%, 6.6%, and 7.6% SS-1 by weight of the blend of surface mix and base.

Test results on the trial mixes are compared in Table 7 with the design criteria. An initial binder content of 4.6% SS-1 emulsified asphalt is selected from Table 6 for cold mix recycling on this job. This is the lowest binder content that satisfies the design criteria. The binder content is subject to adjustment in the field if warranted by construction conditions.

TABLE 6

DESIGN CRITERIA FOR COLD RECYCLED MIXES

Test Method		SPECIFICATION
Coating, %		75 min.
Resistance R$_t$-Value @ 73 ± 5°F	Initial cure[1]	70 min.
	Final cure[2] + water soak	78 min.
Cohesiometer C-Value @ 73 ± 5°F	Initial cure[1]	50 min.
	Final cure[2] + water soak[3]	100 min.
Resilient Modulus, M$_R$ psi @ 73 ± 3°F	Final cure[2]	150,000–600,000
Stabilometer S-Value @ 140 ± 5°F	Final cure[2]	30 min.
Cohesiometer C-Value @ 140 ± 5°F	Final cure[2]	100 min.

[1]Cured in the mold for a total of 24 hrs. @ a temperature of 73 ± 5°F.
[2]Cured in the mold for a total of 72 hrs. @ a temperature of 73 ± 5°F, plus 4 days' vacuum desiccation at 10-20 mercury.
[3]Vacuum saturation at 100mm of mercury.
NOTE: Besides meeting the above requirements, the mix must be reasonably workable (i.e., not too stiff or sloppy).

TABLE 7

TEST RESULTS ON COLD RECYCLED TRIAL MIXES

DESIGN EXAMPLE #1

Test Method		Emulsified Recycling Agent (SS-1), %				Design Criteria
		4.6	5.6	6.6	7.6	
Coating, %		95	95	95	95	75 min.
Resistance R$_t$-Value @ 73 ± 5°F	Initial cure[1]	103	103	101	102	70 min.
	Final cure[2] + water soak[3]	91	91	97	84	78 min.
Cohesiometer C-Value @ 73 ± 5°F	Initial cure[1]	305	325	335	294	50 min.
	Final cure[2] + water soak[3]	254	287	283	287	100 min.
Resilient Modulus, M$_R$, psi @ 73 ± 3°F	Final cure[2]	540,000	380,000	210,000	190,000	150,000–600,000
Stabilometer S-Value @ 140°F	Final cure[2]	44	44	44	44	30 min.
Cohesiometer C-Value @ 140°F	Final cure[2]	217	177	130	99	100 min.

[1]Cured in the mold for a total of 24 hours at a temperature of 73 ± 5°F.
[2]Cured in the mold for a total of 72 hours at a temperature of 73 ± 5°F, + 4 days' vacuum desiccation at 10-22mm mercury.
[3]Vacuum saturation at 100mm of mercury.
NOTE: Besides meeting the above requirements, the mix must be reasonably workable (i.e., not too stiff or sloppy).
Mixing water was 3%.

<u>Design Example #2</u>

A city street is to be recycled cold using 100% reclaimed asphalt pavement. The asphalt content is found from extraction tests to be 5.0 percent by weight of aggregate. The recovered asphalt has a penetration of 38 at 77°F. The recycled pavement will be overlaid with 2 inches of new asphalt concrete mix. Chevron emulsified recycling agent CEMA-1 is selected for cold mix recycling of the base.

The gradation of the aggregate extracted from the reclaimed asphalt pavement is:

Sieve Size	Percent Passing
3/4"	100
1/2"	97
3/8"	93
No. 4	76
No. 8	56
No. 50	20
No. 200	10

The extracted aggregate satisfied the processed dense-graded requirements. Therefore, no adjustment in aggregate properties was necessary.

The asphalt binder demand of the extracted aggregate is determined to be 6.0 percent from the CKE Test.

From Equation (1), the estimated percent CEMA-1 required, Pc, is:

$$Pc = \frac{PR - (Pa \times Pp)}{R}$$

Where:
PR = 6.0 (CKE oil ratio)
Pa = 5.0 (asphalt in reclaimed pavement)
Pp = 1.0 (RAP in mix)
R = .60 (adjustment for 60% res. emul.)

$$Pc = \frac{6.0 - (5.0 \times 1.0)}{.60}$$

Pc = 1.7% (Use 2% minimum as stated in Step 6.)

Trial mixes containing 100% reclaimed asphalt pavement are prepared with 2.0%, 3.0%, and 4.0% CEMA-1 by weight of the reclaimed mix. It is found that 3.0% mixing water is needed to give good coating to the reclaimed mix.

Test results on the trial mixes are compared in Table 8 with the design criteria shown in Table 6. An initial binder content, subject to adjustment in the field, of 3.0% CEMA-1 is selected for recycling on this job. This is the lowest binder content that satisfies the design criteria.

TABLE 8

TEST RESULTS ON COLD RECYCLED TRIAL MIXES

DESIGN EXAMPLE #2

Test Method		Emulsified Recycling Agent (CEMA-1), %			
		2.0	3.0	4.0	
Coating, %		95	95	95	75 min.
Resistance R_t-Value @ 73 ± 5°F	Initial cure[1]	107	108	104	78 min.
	Final cure[2] + water soak[3]	107	109	102	78 min.
Cohesiometer C-Value @ 73 ± 5°F	Initial cure[1]	348	387	321	50 min.
	Final cure[2] + water soak[3]	309	340	274	100 min.
Resilient Modulus, M_R, psi @ 73 ± 3°F	Final cure[2]	640,000	310,000	250,000	150,000–600,000
Stabilometer S-Value @ 140°F	Final cure[2]	40	42	37	30 min.
Cohesiometer C-Value @ 140°F	Final cure[2]	253	180	182	

[1]Cured in the mold for a total of 24 hours at a temperature of 73 ± 5°F.
[2]Cured in the mold for a total of 72 hours at a temperature of 73 ± 5°F, + 4 days' vacuum desiccation at 10-22mm mercury.
[3]Vacuum saturation at 100mm of mercury.
NOTE: Besides meeting the above requirements, the mix must be reasonably workable (i.e., not too stiff or sloppy).
Mixing water was 3%.

APPENDIX C

OREGON MIX DESIGN METHOD

ROUTINE CIR MIX DESIGN PROCEDURE

1.0 Determine the following from the sample obtained with the 16-in mill:

- 1.1 Asphalt content, in percent, and extracted gradation
- 1.2 Penetration at 77°F, in dmm.
- 1.3 Absolute Viscosity at 140°F, in poises.
- 1.4 RAP Gradation (1/2", 1/4", and No. 10)

2.0 Determine the estimated emulsion content from Figure 1 and the following equation:

$EC_{EST} = 1.2 + A_G + A_{AC} + A_{PV}$

where:

EC_{EST}= estimated emulsion content, in percent

A_G= adjustment for gradation, in percent

A_{AC}= adjustment for asphalt content, in percent

A_{PV}= adjustment for penetration or viscosity, in percent

NOTE: For borderline cases in Figure 1, use the adjustment resulting in a lower estimated emulsion content. For discrepancy between penetration and viscosity adjustments (Figure 1), use the adjustment resulting in a lower estimated emulsion content (See Example in Figure 1).

3.0 Prepare test briquets using the following procedure:

3.1 Split the millings into approximately 15,000 gram batches.

3.2 Screen the sample on the 1-in sieve. Reduce all material retained on the 1-in sieve such that 100% of the sample passes the 1-in sieve using a hammer or chisel.

3.3 Batch five 1100 gram ± samples of the millings at the adjusted gradation. The adjusted gradation is determined from Figure 2. Determine the asphalt content.

3.4 Using the remaining material determine the optimum total liquids content using OSHD TM-126 with the modification that the optimum total liquids content occurs at at liquid loss of 1-4 ml (1-4 grams). The Appendix summarizes the procedure for determining the optimum total liquids content.

3.5 Calculate water contents (based on dry weight of millings) to be added to the samples for each emulsion content using the following equation:

%water = opt. total liquids content - %emulsion content

Briquets are to be prepared with emulsion contents at the estimated emulsion content (EC_{EST}), at EC_{EST} - 0.3%, at EC_{EST} + 0.3%, at EC_{EST} + 0.6%, and at EC_{EST} + 0.9%.

3.6 Heat the five 1100 gram samples to 140°F ± for 1 hour.

3.7 Add the water calculated above to the five samples and thoroughly mix by hand.

3.8 Add the emulsion contents to the premoistened millings. The emulsion is to be preheated to 140°F ± for 1 hour and mixed thoroughly into the batch by hand.

3.9 Dump the material into a 12-in x 17-in baking pan and allow to cure for 1 hour at 140°F ± to simulate the average time elapsed between the paver laydown and the initial compaction during actual construction.

3.10 Mold the samples using standard Hveem procedures to produce 2.5-in ± briquets as described below:

1) Preheat molds to 140°F ±.
2) Compact the samples using 50 blows at 500 psi.
3) Cure the briquets overnight at 140°F ± and recompact 50 blows at 500 psi.
4) Lay the molds on their side and cure the briquets for 24 hours at 140°F ± prior to extrusion.
5) Extrude the briquets using a compression testing machine.
6) Lay the briquets on their side to maximize surface exposure and cure for 72 hours at room temperature prior to testing.

4.0 Test the specimens for mix properties as follows:

4.1 Test for Hveem stability. Plot stability versus emulsion content and draw a smooth curve through the data points.

4.2 Test for resilient modulus at 77°F. Plot modulus versus emulsion content and draw a smooth curve throught the data points.

4.3 Check voids after second compaction.

5.0 Analyze mix properties:

5.1 Record the emulsion content corresponding to the peak of the Hveem stability versus emulsion content curve. (This is EC_{DES}.)

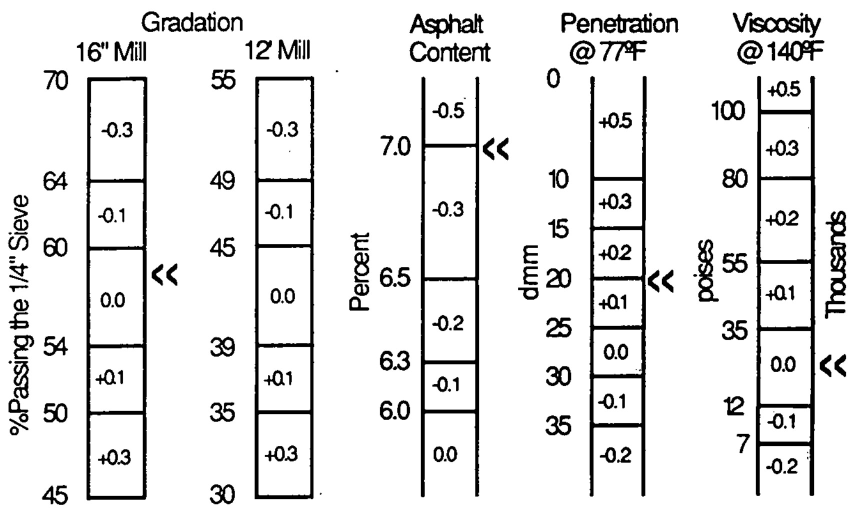
5.2 Record the emulsion content corresponding to the peak of the modulus versus emulsion content curve.

5.3 Check to ensure that EC_{DES} is approximately equal to EC_{EST}. Record EC_{DES} and EC_{EST}.

6.0 Recommended emulsion and W/C:

6.1 Use EC_{EST}.

6.2 Use WC_{CTB}



Example:
Given:
58% passing the 1/4" screen on the 16" mill, 7% residual asphalt, a penetration of 20 dmm, and a viscosity of 19,000 poises.
Adjustments (for borderline cases, use adjustment producing lower emulsion content):
0.0% for gradation, -0.5% for asphalt content, and 0.0% for penetration/viscosity
Estimated Emulsion Content:
1.2 % + 0.0% - 0.5% + 0.0% = 0.7%

Figure 1 - Emulsion Content Adjustments for Gradation, Asphalt Content, and Asphalt Softness.

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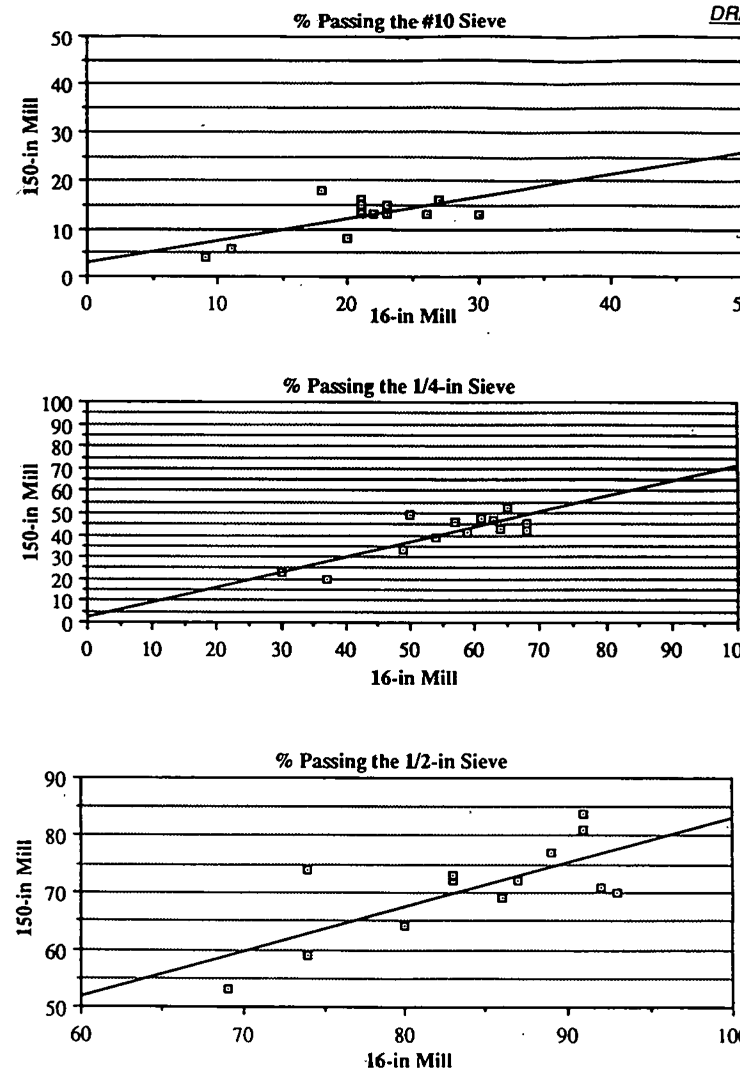

Figure 2 - Determination of the Adjusted Gradation (for the 150-in Mill) from the Gradation on the 16-in Mill.

