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UNIFIED FACILITIES CRITERIA (UFC)

STANDARD PRACTICE FOR PAVEMENT RECYCLING

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STANDARD PRACTICE FOR PAVEMENT RECYCLING

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes TM 5-822-10, dated 26 August 1988. The format of this UFC does not conform to UFC 1-300-01; however, the format will be adjusted to conform at the next revision. The body of this UFC is the previous TM 5-822-10, dated 26 August 1988.

FOREWORD

\1\
The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

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STANDARD PRACTICE FOR PAVEMENT RECYCLING

DEPARTMENTS OF THE ARMY, AND THE AIR FORCE

AUGUST 1988

REPRODUCTION AUTHORIZATION/RESTRICTIONS

TECHNICAL MANUAL
TM 5-822-10
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AFM 88-6, CHAPTER 6

HEADQUARTERS
DEPARTMENTS OF THE ARMY
AND THE AIR FORCE
WASHINGTON, D.C., *26 August 1988*

STANDARD PRACTICE FOR PAVEMENT RECYCLING

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CHAPTER 1
INTRODUCTION

1-1. Purpose and scope.

This manual contains guidance for preparing plans and specifications and for ensuring the quality of recycled bituminous and portland cement concrete. In addition, this manual provides useful information to design engineers, laboratory personnel, and inspectors concerning the mix design, plant production, and laydown of recycled pavement mixtures. The emphasis is on airfield pavements; however, the concepts also apply to other pavements.

1-2. References.

Appendix A contains a list of references used in this document.

1-3. Recycling pavement development.

Recycling pavement materials has proved to be a feasible process to rehabilitate worn-out pavements. Since recycled pavements will not always be cost-effective, recycling should be considered when repairing or rehabilitating existing pavements. The use of recycled materials in pavement maintenance and rehabilitation has increased for the following reasons:

a. Environment. Prior to the inception of recycling techniques, the reconstruction of old pavements often consisted of removing, stockpiling, or disposing of old pavement materials. Recycling of these pavement materials uses an inexpensive, available material and eliminates the disposal problem.

b. Material cost. In the last several decades the public and Government have recognized that there is not an unlimited supply of natural materials. The amount of asphalt and high-quality aggregate available for construction is limited. This fact, along with an inflated economy, has caused a substantial increase in the cost of pavement materials and thus encouraged the use of recycle materials. The rising cost of fuel and equipment required to haul the asphalt and aggregate to job sites has encouraged recycling, especially as the haul distances become longer.

c. Technology and equipment. The increased interest in recycling pavements has brought about the development of technology and equipment for recycling that results in an overall reduction in cost when recycled materials are used. There still exist problems that are peculiar to recycling; however, the number and the complexity of these problems have been reduced significantly in recent years.

1-4. Bituminous pavement recycling.

Bituminous pavement recycling methods can be divided into the following three categories: surface recycling, cold-mix recycling, and hot-mix recycling. Table 1-1 lists the advantages and disadvantages of the various methods. Many types of distresses can be corrected by one of the three pavement recycling methods identified in figure 1-1.

a. Surface recycling. Surface recycling, heater-planing-scarifying, cold milling, and rejuvenating are methods of surface recycling that are used to increase skid resistance, decrease permeability to air and water, and improve properties of the asphalt binder. Depending on the process used, surface recycling may modify the top ¼ to ½ inch of pavement. However, surface recycling does not increase the strength of the pavement. The cost to scarify and rejuvenate pavement is approximately the same as the cost of an additional 1 inch of overlay, but the benefits of the additional 1 inch of overlay usually exceed the benefits obtained from the scarification and rejuvenation.

b. Cold-mix recycling. Cold-mix recycling is a process which reclaims most or all of the existing bituminous pavement by breaking it to a maximum particle size of 1 to 1½ inches, mixing it with virgin materials, if needed, and reusing the mixture as a pavement material. Cold recycling material can be used to surface secondary roads, if a seal coat is applied, and as a base course for high-quality pavements.

c. Hot-mix recycling. Hot-mix recycling is a process which involves removing the existing asphalt concrete, crushing it if necessary, and mixing it in a hot-mix plant with new aggregate, asphalt, and recycling agent, when required. The hot-mix recycled asphalt concrete can be designed for use in all types of pavements. Crushed portland cement concrete has also been used as aggregate for hot recycled mixtures.