OSHD test Method 126-86
Modified for
FIELD ADJUSTMENT OF COLD RECYCLE MIX
or
(Rapid Project Control Test)

1.0 Scope

The purpose of this method is to provide a field basis for adjustment of water and emulsion content to obtain satisfactory mixing, laydown and compaction of cold mix recycle. With the variations found in gradation, asphalt content and properties of millings, adjustments of the cold mix from the design recommendations are necessary to obtain optimum pavement durability.

2.0 Apparatus

Balance with capacity of 3000 grams, accurate to 0.1 gram.

Metal scoop and mixing bowl or bucket.

Split compaction mold, 4 inch diameter x 11.5 inches as shown in Figure G.

Compression machine consisting of a 20 - 25 ton capacity hydraulic jack fitted with a spherically seated head and mounted in a 30 inch frame. (Figure G)

Bottom and upper plunger for compression jack.

Bullet nosed rod, 3/8 inch diameter and approx. 20 inches long.

Hand tamper, one inch diameter by approx. 20 inches long, weighing 6.00 ± 0.05 pounds.

Tin or galvanized liner, four inches x four inches in diameter.

Four inch diameter filter paper (medium filtration speed).

3.0 Sample Preparation

The sample should be taken from within the windrow immediately behind the recycle train. A sample size from 1600 to 1700 grams is normally required to fill the tin. After compaction a gap down from the top of the tin ranging from 1/4 to 1/2 of an inch did not appear to affect the results. Do not over-fill the tin. After obtaining the sample, weigh and record its initial weight. At the beginning of a project it may be necessary to run a test mold to verify the quantity of RAP required to fill the tin mold.

Care should be taken to keep the sample at the representative moisture content. The test should not take more than 15 minutes from the time the sample is removed from the windrow to the time it is weighed for liquid loss.

4.0 Procedure

1. Weigh a tin liner and 2 filter papers together. Record the weight and the sample number on the liner. (It will save time during the test to weigh and record several liners along with their filter paper in advance.)

2. Assemble the 4" split mold with the tin liner in place and the bottom plunger pinned 3 holes from the bottom. For some materials it may be necessary to pin the bottom plunger further away or closer to the bottom of the mold. The proper pin setting can be determined during compaction of a trial specimen. (I have not experienced a project yet that required a pin adjustment.)

3. Set the mold upright on a solid block, such as concrete, at a convenient height. Put in one filter paper and put on the extension sleeve.

4. Spoon approximately 1/2 the sample into the mold and rod 25 times around the edge of the mold with a 3/8" bullet nosed rod to prevent rock pockets. Tamp with the 3/4" faced small end of the 6 pound tamper for 50 blows. Physical exertion in tamping should be only sufficient to move the tamper up and down approximately 4 inches in travel. Guide the tamper over the entire surface of the specimen. The actual compaction should be provided only by the combined weights of the tamper and the operator's hand

5. Place the remaining portion of the sample in the mold and rod the sample 25 times around the edge of the mold. Tamp the second lift using 100 blows with the small (3/4") end of the hand tamper. Level off the top of the compacted specimen by tamping lightly with the large (2") end of the tamper in order to provide a smooth surface and an even plane at right angles to the axis of the mold. After tamping is complete, remove the extension sleeve, brush down the sides of the mold and put on the filter paper. Care must be taken to include the entire sample initially weighed as any material loss will be erroneously shown as liquid loss later.

6. Place the top plunger in position, then place the entire assembly on the hydraulic jack in the compression frame (see Figure G-1). If necessary, place one or more of the spacing rings between the top plunger and the top of the frame to prevent excessive travel of the jack. <u>Remove the pin that holds the bottom in place</u> and gradually

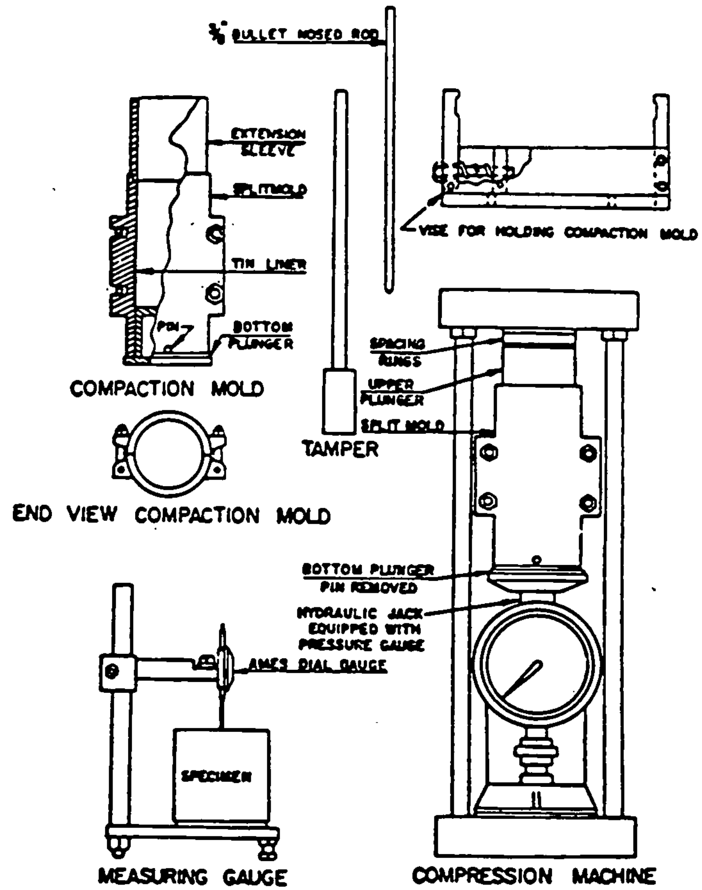

Fig. G.1. Hydraulic Compaction Apparatus (OSHD Test Method 126-86).

apply a total load of 25,000 lbs. Use 1 minute to attain the first 20,000 lbs., and another 1/2 of a minute to attain the next 5,000 lbs. Hold this 25,000 lbs. for 1 minute, then release the load. Remove the assembly from the jack being sure to hold the bottom plunger so it doesn't fall out.

7. Remove the liner from the split mold and wipe any free liquid off from the tin mold and the filter papers. Weigh the specimen (specimen, 2 filters and liner) and record this weight. Subtract the weight of the liner and filter paper to get the net weight of the specimen.

8. The difference between the initial weight of the sample and the net weight of the specimen is the liquid loss.

5.0 Results and Evaluation

Table G.1 and Figure G.2 summarize the results of trial batches of recycle mixture in which the emulsion and the water contents were varied. The emulsion was varied from the actual content used during construction to 0.9% above and 0.5% below this content of 1.0%. The added water was varied from 0.0% to a content in which 20 milliliters, 20 grams, were lost during the test. This 20 milliliter loss occurred at or above 4.5% total liquid (emulsion and water).

These results are obtained using the RAP from the Warm Springs unit. During the casting of the Marshall Molds a water content that would result, when added to the amount of emulsion, in 4.0% total liquid was found to be optimum.

Of the 17 tests recorded, 3 were recast as they appeared to be outside the curve. A standard deviation was not calculated due to the small number of tests. All materials were heated to 140°F prior to mixing, this created some water loss during mixing and usually 2 or more grams of water were added to bring the mixture back up to the required water content prior to adding the emulsion. It was observed at the higher emulsion content that the liquid lost was primarily emulsion. At the lower emulsion content of 0.5% the lost liquid was clear water. The majority of the liquid lost at the mix design emulsion content was water discolored slightly with a small amount of emulsion. The variations in gradation that were visually discernible did not seem to effect the test. All RAP was screened over a 3/4" sieve, the retained material was broken with a hammer.

6.0 Conclusions

Mix that does not loose liquid during compaction requires an increase in emulsion or water content. From our experience with the following data obtained during the 1986 recycle projects a liquid loss between 15 and 20 grams appears to be the optimum.

The void content of the compacted mix specimen can be calculated after measurement of the specimen volume, drying the mix, calculating the dry density and determining the maximum dry specific gravity. The specimens produced under this procedure have reproduced the densities achieved in the roadway. Currently the Marshall data is being used to calculate maximum density and no data are available on the void content of the liquid loss specimen.

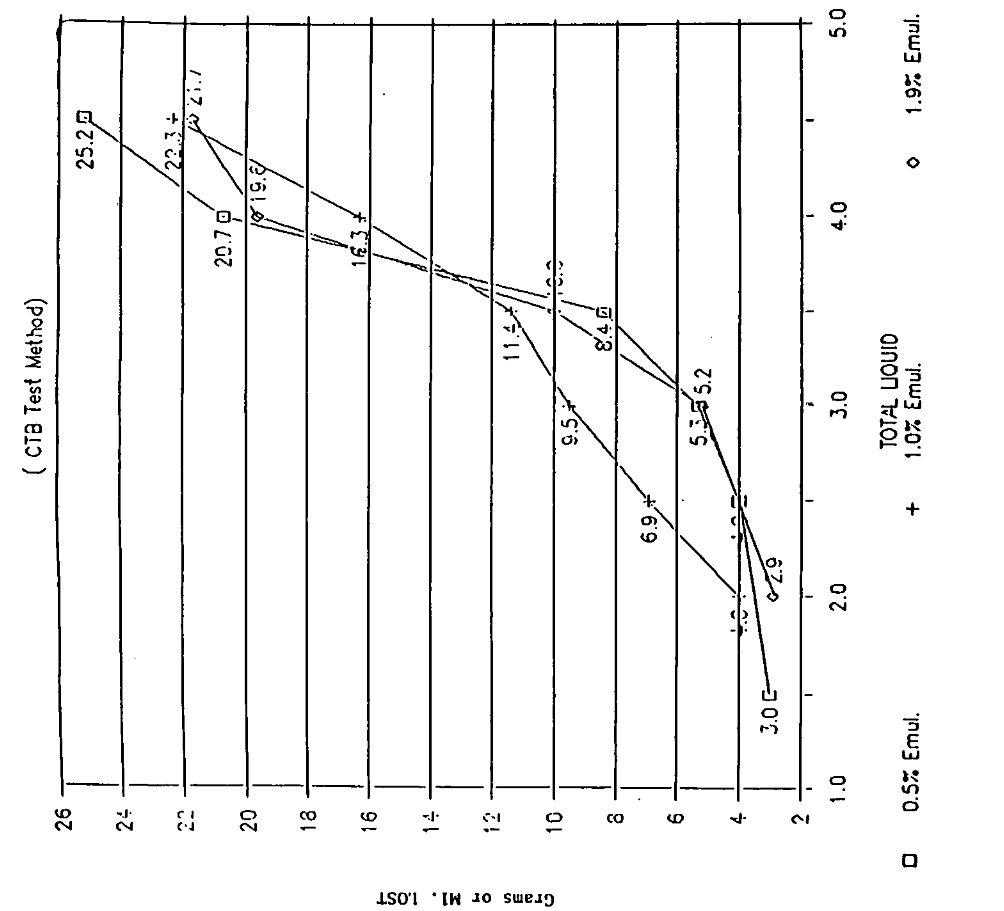

Fig. G.2. Liquid Content vs. Water Loss.

Table G.1 CTB Water Loss Test

Emulsion Content	Dry Wt.	H^2O Wt.	Emulsion Weight	% H^2O	% Emulsion	Total Liquid	Sample Weight	CTB Weight	ml Loss
1.9%	1700.8	1700.8	1733.1	0.0	1.9	1.9	1704.9	1702.0	2.9
which is	1654.8	1671.3	1702.7	1.0	1.9	2.9	1618.1	1612.9	5.2
0.9% over	1701.2	1726.7	1759.0	1.5	1.9	3.4	1740.4	1730.4	10.0
design	1700.2	1734.2	1766.5	2.0	1.9	3.9	1743.7	1724.1	19.6
	1702.3	1746.6	1778.9	2.6	1.8	4.5	1754.8	1733.1	21.7
1.0%	1705.2	1722.3	1739.4	1.0	1.0	2.0	1719.7	1715.7	4.0
this is	1700.1	1725.6	1742.6	1.5	1.0	2.5	1741.3	1734.4	6.9
mix design	1699.0	1733.0	1750.0	2.0	1.0	3.0	1740.5	1731.0	9.5
content	1700.7	1743.2	1760.2	2.5	1.0	3.5	1756.1	1744.7	11.4
	1702.8	1753.9	1770.9	3.0	1.0	4.0	1760.8	1744.5	16.3
	1705.5	1765.2	1782.3	3.5	1.0	4.5	1763.2	1740.9	22.3
0.5	1702.5	1719.5	1728.0	1.0	0.5	1.5	1723.5	1720.5	3.0
This is	1704.6	1738.7	1747.2	2.0	0.5	2.5	1736.1	1732.1	4.0
0.5% below	1700.3	1742.8	1751.3	2.5	0.5	3.0	1742.6	1737.3	5.3
mix design	1699.0	1750.0	1758.5	3.0	0.5	3.5	1735.0	1726.6	8.4
	1700.4	1760.0	1768.4	3.5	0.5	4.0	1755.9	1735.2	20.7
	1701.1	1769.1	1777.7	4.0	0.5	4.5	1766.1	1740.9	25.2

APPENDIX D

PENNSYLVANIA MIX DESIGN METHOD

SAMPLES: 15 six-inch diameter cores (or 5 bags of RAP)
E-5 and E-8C Emulsified Asphalts

STEP 1

Check if the necessary samples and paper work have been received. If not , call the appropriate person.

STEP 2

(a) Document the thickness and types of layers (FJ, ID-2 wearing, ID-2 binder, BCBC, seal coat, FB, penetration macadam, etc.). Also identify the aggregate type in each layer (stone, gravel, slag).

(b) Saw off the top to the depth of recycling (Table 1).

(c) Crush the top layers in the laboratory jaw crusher and combine the RAP into one sample (unless the layers are significantly different requiring different designs).

STEP 3

(a) Run at least three (3) gradation of the combined RAP (Record on Table 4A).

(b) Run Abson Recovery on at least three (3) samples. (Record data on % AC, penetration, viscosity 140 F and gradation on Table 4B).

(c) Calculate the % New Emulsion needed (Pc) from the formulas (Table 5).

(d) Review the information obtained above in (a), (b) and (c) to select the emulsion type (E-5 or E-8C). Check if virgin aggregate is needed for blending.

STEP 4

(a) Use Table 6 to adjust gradation for 100% passing 1" or 3/4". Calculate cumulative weights for 500 g batches for optimum moisture determinations and other batches for Marshall specimens.

(b) Prepare the batches based on calculations in (a) above.

STEP 5

(a) Determine the optimum moisture content (Table 7) starting at 3% in increments of 1%. Keep the emulsion content constant at 2.5% by weight of RAP. (Mixing time 2 minutes - 90%+ coating required after surface drying).

Use RAP at ambient temperature and emulsion at 140 ± 10 F.

Keep the established optimum moisture content same in subsequent design procedures. If both E-5 and E-8C are used, optimum moisture content could be different and, therefore, should be established for each type. Record the observations and recommendations on Table 7.

STEP 6

(a) Make three (3) mixtures each at four (4) emulsion contents using the established optimum moisture content and RAP 100% pass. 1" or 3/4". Use RAP at ambient temperature and emulsion at 140 + 10 F. Normally, use 2.0, 2.5, 3.0 and 3.5% emulsion with 100% RAP (if the RAP is too rich in asphalt, start out with 1.5%). If RAP/virgin aggregate blend is used start out at higher asphalt content based on Table 5 data.

(b) Cure the mixtures in oven @ 105 F for 45 minutes. Remix for 30 seconds and allow to cool to room temperature. Weigh the mixtures before and after curing and report % moisture lost in Table 8.

(c) Compact the specimens with 75 blows on each side. Extrude the specimens on the following day. Weigh each specimen after extrusion.

(d) Cure the specimens in a forced-draft oven at 104 F (40 C) for 3 days. Weigh the specimens daily (unless it is a weekend) and record % lost on Table 8.

STEP 7

(a) Measure thickness (nearest 1/16") and weight of each specimen.

(b) Determine the resilient modulus (77 F) of all specimens after 3 days' curing in oven at 104 F. If testing schedule does not permit this testing right away, the specimens can be kept at ambient temperature. However, record the number of days of this additional curing. Record M_R data in Table 8 (nearest 1000 psi).

STEP 8

(a) Determine the dry weight (A) of the specimens before vacuum saturation with water.

(b) Immerse the specimens under 1 inch of water. Apply a vacuum of 26 inch Hg for 30 minutes gently agitating the container.

(c) Release the vacuum gradually and leave the specimens submerged in water for at least 30 minutes.

(d) Remove the specimen from water, quickly surface dry the specimens by towel blotting, and weigh immediately in air (B), and then weigh submerged in water maintained at 77 F (C). Return the specimens immediately to the water bath (77 F) and keep submerged until tested for resilient modulus (M_R) during the same day.

(e) Calculate the bulk specific gravity and permeable voids of each specimen as follows:

$$\text{Bulk Sp. Gr.} = \frac{A}{B-C}$$

$$\text{Permeable Voids, \%} = \frac{B-A}{B-C} \times 100$$

where: A = weight of dry specimen in air,

B = weight of vacuum saturated blotted specimen in air,

C = weight of vacuum saturated specimens in water

Note: Use PTM 715 (Method A - Volumeter) as an alternate to Steps (d) and (e) above.

(f) Determine the resilient modulus (M_R) of the vacuum saturated specimens. Report on Table 8.

(g) Calculate % retained M_R after vacuum saturation.

(h) Keep the tested specimens @ 77 F in air.

STEP 9

(a) Determine Marshall stability and flow at 77 F. Record the additional curing which took place after M_R testing.

(b) If some curves do not peak, report all stability values at 10 Flow. If all curves peak, report the stability and flow at peak.

STEP 10

Summarize all test data on Table 9.

TABLE 1. COLD RECYCLING PROJECT DETAILS AND RAP GRADATION

A. PROJECT DETAILS:

Name of Contractor____________________

Name of Representative & Phone No.____________________

Location of RAP Stockpile____________________

RAP Type: ID-2 Mix/FJ-1/Other____________________

Project for Recycling: District________ LR________ TR________

Stations____________________ ADT________

Use of Recycled Mix: Main Line/Shoulders/Other____________________

Intended Method of Recycling: Central Plant/ Motopaver/ In-place

Thickness of Recycled Layer________inches. Subbase Type________

Type & Thickness of Surface Course to be used____________________

B. RAP GRADATION:

This need not filled when pavement cores are submitted.

SIEVE	SAMPLE NUMBER					MEAN $\bar{X}$	STD. DEV.	PA. #2A
	1	2	3	4	5			
% Pass.								
2"								100
1½"								-
1"								-
3/4"								52-100
½"								-
3/8"								36-70
#4								24-50
#8								-
#16								-
#200								-

TABLE 2. PROPOSED RAP/RAM/VIRGIN AGGREGATE(S) BLENDS FOR COLD RECYCLING

SIEVE	RAP ________			NO. 1 ________			NO. 2 ________			Total % in Blend	Pa. #2A
	% Pass	X A	= % in Blend	% Pass	X B	= % in Blend	% Pass	X C	= % in Blend		
2"											100
1½"											-
1"											-
3/4"											52-100
½"											-
3/8"											36-70
#4											24-50
#8											-
#16											-
200											-

A, B, C = Decimal Fraction of each aggregate in blend.

TABLE 3. EMULSIFIED ASPHALTS - TYPICAL TEST DATA - COLD RECYCLING

	Medium Setting E-5 (Cationic)	Slow Setting E-8C (Cationic)	Other
Supplier			
Supplier Terminal			
Viscosity, Saybolt Furol (122 F for E-5, and 77 F for E-8) sec.			
Distillation: Asphalt, % by Wt. Oil Distillate, % by Vol.			
Test on Residue: Penetration @ 77 F Ductility @ 60 F			
Sample Provided to the MTD?			

TABLE 4. ANALYSIS OF RAP (MTD DATA)

LAB. NO.____________

District________ County____________ LR________ TR________

A. RAP GRADATION AS RECEIVED:

☐ As received ☐ Crushed in Lab. Particles are (hard) (medium) (soft) Odor____

SIEVE	SAMPLE NUMBER 1	2	3	4	5	MEAN $\bar{X}$	STD. DEV.	PA #2A
% Pass. 2"								100
1½"								-
1"								-
3/4"								52-100
½"								-
3/8"								36-70
#4								24-50
#8								—
#16								-
#200								-

B. RAP COMPOSITION AS EXTRACTED:

SIEVE	SAMPLE NUMBER 1	2	3	4	5	MEAN $\bar{X}$	STD. DEV.	REMARKS
% Pass. 2"								Extracted
1½"								Aggregate Type:
1"								Stone
								Gravel
3/4"								Slag
½"								
3/8"								
#4								
#8								
#16								
#200								
%.AC								
Pentration								

Lab No.________

TABLE 5. EMULSION CONTENT FOR MIX TRIALS

A. % Existing AC in RAP (+ Virgin aggregate) by weight of Aggregate (Pa)

$$Pa = \frac{Pm}{100-Pm} \times 100 =$$

Where Pm = % Existing AC in RAP (+ virgin aggregate) by wt. of mix

=

B. Estimated total Residual Asphalt Content by weight of Aggregate (Pr)

Use extracted gradation of RAP (combinded with the gradation of the virgin aggregate, if necessary.

A = % Ret. on #8 sieve =

B = % Pass. #8 & Ret. on #200 =

C = % Pass. #200 =

D = % Ret. on #4 sieve =

E = % Pass. #4 & Ret. on #200 =

K = 0.15 for 11-15% pass. #200; 0.18 for 6-10; 0.20 for 0-5 } =

F = 1.0 (range 0.7 to 1.0 based on absorption)

Pr

1. Chevron Method: $0.65\,(0.05A + 0.1B + 0.5C) =$

2. A. I. Method: $\dfrac{(0.035A + 0.045B + KC + F)}{100 - (0.035A + 0.45B + KC + F)} \times 100 =$

3. WITCO Method: $\dfrac{(4A + 7B + 12C)}{100} \times 1.1 =$

4. Illinois Method: $0.00138\,DE + 6.358 \log_{10} C - 4.655 =$

C. % Emulsion Needed (Pc)

1. Chevron MEthod: $\dfrac{Pr - Pa}{0.65} =$

2. A.I. Method: $\dfrac{Pr - Pa}{0.65} =$

3. WITCO Method: $\dfrac{Pr - Pa}{0.65} =$

4. Illinois Method: $\dfrac{Pr - Pa}{0.65} =$

Lab No.______

TABLE 6. CUMULATIVE WEIGHTS FOR MIX TRIALS

Sieve	Average RAP or Blend Gradation From Table 4 or Table 2	Adjusted Gradation* 100% Pass. 1" or 3/4"	Cumulative Weights for 500 g-Batch (Col. 3 x 5)	Cumulative Weight for 1200 g-Batch (Col. 3 x 12)	Cumulative Weight for ____g Batch
200					
16					
8					
4					
3/8					
1/2					
3/4					
1					

* Use 1" if passing 3/4" sieve is less than 75%
Use 3/4" if passing 3/4" sieve is more than 75%

Lab No.______

TABLE 7. DETERMINING OF OPTIMUM MOISTURE CONTENT RANGE FOR MIXING

Make at least 5 batches of 500 gm each of RAP (+ virgin aggregate, if necessary) using the weights in Table 6. Add 3,4, 5, 6 and 7% water. Maintain the selected emulsion at 140 + 10 F. After mixing the water, keep the RAP covered for at least 15 minutes before adding the emulsion. A 2-minute spoon bowl mix is required. The mix should be observed carefully and observations recorded. As close as 100% coating is preferred (examined after fan drying), however, mixes will be considered suitable with a minimum coating of 90%. Mixes will be unsatisfactory if (a) they strip or stiffen excessively on mixing, (b) break prematurely, and (c) become excessively soupy and segregate on standing.

% MOISTURE	EMULSION GRADE	% EMULSION	OBSERVATIONS

Recommendations: Optimum Moisture Content = %
Moisture Content Range = %

Tested by______

Lab No. ________

TABLE 9. COLD RECYCLING DESIGN DATA SUMMARY

Mix ______________________ Optimum Moisture Content ________ % Emulsion Type ______________________

	EMULSION CONTENT
Specimen Sp. Gr.	
% Total Moisture Loss	
Resilient Modulus (M_R) @ 77 F, PSI	
% Permeable Voids (Vac. Sat.)	
Resilient Modulus (M_R) after Vac. Sat.	
% Retained M_R	
Marshall Stability @ 77 F	
Flow @ 77 F	

APPENDIX E

ASPHALT INSTITUTE MIX DESIGN METHOD

Chapter III

MIX DESIGN

3.01 GENERAL—For cold-mix recycling, the primary objective of the mix design is to produce a mixture comparable to one made from all new materials. However, there are no universally accepted mix-design methods for cold-mix recycling. In general, laboratory tests, empirical formulas or past experience with identical projects are used to establish the initial asphalt content, with the intention of adjusting it, if necessary, after construction begins.

3.02 PREPARATORY STEPS—This interim mix-design procedure follows:

The aggregate from a reclaimed asphalt pavement is blended with reclaimed aggregate materials and/or new aggregate that is required to obtain a combined aggregate gradation meeting the specification requirements. Once the relative aggregate proportions are determined, a grade of new asphalt is selected. A total asphalt demand for the blend is determined. Calculations then follow to estimate the required amount of new asphalt for recycling. Following these determinations, asphalt content adjustments are made from field trials.

3.03 MIX DESIGN—With the information obtained from the materials evaluation (Chapter II) the recycled cold-mix design may be formulated.

Figure III-1 is a flow chart setting forth the steps for this interim design procedure. The steps are:

(1) *Combined Aggregates in the Recycled Mixture*—Using the gradation of the aggregate from the reclaimed asphalt pavement, the reclaimed aggregate material (if any) and new aggregate, a combined gradation meeting the desired specification requirements is calculated.

As a practical matter, most cold-mix recycling specifications allow a reasonable variation in allowable gradations (*See* Table III-1), and correction by adding new aggregate is not commonly required. The gradation of the sampled material must always be evaluated, however.

(2) *Select Grade of New Asphalt*—A grade of asphalt is selected using the general guidelines given in paragraph 2.06, 2.07 and 2.09.

(3) *Percent Asphalt Demand of the Combined Aggregates*—Asphalt demand of the combined aggregates may be calculated by the empirical formula:

$$P_c = \frac{0.035a + 0.045b + Kc + F}{R}$$

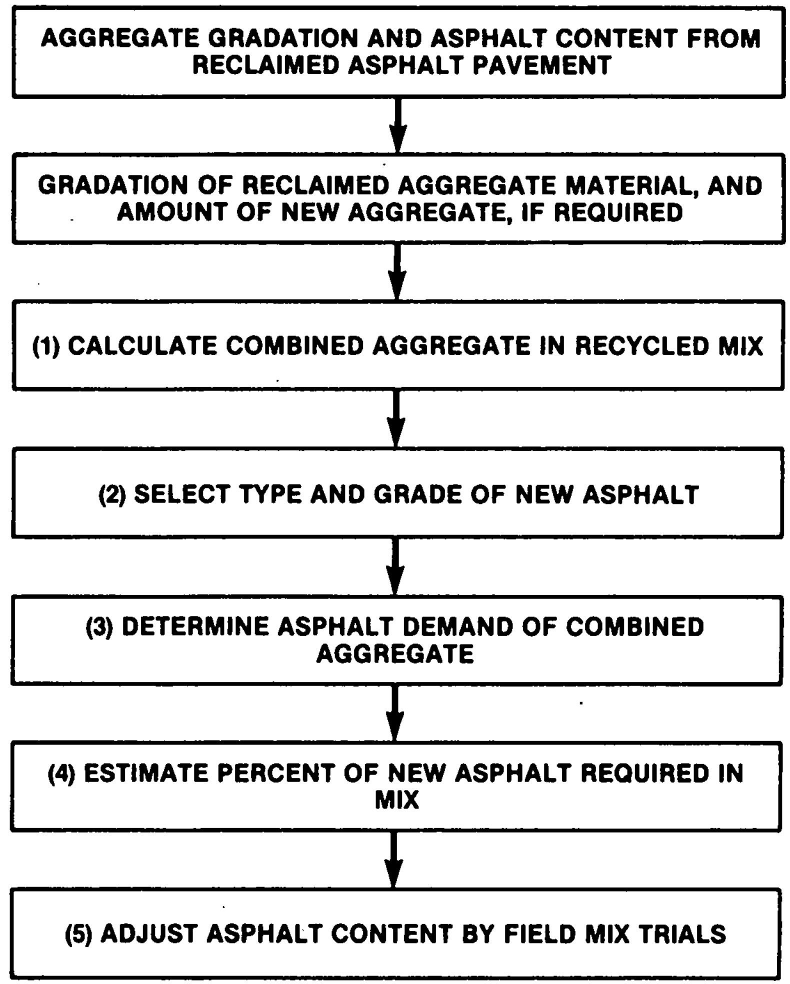

Figure III-1—Flow chart of cold-mix design procedure.

Where: P_c = Percent* of asphalt material by weight of total mix

K = 0.15 for 11-15 percent passing 75μm (No. 200) sieve
0.18 for 6-10 percent passing 75μm (No. 200) sieve
0.20 for 5 percent or less passing 75μm (No. 200) sieve

a = Percent* of mineral aggregate retained on 2.36mm (No. 8) sieve

b = Percent* of mineral aggregate passing 2.36mm (No. 8) sieve and retained on 75μm (No. 200) sieve

c = Percent* of mineral aggregate passing 75μm (No. 200) sieve

F = 0 to 2.0 percent. Based on absorption of light or heavy aggregate. The formula is based on an average specific gravity of 2.60 to 2.70. In the absence of other data a value of 0.7 to 1.0 should cover most conditions.

R = 1.0 for asphalt cement; 0.60 to 0.65 for asphalt emulsions

**Expressed as a whole number.*

(4) *Percent of New Asphalt In Mix*—The quantity of new asphalt to be added to the recycled mixtures equals the calculated asphalt demand (Step 3) minus the percentage of asphalt in the reclaimed asphalt pavement.

The formula is:

$$P_r = P_c - \frac{(P_a \times P_p)}{R}$$

Where: P_r = Percent* new asphalt in the recycled mix

P_c = Percent* of asphalt by weight of total mix (Step 3)

P_a = Percent* of asphalt in the reclaimed asphalt pavement

P_p = Decimal percent reclaimed asphalt pavement in the recycled mix

R = 1.0 for asphalt cement in reclaimed pavement; 0.60 to 0.65 for emulsified asphalt; 0.70 to 0.80 for cutback asphalt.

**Expressed as a whole number*

(In in-place construction it is often desirable to proportion asphalt based on the weight of aggregate P_d. This conversion is as follows:

$$P_d = \frac{100\,P_r}{100 - P_r} = \text{percent, expressed as a whole number, of new asphalt by weight of aggregate)}$$

(5) *Field Mix Trial*—Final adjustment of asphalt content may be made by the field engineer to obtain a durable roadway (based on the need to minimize deformation and cracking).

TABLE III-1 GRADATION GUIDELINES FOR COLD-MIX RECYCLING

Sieve Size	Percent Passing by Weight						
	Open-Graded			Dense-Graded			
	A	B	C	D	E	F	G
38.1mm (1½ in.)	100			100			
25.0mm (1 in.)	95-100	100		80-100			
19.0mm (¾ in.)		90-100					
12.5mm (½ in.)	25-60		100		100	100	100
9.5mm (3/8 in.)		20-55	85-100				
4.75mm (No. 4)	0-10	0-10		25-85	75-100	75-100	75-100
2.36mm (No. 8)	0-5	0-5					
1.18mm (No. 16)			0-5				
300 μm (No. 50)						15-30	
150 μm (No. 100)							15-65
75 μm (No. 200)	0-2	0-2	0-2	3-15	0-12	5-12	12-20

Design Example 1

A rural roadway is sampled and found to be 25mm (1 in.) asphalt surface treatment over 175mm (7 in.) of untreated stone base. The pavement is to be recycled to a 125mm (5 in.) depth. Asphalt extraction tests show the asphalt content of the surface treatment to be 10 percent. The gradation of the aggregates is as follows:

Sieve Size	Percent Passing: Surface Treatment	Percent Passing: Stone Base
19.0 mm (3/4 in.)		100
12.5 mm (1/2 in.)	100	90
9.5 mm (3/8 in.)	60	70
4.75mm (No. 4)	10	45
2.36mm (No. 8)	2	25
300 μm (No. 50)		9
75 μm (No. 200)		6

For this example, the density of the asphalt surface layer is 2080 kg/m^3 (130 lb/ft^3)* and the density of the stone base layer is 1760 kg/m^3 (110 lb/ft^3)†.

*Normal range 2080-2480 kg/m^3 (130-155 lb/ft^3). ASTM D 2726, *Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface Dry Specimens.*

†Normal range 1600-1760 kg/m^3 (100-110 lb/ft^3). AASHTO T 191, *Density of Soil In-Place by Sand-Cone Method,* AASHTO T 205, *Density of Soil In-Place by the Rubber-Balloon Method,* or AASHTO T 238, *Density of Soil and Soil-Aggregate In-Place by Nuclear Methods.*

The ratio of material (by weight) to be utilized in a 125mm (5 in.) recycled depth is calculated as follows:

(a) Determine the mass in kilograms per square metre (lb/ft²) of the asphalt layer corrected for asphalt on the basis of 25mm (1 in.) of depth.

2080 − (0.10 x 2080) = 1872/40* = 46.8 kg/m²/25mm
[130 − (0.10 x 130) = 117/12† = 9.75 lb/ft²/in.]

(b) Stone base layer per 25mm (1 in.) of depth.

1760/40 = 44.0 kg/m²/25mm
[110/12 = 9.17 lb/ft²/in.]

(c) For depth of recycling—125mm (5 in.)

25mm asphalt surface layer	= (25/25) (46.8) =	46.8 kg
100 mm stone base layer	= (100/25) (44.0) =	176.0
		222.8 kg
[1-in. asphalt surface layer	= 1 x 9.75 =	9.75 lbs
4-in. stone base layer	= 4 x 9.17 =	36.68
		46.43 lbs]

(d) Ratio for blending of aggregates

Asphalt surface layer = 46.8/222.8 = 0.21
[9.75/46.43 = 0.21]
Stone base layer = 176.0/222.8 = 0.79
[36.68/46.43 = 0.79]

Step 1: Combined Aggregates in the Recycled Mixture

Sieve Size	Surface Treatment		Stone Base		Blend
19.0 mm (3/4 in.)	[100 x 0.21 = 21.0]	+	[100 x 0.79 = 79.0]	=	100.0
12.5 mm (1/2 in.)	[100 x 0.21 = 21.0]	+	[90 x 0.79 = 71.1]	=	92.1
9.5 mm (3/8 in.)	[60 x 0.21 = 12.6]	+	[70 x 0.79 = 55.3]	=	67.9
4.75mm (No. 4)	[10 x 0.21 = 2.1]	+	[45 x 0.79 = 35.6]	=	37.7
2.36mm (No. 8)	[2 x 0.21 = 0.4]	+	[25 x 0.79 = 19.8]	=	20.2
300 μm (No. 50)	[0 x 0.21 = 0.0]	+	[9 x 0.79 = 7.1]	=	7.1
75 μm (No. 200)	[0 x 0.21 = 0.0]	+	[6 x 0.79 = 4.7]	=	4.7

Step 2: Select Grade of New Asphalt

This blend (Step 1) meets the requirements of Gradation D, Table III-1.

*1m = 1,000mm †12 in. = 1 ft.
1,000/25 = 40

In Chapter II, using guidelines from paragraphs 2.06, 2.07 and 2.09, and when in-place construction with a travel plant is to be used—an SS-1 grade of asphalt emulsion is selected for this design.

Step 3: Percent Asphalt Demand of Combined Aggregates

Estimate asphalt requirements of aggregate blend using the formula:

$$P_c = \frac{0.035a \times 0.045b + 0.20c + F}{R}$$

$$= \frac{(0.035)(79.8) + (0.045)(15.5) + (0.20)(4.7) + 0.7}{0.60}$$

= 8.55 percent by weight of total mix

Step 4: Percent of New Asphalt in Mix

$$P_r = P_c - \frac{(P_a \times P_p)}{R}$$

$$= 8.55 - \frac{(10.0 \times 0.21)}{0.60}$$

= 5.05 say 5.1 percent of new asphalt by weight of mix.

(or $P_d = \frac{100P_r}{100 - P_r} = \frac{(100)(5.1)}{100 - 5.1} = 5.4$ percent of new asphalt by weight of aggregate, if needed, for windrow calculations)

Step 5: Field Mix Trial

Therefore, 5.1 percent (5.4 percent by weight of aggregate) of SS-1 emulsified asphalt is used for initial value for in-place cold-mix recycling and is subject to adjustment as needed after construction begins (*see* Chapter IV for requirements of surface course or surface treatment).

Design Example 2

A rural roadway is sampled and found to consist of an 50mm (2 in.) asphalt road mix surface course over 200mm (8 in.) of untreated gravel base. The pavement is to be recycled to a 150mm (6 in.) depth. Extraction tests indicate the asphalt content of the reclaimed asphalt pavement to be 7.0 percent. The gradation of the aggregate contained in the road-mix and gravel base courses is as follows:

Sieve Size	Percent Passing	
	Road Mix	Gravel Base
19.0 mm (3/4 in.)	100	100
12.5 mm (1/2 in.)	95	90
9.5 mm (3/8 in.)	70	78
4.75mm (No. 4)	50	65
2.36mm (No. 8)	30	40
300 μm (No. 50)	10	15
75 μm (No. 200)	8	12

For this example, the mass of the road-mix layer is 2320 kg/m^3 (145 lb/ft^3) and the mass of the gravel base layer is 1600 kg/m^3 (100 lb/ft^3) (*See* References Example No. 1).

The ratio of material to be utilized in a 150mm (6 in.) recycled depth is calculated as follows:

(a) Determine the mass in kilograms per square metre (lb/ft^2) of the road mix layer corrected for asphalt on the basis of 25mm (1 in.) of depth

2320 – (0.07 x 2320) = 2158/40* = 53.95 kg/m^2/25mm
[145 – (0.07 x 145) = 135/12† = 11.25 lb/ft^2/in.]

(b) Gravel base layer per 25mm (1 in.) of depth

1600/40 = 40.0 kg/m^2/25mm
[100/12 = 8.33 lb/ft^2/in.]

(c) For depth of recycling—150mm (6-in.)

50mm road mix layer	= (50/25) (53.95)	=	107.9 kg
100mm gravel base layer	= (100/25) (40)	=	160.0
			267.9 kg

[2-in. road mix layer	= 2 x 11.25	=	22.50 lbs
4-in. gravel base layer	= 4 x 8.33	=	33.32
			55.82 lbs]

(d) Ratio for blending of aggregates

Road-mix layer = 107.9/267.9 = 0.40
[22.50/55.82 = 0.40]
Gravel base layer = 160.0/267.9 = 0.60
[33.32/55.82 = 0.60]

*1m = 1,000mm †12 in. = 1 ft.
1,000/25 = 40

Step 1: Combined Aggregates in the Recycled Mixture

Sieve Size	Road-Mix		Gravel Base		Blend
19.0 mm (3/4 in.)	[100 x 0.40 = 40.0]	+	[100 x 0.60 = 60.0]	=	100.0
12.5 mm (1/2 in.)	[95 x 0.40 = 38.0]	+	[90 x 0.60 = 54.0]	=	92.0
9.5 mm (3/8 in.)	[70 x 0.40 = 28.0]	+	[78 x 0.60 = 46.8]	=	74.8
4.75mm (No. 4)	[50 x 0.40 = 20.0]	+	[65 x 0.60 = 39.0]	=	59.0
2.36mm (No. 8)	[30 x 0.40 = 12.0]	+	[40 x 0.60 = 24.0]	=	36.0
300 μm (No. 50)	[10 x 0.40 = 4.0]	+	[15 x 0.60 = 9.0]	=	13.0
75 μm (No. 200)	[8 x 0.40 = 3.2]	+	[12 x 0.60 = 7.2]	=	10.4

Step 2: Select Grade of New Asphalt

This blend (Step 1) meets the requirements of Gradation D, Table III-1.

In Chapter II, using guidelines from paragraph 2.06, 2.07 and 2.09, and as mixed-in-place construction with a motor patrol is to be used—a HFMS-2s asphalt emulsion is selected for this design.

Step 3: Percent Asphalt Demand of Combined Aggregate

Estimate asphalt requirement of combined aggregate using the formula:

$$P_c = \frac{0.035\,a + 0.045\,b + 0.18\,c + F}{R}$$

$$= \frac{(0.035)(64.0) + (0.045)(25.6) + (0.18)(10.4) + 0.0}{0.65}$$

= 8.10 percent weight of total mix

(Aggregate is non-absorptive, no (F) correction needed).

Step 4: Percent of New Asphalt in Mix

$$P_r = P_c - (P_a \times P_p)/R$$

$$= 8.10 - (7.0 \times 0.40)/0.65$$

= 3.79 say 3.8 percent of new asphalt by weight of mix

or $P_d = \frac{100\,P_r}{100 - P_r} = \frac{(100)(3.8)}{(100 - 3.8)} = 4.0$ percent of new asphalt, by weight of aggregate, if needed, for windrow calculations.

Step 5: Field Mix Trial

Therefore, 3.8 percent of HFMS-2s (4.0 percent by weight of aggregate) is used as initial value for in-place cold-mix recycling and is subject to adjustment as needed after construction begins (*see* Chapter IV for requirements of surface course or surface treatment).

APPENDIX F

MICHIGAN DOT COLD IN-PLACE RECYCLING SPECIFICATION

RECOMMENDED SPECIFICATIONS FOR
BITUMINOUS AGGREGATE BASE COURSE
STABILIZED IN PLACE

Description

This work shall consist of scarifying, pulverizing, crushing, adding new material as required, and shaping to the plan grade for stabilizing with bituminous material, and shaping, rolling, and compacting the stabilizer aggregate to the proper elevation and slope.

Materials

The bituminous materials shall meet the requirements specified in MDSHT Standard Specifications (4) as follows:

Bituminous Materials
MC-800, Asphalt Cement Penetration Grade 120/150, 200/250 and Emulsion MS-2s

The bituminous material shall be applied at the rate as determined by the Engineer so that the residual bitumen added will be between 2 and 5 percent by weight of the bituminous mixture. Residual bitumen content shall be computed based on the residue of the bituminous material being applied.

When additional aggregate is required, it shall be 20A or 22A aggregate (4).

When the bituminous material to be used is not specified on the plans or in the proposal, the Contractor shall select one of the bituminous materials specified above.

EQUIPMENT REQUIREMENTS

Rollers

Rollers shall meet the requirements as specified under Rollers, (4.12.03-f) Standard Specifications (4), except that combination pneumatic-steel wheel and vibratory rollers will be permitted.

Crushing Equipment

When the use of crushing equipment is specified in the proposal, the equipment shall be an approved rotary reduction machine having positive depth control adjustments in increments of 1/2 in. and capable of reducing material which is at least 6 in. in thickness. The machine shall be of a type designed by the manufacturer specifically for reduction in size of pavement material, in place, and be capable of reducing the pavement material to the specified size. The cutting drums shall be enclosed and shall have a sprinkling system around the reduction chamber for pollution control. The rate of forward speed must be positively controlled in order to ensure consistent size of reduced material. The machine must be equipped with an accurate tachometer mounted in full view of the operator. The crushing equipment shall meet the approval of the Engineer.

Mixers

Mixers shall be self-propelled and a combination scarifier, pulverizer, mixer, and liquid distributor. Unless otherwise specified, a minimum of two mixers will be required. The mixing rotor or rotors shall have a positive depth control to ensure a uniform depth of mixing. The spray bar for distribution of the liquid shall operate in such a manner that all asphalt will be uniformly applied through the mixer at the time of mixing. The equipment for distributing the bituminous material shall be adjustable and shall measure accurately the amounts of bituminous material being applied. The bitumen pump shall be a positive displacement type pump. It shall be equipped in such a manner as to make it possible to check accurately the rate of application of the bitumen at any time. The mixer shall meet the approval of the Engineer. If asphalt cement is used, one mixer shall be a self-propelled single pass stabilizer, combining a cutting rotor, a blending rotor, and at least one mixing rotor in the mixing chamber.

CONSTRUCTION METHODS

Scarifying and Pulverizing

The material shall be scarified and pulverized to a maximum size of 2 in. and to the depth specified on the plans or in the proposal, by one or more passes. The maximum length or width of roadbed to be scarified and pulverized at any one time shall be as directed by the Engineer.

Grading

Excess material not incorporated into the work will become the property of the Contractor and shall be disposed of as specified under Disposing of Surplus and Unsuitable Material, (2.08.07) Standard Specifications (4).

Additional aggregate shall be placed as necessary to attain the plan cross section.

After the material has been balanced, it shall be thoroughly mixed. In guardrail areas, on ramps, and in bridge areas, the material to be mixed may be bladed into a windrow to provide working room for the mixer.

The grade shall be shaped to a uniform crown and grade.

Mixing with Bituminous Material

The bituminous material shall be added only to that material which can be completely mixed, aerated, dried, and compacted in one day. The bituminous material shall be added through the mixer, at the rate and temperature directed by the Engineer. The aggregate-bituminous mixture shall then be bladed into a windrow and mixed with the mixer, the operation proceeding from one side of the work area to the other (approximately four to eight windrow-mix coverages) until the mixture presents a uniform composition, free from fat spots and excess moisture, except that windrowing will not be required where asphalt cement is used, or for shoulder stabilization.

Aeration

Aeration of the mixture shall continue until the mixture is dried to the moisture content approved by the Engineer, within the range of 2 to 5 percent, based on dry weight.

Shaping, Rolling, and Compacting

Mixing, shaping, and compacting shall be done while the bituminous material is in a workable state. The mixed material shall be so shaped that, when compacted, it shall be in reasonably close conformity with the lines, grades, and cross-sections shown on the plans or established by the Engineer. Initial rolling may be done with a pneumatic-tired roller or rollers. The aggregate-bituminous mixture shall be compacted to not less than 98 percent of the unit weight obtained by the AASHTO T-180 test method. Such test shall be made on the aggregate-bituminous mixture at the field moisture content existing during the compacting operation. Required density shall be maintained until the material has been surfaced.

Curing

The base may be opened to traffic for a period of time as approved by the Engineer prior to placing of the surface.

Stability

The stabilized base shall be firm and stable under traffic loadings. The base shall be capable of carrying construction equipment during all phases of construction and paving of the wearing surface without excessive deformation or cracking of either the base or the applied paving. The Engineer may require test rolling prior to paving. Any imperfections shall be repaired as directed by the Engineer at contract unit price for base course stabilized in place.

Weather Limitations

Bituminous material shall not be applied to the grade or to the aggregate when rain is threatening or when the air temperature is lower than 55 F.

The stabilization work shall be performed in the Lower Peninsula during the period June 1 to September 15, and in the Upper Peninsula during the period June 15 to September 1, unless otherwise authorized by the Engineer.

MEASUREMENT AND PAYMENT

Method of Measurement

Bituminous Base Stabilization, to the depth specified, will be measured in square yards.

Bituminous base stabilizer required for stabilization will be measured by volume in gallons of residual bitumen at a temperature of 60 F in accordance with the methods specified under Measurement of Quantities, MDSHT Standard Specifications (4).

When additional aggregate is required, the additional aggregate will be measured by weight in tons or in cubic yards, loose measure, as Aggregate - Base Stabilizing. The pay weight for aggregate used in road mix will be based on the scale weight of the material, provided the moisture content, determined at the time of weighing, does not exceed 6 percent. If the material contains more than 6 percent moisture, the excess weight of water over 6 percent will be deducted from the scale weight. No correction or additions will be made to the scale weight if the aggregate contains less than 6 percent moisture. The determination of moisture content and pay weights will be as specified under Measurement of Quantities, MDSHT Standard Specifications (4).

Basis of Payment

The completed work as measured for BITUMINOUS AGGREGATE BASE COURSE STABILIZED IN PLACE will be paid for at the contract unit prices for the following contract items (pay items).

Pay Item	Pay Unit
Bituminous Base Stabilization	Square Yard
Bituminous Material -- Base Stabilizing	Gallon
Aggregate -- Base Stabilizing	Ton
Aggregate -- Base Stabilizing (LM)	Cubic Yard

APPENDIX G

PENNSYLVANIA DOT COLD IN-PLACE RECYCLING SPECIFICATION

COLD RECYCLED BITUMINOUS BASE COURSE
Supplementing the Specifications
Publication 408 dated 1983

THIS IS A TOTALLY NEW SECTION

341.1 DESCRIPTION - This work is the construction of a cold recycled bituminous base course, using either reclaimed asphalt pavement (RAP) material and/or reclaimed aggregate material (RAM), combined with virgin aggregates and/or bituminous material.

DO NOT PLACE COLD RECYCLED BITUMINOUS BASE COURSE FROM SEPTEMBER 1 TO APRIL 15 IN DISTRICTS 1-0, 2-0, 3-0, 4-0, 9-0, 10-0, 11-0, 12-0 and 5-0 (MONROE, CARBON AND SCHUYLKILL COUNTIES ONLY); AND FROM SEPTEMBER 15 TO APRIL 15 IN DISTRICTS 6-0, 8-0 and 5-0 (BERKS, LEHIGH AND NORTHAMPTON COUNTIES ONLY).

341.2 MATERIAL -

(a) Reclaimed Material.

1. Reclaimed Aggregate Material. Aggregate material which has been removed, hereinafter called (RAM).

2. Reclaimed Asphalt Pavement. Processed paving material containing bitumen and aggregates, hereinafter called (RAP).

Ninety-five percent of the material is required to pass through a 2-inch sieve.

(b) Bituminous Material. Add to the mix the type and quantity of bituminous material as determined by the Engineer. Use bituminous material conforming to the applicable requirements of Bulletin 25. Use one of the following:

- Emulsified Asphalt - E-4, E-5, E-6, E-8
- Asphalt Cement - AC-2.5

(c) Aggregate. Section 703.2, No. 8, 57 and 67 (Type A), No. 2A (Type C or better). Add the gradation and quantity to the mix as required and/or directed.

(d) Testing. Supply representative samples of the RAP material or six-inch diameter pavement cores, bituminous materials and virgin aggregate to the MTD for preliminary testing to determine the optimum moisture content, type of bituminous material and mix proportions. Obtain guidelines on sampling procedures from the MTD.

(e) Mixture. Combine the reclaimed material, aggregates and bitumen, meeting the requirements specified, in such proportions that the total aggregate and bitumen in the base course conforms to the composition accepted by the Engineer. Make field adjustments to the MTD recommended moisture content and mix proportions under the guidance of the Engineer to obtain a satisfactory recycled mixture.

(f) Stockpiling. In the event the reclaimed material is stockpiled, store the material in an acceptable manner so as to preserve its quality and suitability.

341.3 CONSTRUCTION -

(a) Equipment. Use any equipment which will produce the completed base course and as follows:

1. Use only mechanical mixers, travel mixers, or central mix plants for mixing the base course materials.

2. Use equipment capable of automatically metering liquids with a variation of not more than plus or minus 0.5% from the specified percentage.

3. Maintain all equipment in a satisfactory operating condition as specified in Section 108.05(c).

(b) Mixing. Maintain a proper moisture content to assure thorough mixing of the reclaimed material and aggregate with the emulsified asphalt and AC-2.5 asphalt cement. Determine the total moisture content in the field using PTM No. 503. Perform at least 3 tests during each day's operation.

1. Central Plant Mixing. For central plant mixing, mix the materials in an acceptable continuous flow or batch-type mixer equipped with batching or metering devices designed to measure the specified quantities of the respective materials. Continue mixing until a thorough and uniform mixture is obtained without stripping of the bituminous material.

Transport the mixture from central mix plants in clean, tight vehicles. Deposit the mix on the prepared area by means of acceptable mechanical spreaders in a uniform loose condition for the full depth of layer being placed. Protective covers for the vehicles may be required by the Engineer.

2. In-Place Mixing. For in-place mixing, spread the required quantity of reclaimed material and aggregate, if required, on the prepared area in a uniform loose layer to obtain the specified compacted depth. Adjust the travel speed and/or the number of passes of the mixer to obtain a thorough and uniform mixture.

If a continuous milling - mixing and placement operation is used, insure that positive discharge pumps accurately meter the bituminous material and the cutting drum of the milling machine mixes it thoroughly with the RAP materials.

3. Mobile Mixing Plant. Use a mobile plant equipped to mix, spread, and strike-off the surface; having the capacity to assure a constant supply and proper proportioning of materials; capable of mixing the materials until a uniform coating of the particles and a thorough distribution of the bituminous material throughout is secured; and having a positive-driven feed to proportion the material from the bins and a positive pump to proportion the bituminous material from the tank. Synchronize the feeder and pump to discharge materials in the desired proportions for mixing. Calibrate the plant prior to actual use.

(c) Compaction. Construct the base course in approximately equal depth layers. Provide a compacted layer depth of not less than 3 inches nor more than 5 inches. After each course has been uniformly spread, allow that course to cure as necessary prior to rolling. Roll with rollers meeting the requirements of Section 108.05(c).

Commence rolling at the low side of the course except leave 3 to 6 inches from any unsupported edge or edges unrolled initially to prevent distortion. Determine in-place density requirements for each course by the construction of at least one control strip for each course under the guidance of a nuclear gauge operator. After each pass of the compaction equipment, take a nuclear density reading following PTM No. 402. Continue compaction with each piece of equipment until no appreciable increase in density is obtained by additional passes. Upon completion of compaction, a minimum of 10 tests will be made at random locations to determine the average in-place density of the control strip. Compact layer or course of the recycled mixture to a target density of at least 96 percent of the average control strip density. The in-place density of each compacted course will be determined in accordance with PTM No. 402.

(d) Finishing. Complete the finishing operation during daylight hours.

(e) Protection. Protect any finished portion of the base course upon which construction equipment is required to travel to prevent marring, distortion, or damage of any kind. Immediately and satisfactorily correct any such damage.

(f) Surface Tolerance. Check the surface smoothness transversely with acceptable templates and longitudinally with straightedges in accordance with the requirements of Section 401.3(k). Satisfactorily correct any surface irregularity that exceeds 1/2 inch under a template or straightedge.

(g) Tests for Depth of Finished Base Course. Determine the depth by cutting or drilling holes to the full depth of the completed base course. Make one depth measurement for each 3,000 square yards or less, of completed base course. Remove and satisfactorily replace any section deficient 1/2 inch or more from the specified depth at no expense to the Department.

Start the immediate correction of sections of base course which are deficient in depth at the point of the determined deficiency and proceed longitudinally and transversely until the base course is found to meet specifications.

Cut or drill all test holes, backfill with similar and/or acceptable material, and satisfactorily compact at no expense to the Department. This operation will be under the supervision of the Engineer who will check the depth for record purposes.

(h) Maintenance and Traffic. Maintain the completed base course and control traffic as specified in Section 401.3(n). USE A PILOT CAR FOR SPEED CONTROL IF DAMAGE TO THE COMPLETED BASE COURSE, SUCH AS RAVELLING, IS LIKELY TO OCCUR.

(i) CURING. ALLOW THE RECYCLED BASE COURSE TO CURE FOR AT LEAST ONE WEEK BEFORE PLACING THE WEARING COURSE.

341.4 MEASUREMENT AND PAYMENT -

(a) Cold Recycled Bituminous Base Course. Square Yard.

(b) Aggregate. Ton.

(c) Bituminous Material. Gallon.

APPENDIX H

ASPHALT RECYCLING AND RECLAIMING ASSOCIATION COLD IN-PLACE RECYCLING SPECIFICATION

1. *Description*

1.1 This work shall consist of pulverizing the existing bituminous surface to the width and depth shown on the plans, mixing an additive with the pulverized bituminous surfacing, then spreading and compacting said mixture as shown on the plans and as provided herein.

2. *Materials*

2.1 The additive shall be the type called for on the plans or in the proposal.

2.2 The pulverized bituminous material shall meet the following gradation requirements:

Sieve Size	% Passing
1¼"	100
1"	90-100

Gradation may be changed. However the top size of the Rap shall not exceed ½ the depth of the recycled mat.

3. *Construction Requirements*

3.1 The existing bituminous surfacing shall be cold recycled in a manner that does not disturb the underlying material in the existing roadway. However, in some circumstances an equal amount of the base may have to be incorporated.

3.2 Recycling operations shall not be performed when the atmospheri temperature is below 50 degrees Fahrenheit or when the weather is foggy or rainy, or when weather conditions are such that proper mixing, spreading, and compacting of the recycling material cannot be accomplished in the judgement of the project engineer.

3.3 When commencing recycling operations, the additive shall be applied to the pulverized bituminous material at the initial design rate determined by the material laboratory. The exact application rate of additive will be determined and varied by the project engineer as required by existing pavement conditions. An allowable tolerance of plus or minus 0.2 percent of the initial design rate or project engineer directed rate of application shall be maintained at all times. The contractor may add water to the pulverized material to facilitate uniform mixing with the additive. Water may be added prior to or concurrently with the additive. Said water shall not cause any adverse effect on the additive or the recycled material.

3.4 The contractor shall demonstrate his ability to obtain a minimum density of 96 percent of a laboratory specimen prepared in accordance with AASHTO T-245 (50 blows). The project engineer may require a redemonstration of rolling capabilities when a change in the recycled material is observed, whenever a change in the rolling equipment is made or if densities are not being obtained with the rolling pattern being used.

After the recycled material has been spread and compacted the area may be opened to traffic. Before placing bituminous surfacing the recycled material shall be allowed to cure such that the free moisture content is reduced to 1% or less.

4. Equipment

4.1 The contractor shall furnish a self-propelled machine capable of pulverizing the existing bituminous materials to the depth shown on the plans in one pass. The machine shall be equipped with standard automatic depth controls and must maintain a constant cutting depth and width. Said machine shall be capable of producing the proper size Rap required or additional screening and crushing will be required.

The equipment shall be capable of capable of mixing the pulverized bituminous material and additive to a homogeneous mixture, and placing the mixture in a windrow or directly into the hopper of a paver. The method of depositing the mixed material shall be such that segregation does not occur.

A positive displacement pump, capable of accurately metering the required quantity of additive, down to a rate of 4 gal./min., into the pulverized bituminous material shall be used. Said pump shall be equipped with positive interlock system which will permit addition of the additive only when the pulverized bituminous material is present in the mixing chamber and will automatically shut off when the material is not in the mixing chamber.

Each mixing machine shall be equipped with a meter capable of registering the rate of flow and total delivery of the additive introduced into the mixture.

4.2 Placing of the recycled bituminous base course shall be accomplished with a self-propelled bituminous paver. The bituminous recycled material shall be spread in one continous pass, without segregation, to the lines and grades established by the project engineer. When a pick-up machine is used to feed the windrow into the paver hopper, the pick-up machine shall be capable of picking up the entire windrow to the underlying materials.

4.3 The number, weight, and type of rollers shall be sufficient to obtain the required compaction while the mixture is in a workable condition.

Rolling shall be performed until no displacement is discerned. Final rolling to eliminate pneumatic tire marks and achieve density shall be done by steel wheel roller(s), either in static or vibratory mode, as required to achieve required density.

Rollers shall not be started or stopped on uncompacted recycled material. Rolling shall be established so that starting and stopping will be on previously compacted recycled material or on the existing bituminous roadway, if at all possible.

Any type of rolling that results in cracking, movement, or other types of pavement distress shall be discontinued until such time as the problem can be resolved. Discontinuation and commencement of rolling operations shall be at the sole discretion of the project engineer.

5. Method of Measurement.

Cold in-place recycling shall be measured by the square yard or by the station.

The additive of the type shown on the plans will be measured by the ton or gallon.

APPENDIX I

OREGON DOT COLD IN-PLACE RECYCLING SPECIFICATION

SECTION 420 - COLD INPLACE RECYCLED (CIR) ASPHALT CONCRETE PAVEMENT

Description

Subsection 420.01 Scope - This work shall consist of constructing Cold Inplace Recycled (CIR) asphalt concrete pavement using Class I and Class II recycling treatments in accordance with these specifications, and in reasonably close conformity to the lines, grades, thicknesses and cross sections shown on the plans or established by the Engineer.

Definitions

420.04 CIR Asphalt Concrete Pavement - CIR asphalt concrete pavement is a mixture of pulverized existing asphalt pavement (RAP), which has been removed and mixed with emulsified asphalt cement and water, then relayed and compacted in a continuous operation.

420.05 Class I Recycling Treatment - Class I recycling treatment is performed on a uniform pavement, designed and built to specifications. The CIR mixture produced under Class I is based on a rational mix design method.

420.06 Class II Recycling Treatment - Class II recycling treatment is performed on either a pavement with significant maintenance patches over a uniform pavement or a pavement with minimal design used in the original construction. The CIR mixture produced under Class II is less uniform than for Class I and is based on either a rational mix design method or mix design guidelines.

(Use following paragraph when single unit is allowed.)

420.07 Option A or B - Under these specifications the Contractor shall perform CIR work using either a recycling train (Equipment Option A) or a single processing unit (Equipment Option B) as hereinafter specified.

420.08 Prepaving Conference - The Contractor and the Contractor's supervisory personnel plus any subcontractors and their supervisory personnel who are to be involved in the recycle and paving work shall meet with the Engineer's representatives for a prepaving conference at a time mutually agreed upon. At this conference, the Contractor shall present the methods of accomplishing all phases of the recycle and paving work. The plan of the work, order of work and other details of performance shall meet with the approval of the Engineer.

New supervisory personnel replacing anyone engaged in the recycle and paving work, after the first conference, shall be required to attend a new prepaving conference prior to performing their duties on this project.

Materials

420.11 Asphalt - Emulsified asphalt shall be CMS-2S or HFE-150 as directed by the Engineer and shall meet the applicable requirements of Section 702.

420.12 Water - Water shall conform to the requirements of subsection 233.11.

(Use bracketed item when single unit option is allowed.)

420.13 Recycled Asphalt Pavement (RAP) - Recycled material removed from the existing asphalt pavement (using Equipment Option A) shall have a maximum size of 1-1/2-inch prior to entering the mixer unless otherwise directed by the Engineer. Any recycled material larger than 1-1/2-inch shall be separated by screening or other means, broken down by mechanical means to pass a 1-1/2-inch sieve and uniformly reincorporated with the balance of the recycled material.

(Use following paragraph when single unit option is allowed.)

Recycled material removed from the existing asphalt pavement using Equipment Option B shall have a maximum size of two inches. Incidental oversize may be allowed by the Engineer if it is not detrimental to the mixture or wearing surface. If the gradation is determined to be detrimental, the Contractor shall take such action necessary to correct the oversize problem. These actions may include reducing the milling speed, crusher, changing screen size (when screens are used) or other such measures as may be necessary. Failure of the Contractor to be able to provide an acceptable product will cause a rejection of the equipment or processing equipment.

(Use the following paragraph when the Contractor will produce choke aggregate.)

420.14 Choke Aggregate - The material to be used as choke aggregate shall be either clean sand, crushed gravel or quarry rock free of clay, loam or other extraneous material and shall conform to the following:

Sieve Size	Percent Passing
3/8"	100
1/4"	95-100
40	20-40
100	0-5

(Use the following paragraph with State-furnished material.)

420.14 Choke Aggregate - Choke aggregate will be furnished by the State. Material to be used on this project is stockpiled on State-controlled property located on Highway _____ at Milepost _____.

420.15 Job Mix Formula - The CIR asphalt concrete mixture shall consist of RAP from the existing pavement, emulsified asphalt cement and water combined in the proportions designated by the Engineer. Variability in the composition of the RAP material may require changes in the proportions of the constituents, as directed by the Project Manager. Normally, the emulsified asphalt content will be between 0.3 and 2.5 percent, by weight, and water between 1.5 and 4.0 percent by weight.

420.16 Process Control Testing - Process control sampling and testing will be performed by the Engineer.

420.17 Acceptance of CIR Mixture - The CIR mixture will be accepted visually on the grade following initial compaction. Any mixture that ravels or does not provide any acceptable wearing surface shall be corrected. Any area showing an excess or deficiency of emulsified asphalt cement shall be reprocessed or replaced. Replacement shall be by a method approved by the Engineer. Removal and replacement under these provisions shall be at the expense of the Contractor unless the Engineer determines that the defects, excesses or deficiencies are not caused by or the fault of the Contractor's operations.

Construction

420.31 Season and Weather Limitations - Inplace recycling of existing asphalt concrete pavement shall not begin until the pavement surface temperature is 70°F and rising. Pavement damaged by rain after placement shall be reprocessed, or other method approved by the Engineer, at the Contractor's expense. The construction of CIR asphalt concrete pavement will not be allowed before May 15 or after August 1, except the Engineer may approve a start-up before the pavement surface temperature is 70°F under the following conditions:

(1) The Contractor requests such an early start in writing;

(2) The Contractor assumes all financial responsibility for correction of raveling problems with the CIR mixture during the early start period. This includes, but is not limited to, the cost of complete recycling, additional choke, rollers, pilot cars and flaggers, etc. as determined by the Engineer.

If recycling and placement operations are not completed by August 1, the Contractor will not be allowed to resume operations until May 15 of the following year.

The Contractor shall stop milling work at the end of each day when the temperature of the mixture behind the paver drops below 90°F or three hours before sunset, whichever occurs first.

420.32 Rate of Progress and Scheduling - The Contractor shall plan and schedule the recycle operation in such a manner that the materials are removed, mixed, replaced and the area open to traffic immediately after initial compaction is completed.

All recycled areas shall be competely backfilled with reprocessed and compacted asphalt concrete materials so the area is open to two-way traffic during all hours of darkness.

(Use bracketed item when single unit option is allowed.)

(Equipment Option A)

420.34 Recycling Train - (Under this option the) existing pavement shall be recycled using a recycling train consisting of the following major components: (a) Planing machine or grinder, (b) crusher and (c) pugmill mixer.

(a) Planning machine or grinder - The existing pavement shall be removed by a self-propelled planing machine having a minimum 144-inch wide rotary cutter and be capable of removing the existing pavement to a depth of four inches in a single pass.

The unit, also, shall be capable of accurately establishing profile grades within a tolerance of 0.02-foot by reference from either the existing pavement or from independent grade control and shall have a positive means for controlling cross slope elevations. The equipment shall incorporate a totally enclosed cutting drum with replaceable cutting teeth and shall have an effective means for removing excess material from the surface and for preventing dust from escaping into the air. The use of a heating device to soften the pavement will not be permitted.

The unit shall be equipped to discharge not less than 70 gallons of water per minute into the cutting chamber, with fully variable control and meter capable of measuring the rate of feed within five gallons per minute.

(b) Crusher - The crusher shall be of the portable type capable of reducing the oversized RAP materials to the specified size.

(c) Pug mill mixer - The CIR asphalt concrete mixture shall be mixed in a pug mill type plant capable of providing a mix of RAP, emulsified asphalt and water at a minimum rate of 700 tons/hour to uniform proportions as designated by the Engineer.

Mixing plants shall be equipped with a positive control linking the RAP, emulsified asphalt and water feed in a manner that will maintain a constant ratio of each constituent. The plant shall be equipped with facilities so that the Contractor can verify and calibrate the RAP, asphalt and water quantities by a method acceptable to the Engineer.

The RAP shall be measured by weight and the emulsified asphalt and water may be proportioned by either weight or volume. The equipment shall be capable of feeding and maintaining a constant rate of RAP feed within a tolerance of plus or minus 5% (by weight) or the designated amount and a constant rate of emulsified asphalt and water feeds within plus or minus 0.2% (by weight) of the designated amounts.

The mixing plant shall be equipped with positive displacement pumps and a computerized metering system which can accurately meter the amount of emulsified asphalt and water. The pumps shall be interlocked belt weighing system that measures the quantity of RAP material entering the mixing plant. The interlock shall be designed so that emulsified asphalt and water cannot be added until RAP material enters the mixer. Overrides of the interlock system shall be equipped with short duration timers to prevent their continuous use. Overrides shall be used only during start-up periods.

The belt weighing device and computerized-metering system shall have readouts that indicate the quantity in tons of RAP, water and emulsified asphalt being fed into the mixer at any given time. Totalizer readouts shall also be provided to allow determination of accumulative quantities of each constituent.

(Use following four paragraphs when single unit option is allowed.)

Equipment Option B - Single Processing Unit:

Under this option the existing pavement shall be processed using a planing machine meeting all of the requirements of a planing machine under "Equipment Option A".

In addition, the planing machine shall be capable of adding emulsified asphalt and water to the RAP in amounts directed by the Engineer to produce a uniform mixture.

Positive displacement pumps which can accurately meter the planned amount of emulsified asphalt and water into the pulverized asphalt concrete shall be used. The pumps shall be interlocked to the movement of the machinery used to apply the emulsified asphalt and water to provide that no emulsified asphalt or water can be added when the machinery is not moving.

The emulsified asphalt and water feeds shall have positive readout capabilities so that the amount of emulsified asphalt and water in tons incorporated into at any given time can be read directly. Totalizer readouts shall also be provided to allow determination of accumulative quantities of water and emulsified asphalt used in the mixture.

(d) Asphalt storage and heating tanks - Storage tanks shall be equipped with accurate volume measuring devices or manufactures calibration charts for each storage tank and a thermometer for measuring the temperature of tank's contents.

Between the storage tanks and the liquid asphalt mixing device or recycling equipment, a parallel piping filter system with at least one filter per line shall be used. Filters shall be capable of eliminating solid or semisolid particles from the emulsified asphalt liquid.

Each filtering line shall be equipped with on-off valves and changeable filter elements.

The emulsified asphalt cement shall be routed alternately through each filter line for a period of two to four hours, and alternate filters changed on the same frequency unless otherwise directed by the Engineer.

Loads of emulsified asphalt which break prematurely in the storage tanks or haul vehicles or which cause frequent plugging of the filters as determined by the Engineer will be rejected for use.

420.35 Asphalt Concrete Pavers - Pavers shall be self-contained, power-propelled units, provided with an activated screed or strike-off assembly, heated if necessary, and capable of spreading and finishing layers of recycled asphalt concrete material in widths applicable to the specified typical sections, and to required thicknesses, lines, grades and cross sections.

Extensions added to the paver when used on traffic lanes shall have the same augering and screeding equipment as the rest of the paver.

The paver shall be equipped with a receiving and distribution system of sufficient capacity for a uniform spreading operation and capable of placing the mixture uniformly in front of the screed without segregation of materials.

The paver shall be designed to compensate for minor irregularities of the base on which it is supported so that such will not be reflected immediately in the surface of the layer being placed. The weight of the paver shall be supported on tracks or wheels, none of which shall contact the mixture being laid. The contact area of the screed or strike-off assembly shall be uniform over the entire width of the strip of mixture being placed.

Pavers shall be equipped with a paver control system which shall automatically control the layer of the mixture to specified cross slope and grade. The control system shall be automatically actuated from independent line and grade control references through a system of mechanical sensors and sensor-directed devices which shall automatically maintain the paver screed in proper position to provide specified results.

The screed of strike-off assembly shall produce a finished surface of the required evenness and texture without tearing, shoving or gouging the mixture.

420.36 Compactors - Rollers shall be steel wheel, pneumatic tire, vibratory or a combination of these types as specified. They shall be in good condition and capable of reversing without backlash.

(a) Steel wheeled rollers - Steel wheeled rollers shall have a minimum gross static weight of 10 tons and a minimum static weight on the drive wheel of 250 pounds per inch of width.

(b) Vibratory rollers - Vibratory rollers shall be a tandem steel wheeled type having a minimum gross static weight of 8 tons and shall be equipped with amplitude and frequency controls and shall be specifically designed for compaction of asphalt concrete mixtures. The rollers shall be capable of frequencies of not less than 2,000 vibrations per minute.

(c) Pneumatic rollers - The pneumatic-tired rollers shall have a minimum static weight of 20 tons and shall be self-propelled, tandem or multiple axle, multiple wheel type with smooth-tread pneumatic tires of equal size staggered on the axles at such spacings and overlaps as will provide uniform capacting pressure for the full compacting width of the roller and shall be capable of exerting ground pressures of at least 80 pounds per square inch of tire contact area.

420.37 Preparation of Foundation - Just prior to windrowing the recycled pavement mixture, a tack coat conforming to Section 407 of these special provisions shall be applied to the entire profiled area including the vertical edges. Rates of application shall be as directed by the Engineer.

Care shall be taken to minimize the amount of fines on the milled surface that can be detrimental to a proper bond of the tack coat.

420.40 Heating Emulsified Asphalt Cement - The temperature of the emulsified asphalt cement prior to entry into the mixture shall be not less than 125°F nor more than 185°F.

420.41 Mixing - All the various required components of the asphalt concrete mixer shall be utilized and operated in a manner to assure compliance with this section.

The RAP, emulsified asphalt cement and water shall be measured and introduced into the mixer in the amounts specified in the "job mix formula" and as designated by the Engineer.

Mixing shall continue until the emulsified asphalt water have been distributed through the RAP to form a uniformly coated mixture.

420.43 Control of Line and Grade - The line and grade reference control shall be a floating beam device of adequate length and sensitivity to provide adequate control on either or both sides of the paver.

Manual control of line and grade for the paver will be permitted when approved by the Engineer.

420.44 Spreading - Except for unavoidable delay or breakdown, recycling and placing recycled pavement by the paving machine shall be at a rate sufficient to provide continuous operation of the paving machine. If paving operations result in excessive stopping of the paving machine, as determined by the Engineer, recycling and paving operations shall be suspended until the Contractor can synchronize the rate of recycle with the capacity of the paving machines.

(a) General - The mixture shall be laid on an approved surface, spread and struck off to established grade and elevation. Specified asphalt pavers shall be used to distribute the mixture.

The asphalt mixture shall be deposited in a windrow, then picked up and placed in the asphalt paver.

The loading equipment shall be self-supporting and shall not exert any vertical load on the paving machine nor cause vibrations or other motions which could have a detrimental effect on the riding quality of the completed pavement. The loading equipment shall pick up substantially all of the material deposited on the roadbed and place it directly into the receiving hopper of the paving machine.

In areas where patching, irregularities or unavoidable obstacles make the use of specified equipment impracticable, the mixture may be spread with special hopper equipment with adjustable strike-off or by other equipment and means approved by the Engineer, provided the surface finish is within a tolerance of 0.01-foot of that hereinafter set forth.

(b) Drop-offs - Prior to any suspension of operations at the end of each shift, the full width of the area to be paved, including outside shoulders, shall be completed to the same elevation with no longitudinal drop-offs.

If unable to complete the pavement without longitudinal drop-offs as specified above, the Contractor shall, within the specified time constraints, construct and maintain a wedge of asphalt concrete at a slope of 10:1 or flatter along the exposed longitudinal joint located within the area to be paved. Longitudinal joints one inch or less will not require a wedge. The wedge shall be removed and disposed of prior to continuing paving operations. Construction, material, maintenance, removal and disposal of the temporary wedge shall be at the Contractor's expense.

Where allowable abrupt or sloped drop-offs occur within or at the edge of the paved surface the Contractor shall provide, at his expense, suitable warning signs as required under Section 111.

(c) Finishing and details - Special care shall be taken at longitudinal joints to provide positive bond and to provide density and finish to new mixture equal in all respects to the mixture against which it is placed.

420.45 Choke Aggregate Placement - Immediately prior to the last roller coverage during initial compaction as hereinafter specified and before opening to traffic, the Contractor shall place choke aggregate at a rate of approximately 0.001 to 0.003 cubic yard per square yard. Choke aggregate shall be spread by a method that provides uniform coverage across the CIR mat. Any piles, ridges or uneven distribution of choke aggregate shall be eliminated by spreading and/or removing with hand tools or mechanical means as the Contractor elects prior to the final roll or coverage.

If raveling of the CIR mixture occurs following placement, the Contractor shall provide traffic control for these areas immediately or as directed by the Engineer. When the Engineer determines that additional rolling of the raveled areas is required, the additional rolling will be paid as Extra Work.

420.46 Compaction:

(a) General - Immediately after the CIR asphalt concrete mixture has been spread, struck off and surface irregularities and other defects remedied, it shall be thoroughly and uniformly rolled until the mixture is compacted as hereinafter set forth.

(a-1) Surface repair - Any displacement of the mat regardless of thickness occurring as a result of the reversing of the direction of a roller, or from other causes, shall be corrected. Steel roller wheels shall be moistened with water or other approved material to the least extent necessary to prevent pickup of mixture.

When the rolling causes undue tearing, displacement, cracking or shoving the Contractor shall make changes in compaction equipment and/or rolling procedures necessary to alleviate the problem.

(a-2) Rolling - The CIR asphalt concrete mixture shall be compacted with rollers conforming to the requirements hereinbefore set forth. The type, number and weight of rollers shall be sufficient to compact the mixture.

Rollers shall move at a slow but uniform speed recommended by the manufacturer with the drive rolls or wheels nearest the paver. Vibratory rollers, when used in the vibratory mode, shall be operated at frequencies of at least 2,000 vibrations per minute. The maximum operating speed of pneumatic rollers shall be 5 MPH.

Normal rolling shall begin at the sides and proceed longitudinally parallel to the road centerline, each trip overlapping one-half the roller width, gradually progressing to the center. On superelevated curves the rolling shall begin at the low side and progress to the high side, each trip overlapping one-half the roller width. When paving is in echelon or when abutting a previously placed lane, the longitudinal joint shall be rolled first followed by the regular rolling procedure. Rollers shall not make sharp turns on the course being compacted and they shall not be parked on the fresh CIR mixture. Alternate trips of a roller shall terminate in stops at least five feet distant longitudinally from adjacent preceding stops.

(b) Initial compaction - Compaction of the fresh CIR asphalt concrete mixture shall be performed with a minimum of two vibratory rollers meeting the requirements hereinbefore set forth. Rollers shall be operated in either vibratory or static mode as directed by the Engineer. The mixture shall be compacted with at least one coverage by each roller and such additional coverages as the Engineer may direct.

The overlapping of one-half of roller width on each trip by the rollers as required does not constitute two coverages on that particular area rolled.

(c) Recompaction - After initial compaction and prior to recompaction, the CIR asphalt concrete pavement shall be opened to public traffic and allowed to cure. Recompaction shall be performed between 3 and 15 days after laydown when directed by the Engineer. Rolling shall not be performed when the surface temperature is less than 90°F.

The entire recycled pavement area shall be recompacted with at least one steel wheeled roller and one pneumatic roller. Each roller shall make at least three coverages and such additional coverages as the Engineer may direct.

420.40 Pavement Smoothness:

(a) General - The top surface of CIR asphalt concrete pavement shall be tested with a 12-foot straightedge furnished and operated by the Contractor parallel to or perpendicular to the centerline, and shall not vary by more than 0.02-foot. The Engineer will observe this testing and may require additional testing.

When utility appurtenances such as manhole covers and valve boxes are located in the traveled way and they are not required to be adjusted or are required to be adjusted before paving, this tolerance will not apply.

(b) Corrective action - When tests show the pavement is not within the specified tolerance, the Contractor shall take immediate action to correct equipment or procedures in his paving operation to eliminate the unacceptable pavement roughness.

Any surface irregularities exceeding the specified tolerances shall be corrected by the Contractor within the period of 2 to 5 days following initial compaction using one of the following methods:

(1) Remove, replace or reprocess the surface course.

(2) Grind the pavement surface utilizing the planing machine or grinder as hereinbefore set forth to a maximum depth of 0.3-inch.

The cost of all corrective work, including traffic control and furnishing of materials, shall be performed at the Contractor's expense and no adjustment in contract time will be made for corrective work.

Measurement

420.81 Measurement - The number of square yards of recycled emulsified asphalt mixture shall be based on the paved widths and milled depths shown on the plans and the horizontal measurement along the centerline of the actural length of the pavement recycled.

No allowance will be made for pavement recycled in excess of the paved width and milled depth shown on the plans unless directed by the Engineer.

No change in unit price per square yard will be made for depths deviating from plan depths unless the milled depth is deviated by more than plus or minus one-half inch from the nominal thickness called for by the plans and directed by the Engineer. Where the Engineer directs construction of recycled emulsified asphalt concrete to a thickness other than plus or minus of one-half inch from the nominal thickness specified, these areas will be adjusted by converting in one-half-inch increments to the equivalent number of square yards of nominal thickness on a proportionate volume basis above or below the specified tolerance limits.

For example, if the plans require a nominal depth of 1-1/2-inch and the Engineer directs a milling depth of 2-1/2 inches, the adjustment will be based on an additional 1/2-inch depth. (2-1/2"-1-1/2"-1/2" (tolerance) = 1/2" adjustment)

The quantity of emulsified asphalt in the recycled asphalt concrete mixture to be paid for will be the number of tons used in the accepted mixture measured as set forth in subsection 109.01 of the Standard Specifications.

The quantity of water used in the mixture will be measured as set forth in Section 233.

The quantity of choke aggregate to be paid for will be the number of cubic yards actually spread on the inplace recycled emulsified asphalt mixture at the rate specified, measured as set forth in subsection 109.01 of the Standard Specifications.

Payment

420.01 Payment - Payment when made at the contract unit price per square yard for the item "Recycled Emulsified Asphalt Pavement Mixture" will be full compensation for all equipment, labor and incidentals required to remove and pulverize the existing surfacing, and to mix the materials, place, compact and finish the work as specified.

Payment, when made at the contract unit price per ton for "Emulsified Asphalt in Recycled Mixture", will be full compensation for all costs of material, labor, tools and equipment necessary for the addition of the emulsion as specifed.

(Use word "furnish" when Contractor is to supply choke aggregate.)

Payment, when made at the contract unit price per cubic yard for "choke aggregate", will be full compensation for all costs to (furnish,) haul and place choke aggregate as specified.

Payment for water used in the CIR asphalt concrete mixture will be made as set forth in Section 233 and will comprise full compensation for the water used in connection with the recycle work.

SECTION 407 - ASPHALT TACK COAT

Delete Section 407 of the 1984 Standard Specifications and insert the following:

Description

407.01 Scope - This work shall consist of the furnishing of asphalt and the application thereof to a prepared asphalt concrete surface to ensure thorough bond between profiled asphalt cement surface and recycled emulsified asphalt mixture. The tack coat shall be applied on the areas designated by the Engineer in accordance with these specifications.

Materials

407.11 Asphalt - The asphalt to be used in the tack coat shall be CMS-2S and shall meet the applicable requirements of Section 702. The material may be conditionally accepted at the source or point of loading for transport to the project.

Emulsified asphalt in tack shall be diluted prior to application with 15-30 percent additional water conforming to the requirements of subsection 233.11, as determined by the Engineer.

Construction

407.31 General - The tack coat shall be applied to the milled surface prior to placement of the recycled emulsified asphalt mixture is placed in a berm into the profiled area.

The tack coat shall be applied to the entire milled surface including the vertical edges.

407.32 Distribution Equipment - The asphalt shall be spread by means of a pressure distribution system capable of applying the tack coat uniformly on surfaces having widths of up to 13 feet at readily determined and controlled rates from 0.05 to 2.0 gallons per square yard with uniform pressure, and with an allowable variation from any specified rate not to exceed 0.05 gallon per square yard.

Distribution system equipment shall include pressure gauges, accurate volume measuring devices or a calibrated tank and a thermometer for running temperature of tank contents. The distribution system shall have a power unit for the pump and a full circulation system for the tank and spray bar.

The spray bar shall be capable of being easily adjustable laterally.

407.33 Application Rate - Normally, the diluted emulsified asphalt shall be applied to the milled surface at a rate of 0.05-0.20 gallon/sq.yd. as directed by the Engineer.

Measurement

407.81 General - Asphalt used as directed in the asphalt tack coat will be measured by the ton as set forth in Section 109.

Payment

407.91 General - The accepted quantity will be paid for at the contract price per ton for the item "Asphalt in Tack Coat". The water in the tack coat will be measured and paid for in accordance with subsections 233.81 and 233.91 of the Standard Specifications.

APPENDIX J

NEW MEXICO STATE HIGHWAY AND TRANSPORTATION DEPARTMENT COLD IN-PLACE RECYCLING SPECIFICATION

August 26, 1985
Revised September 26, 1985
Revised November 19, 1985
Revised July 25, 1986
Revised November 13, 1986

NEW MEXICO STATE HIGHWAY AND TRANSPORTATION DEPARTMENT
SPECIAL PROVISIONS
FOR
IN-SITU COLD RECYCLING OF BITUMINOUS MATERIAL
SECTION 405-A

All applicable provisions of the New Mexico State Highway and Transportation Department's Standard Specifications for Road and Bridge Construction shall apply in addition to the following:

1. DESCRIPTION.

1.1 This work shall consist of pulverizing the existing bituminous surfacing, to the depth shown on the plans, to provide the nominal thickness lift shown on the plans, of recycled bituminous base course throughout the width shown on the plans, mixing an emulsified binder agent and water (if required) with the pulverized bituminous surfacing, then spreading and compacting said mixture as shown on the plans and as provided herein unless otherwise directed by the Project Manager.

The Contractor shall furnish all equipment, tools, labor, all materials (except the pulverized bituminous material), and any other appurtenances necessary to complete the work.

2. MATERIALS.

2.1 The emulsified binder agent shall be High Float Emulsion of the type shown on the plans with the option, by the Department, to change one grade, at no increase in price. Any change in grade of binder agent shall be made only with the concurrence of the Central Laboratory. The High Float Emulsion shall meet the requirements of Section 402 - BITUMINOUS MATERIALS of the Standard Specifications.

2.2 The Cold Recycled Material shall meet the following gradation requirements:

Sieve Size	% Passing
1 1/4"	100
1"	90-100

2.3 The Sealing Emulsion shall be High Float Emulsion (diluted) CSS-1 h or other approved equal.

3. CONSTRUCTION REQUIREMENTS.

3.1 The existing bituminous surfacing shall be cold recycled in a manner that does not disturb the underlying material in the existing roadway.

3.2 Prior to initiating any recycling operations or other inherent work, the Contractor shall clear, grub and remove all vegetation and debris within the width of pavement to be recycled. Disposal of said vegetation and debris shall be as directed by the Project Manager.

3.3 Recycled operations shall not be performed when the atmospheric temperature is below 50 degrees F. and/or when the chill factor is below 35 degrees F., (chill factor shall be determined as per Subsection 401.31 General., part (a) Weather Limitations of the Standard Specifications, or when the weather is foggy or rainy or when weather conditions are such that in the judgment of the Project Manager, proper mixing, spreading and compacting of the recycled material cannot be accomplished.

3.4 When commencing recycling operations, the emulsified binder agent shall be applied to the pulverized bituminous material at the initial design rate determined by the Materials Laboratory Bureau based on samples submitted at the time of construction. The exact application rate of the emulsified binder agent will be determined and varied by the Project Manager as required by existing pavement conditions. An allowable tolerance of plus or minus 0.2 percent of the initial design rate or Project Manager directed rate of application shall be maintained at all times.

The Contractor may add water to the pulverized material to facilitate uniform mixing with the emulsified binder agent. Water may be added prior to or concurrently with the emulsified binder agent.

In the event segregation occurs behind the paver, the Project Manager may require that the forward speed of the milling operation be reduced and/or that the amount of material going through the crusher be increased and the crusher adjusted to produce more fines. The Contractor may be required to make other changes in his equipment and/or operations, as necessary to obtain a satisfactory end-product.

3.5 The Contractor shall demonstrate his ability to obtain a minimum density of 96 percent of a laboratory specimen prepared in accordance with AASHTO T-245 (50 blows). The Project Manager may require a redemonstration of rolling capabilities when a change in the recycled materials is observed, whenever a change in rolling equipment is made or if densities are not being obtained with the rolling pattern being used.

After the recycled material has been spread and compacted, **NO TRAFFIC** (this includes Contractor's equipment) shall be permitted on the completed recycled bituminous base for at least two hours. The area may then be opened to all traffic and shall be allowed to cure such that the moisture content is reduced to 1% or less, by total weight of mix, before placing hot bituminous concrete surfacing.

After the moisture content of the recycled material is 1% or less, the Contractor may, with the concurrence of the Project Manager elect to seal the surface with emulsion at an approximate rate of 0.05 to 0.10 gallon per square yard. Said emulsion, if used, will be paid for under the Item Sealing Emulsion.

Any damage to the completed recycled bituminous base shall be repaired by the Contractor, as directed by the Project Manager prior to placing any hot bituminous surfacing. Said repair(s) shall be made at no additional cost to the New Mexico State Highway and Transportation Department.

Any fillet of fine, pulverized material which forms adjacent to a vertical face shall be removed prior to spreading the recycled mix, except that such fillet adjacent to existing pavement which will be removed by overlapping during a subsequent milling operation need not be removed.

4. EQUIPMENT.

4.1 The Contractor shall furnish a self-propelled machine capable of pulverizing in-situ bituminous materials to the depth shown on the plans, in one pass. Said machine shall have a minimum rotor cutting width of twelve feet, standard automatic depth controls and maintain a constant cutting depth. Said machine shall also incorporate screening and crushing capabilities to reduce or remove oversize particles prior to mixing with emulsion. Oversize particles shall be reduced to size by crushing, however, the Contractor may, with concurrence of the Project Manager, waste oversize particles prior to adding emulsion.

The emulsified agent shall be applied through a separate mixing machine capable of mixing the pulverized bituminous material and the emulsified binder agent to a homogeneous mixture and placing the mixture in a windrow. The method of depositing the mixed material in a windrow shall be such that segregation does not occur.

A positive displacement pump, capable of accurately metering the required quantity of emulsified binder agent, down to a rate of 4 gal./min., into the pulverized bituminous material, shall be used. Said pump shall be equipped with a positive interlock system which will permit addition of the emulsified binder agent only when the pulverized bituminous material is present in the mixing chamber and will automatically shut off when the material is not in the mixing chamber.

Each mixing machine shall be equipped with a meter capable of registering the rate of flow and total delivery of the emulsified binder agent introduced into the mixture.

4.2 Placing of the recycled bituminous base course shall be accomplished with a self-propelled bituminous paver meeting the requirements of Subsection 401.32 Equipment Part 3. Bituminous Pavers., except that heating of the screed will not be permitted. The bituminous recycled material shall be spread in one continuous pass, without segregation, to the lines and grades established by the Project Manager.

When a pick-up machine is used to feed the windrow into the paver hopper, the pick-up machine shall be capable of picking up the entire windrow to the underlying materials.

4.3 Rollers shall meet the requirements of Subsection 401.32 EQUIPMENT., Part 4. Rollers. The number, weight, and type of rollers shall be sufficient to obtain the required compaction while the mixture is in a workable condition except that the pneumatic roller(s) shall be 30 ton minimum weight.

Initial rolling shall be performed with the pneumatic roller(s) and continued until no displacement is discerned or until the pneumatic rollers have walked out. Final rolling to eliminate pneumatic tire marks and achieve density shall be done by steel wheel roller(s), either in static or vibratory mode, as required, to achieve required density.

Rolling shall be performed in accordance with paragraph 3, Section 401.35 Compaction, of the 1984 Standard Specifications.

Rollers shall not be started or stopped on uncompacted recycled material. Rolling shall be established so that starting and stopping will be on previously compacted recycled material or on existing PMBP.

Any type of rolling that results in cracking, movement or other types of pavement distress shall be discontinued until such time as the problem can be resolved. Discontinuation and commencement of rolling operations shall be at the sole discretion of the Project Manager.

5. METHOD OF MEASUREMENT

5.1 In-Situ Cold Recycling of Bituminous Material shall be measured by the Square Yard.

Water will not be measured and paid for separately but shall be included in the In-Situ Cold Recycling of Bituminous Material work.

The High Float Emulsion of the type shown on the plans will be measured by the Ton.

The Sealing Emulsion will be measured by the Ton.

6. BASIS OF PAYMENT.

The accepted quantity of In-Situ Cold Recycling of Bituminous Material will be paid for at the contract unit price per Square Yard complete and in place.

The accepted quantity of High Float Emulsion of the type shown on the plans will be paid for at the contract unit price per Ton complete and in place.

The accepted quantity of Sealing Emulsion will be paid for at the contract unit price per Ton complete and in place.

Payment will be made under:

PAY ITEM	PAY UNIT
In-Situ Cold Recycling of Bituminous Material. .	Sq. Yd.
High Float Emulsion	Ton
Sealing Emulsion	Ton

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