1-5. Portland cement concrete recycling.

Portland cement concrete recycling involves reclaiming existing portland cement concrete pavements and structures by crushing them to produce construction aggregate for reuse. Table 1-1 lists the advantages and disadvan-

Table 1-1. Advantages and disadvantages of bituminous and portland cement concrete pavement recycling

Pavement Recycling Method	Advantages	Disadvantages
1. Surface recycling		
Heater-remix-overlay	1. Minimizes traffic disruption 2. Requires less new materials 3. Retards reflective cracking with thin overlay 4. Smooths out minor roughness	1. Tendency to violate pollution standards 2. Difficult to control quality of overlay mix 3. Should be used only on structurally sound pavements 4. Burning of old asphalt may occur 5. Quality control on job is difficult to obtain
Cold milling	1. Improves rideability of pavement 2. Can be used with asphalt concrete and portland cement concrete pavements 3. Improves skid resistance of overlay 4. Provides a good temporary solution if money is not available for complete overlay 5. Reduces thickness of overlay required 6. Minimizes traffic disruption	1. Possible foreign object damage problem 2. Should be used only on structurally sound pavements
Rejuvenator	1. Minimizes traffic disruption 2. Quick and easy to apply 3. Least expensive	1. Temporarily reduces skid resistance 2. Should be used only on structurally sound pavements 3. Cannot be used on pavement with rich asphalt content
2. Cold-mix recycling	1. Uses old pavement 2. Prevents reflective cracking 3. Improves structural soundness of pavement 4. Improves frost susceptibility 5. Allows for subgrade repairs if necessary	1. Traffic disruption 2. Requires an overlay 3. May not be cost-effective
3. Hot-mix recycling	1. Uses old pavement 2. Requires less new materials 3. As good as new pavement 4. Maintains present drainage patterns and structures 5. Prevents reflective cracking 6. Allows for subgrade repairs if necessary	1. Traffic disruption 2. May not be cost-effective
4. Portland cement concrete recycling	1. Uses old pavement, eliminating disposal problems 2. A good source of aggregate for either asphalt concrete or portland cement concrete pavements 3. Allows for subgrade repairs if necessary 4. Can be used as cement-treated base or an aggregate base	1. Traffic disruption 2. Angularity of fines may require addition of natural sands to improve workability 3. If concrete contains steel reinforcement, the removal of this reinforcement is necessary

Pavement Distress[a]	Severity Level[b]	Surface Recycling			Cold-Mix Recycling	Hot-Mix Recycling	SEAL Cracks	Remove and Replace	Surface Seal	Overlay
		Rejuvenators	Heater-Planer-Scarifier	Cold-Milling						
Alligator or Fatigue Cracking	L	X					X		X	
	M		X			X				X
	H				X	X		X		X
Bleeding			X	X		X				X
Block Cracking	L	X					X		X	
	M		X			X	X	X		X
	H					X		X		X
Corrugation	L									
	M				X	X		X		X
	H				X	X		X		X
Depression	L		X					X		
	M		X		X	X		X		X
	H				X	X		X		X
Jet Blast Erosion									X	X
Joint Reflection Cracking from PCC (Longitudinal and Transverse)	L						X			
	M						X			
	H					X	X			X
Longitudinal and Transverse Cracking (Non-PCC Joint Reflective)	L	X							X	
	M	X					X		X	
	H				X	X	X	X		X
Oil Spillage				X						
Patching and Utility Cut Patch	L									
	M			X					X	
	H							X		
Polished Aggregate			X	X						X
Raveling and Weathering	L	X							X	
	M	X	X						X	X
	H					X				X
Rutting	L									
	M		X			X				X
	H					X				X
Shoving of Asphalt Pavement by PCC Slabs	L									
	M			X						
	H							X		
Slippage Cracking						X		X		
Swell	L									
	M			X						
	H							X		

a Detail description given in Air Force Regulation AFR 93-5, "Airfield Pavement Evaluation Programs," 18 May 1981.
b L = Low, M = Medium, H = High, refer to AFR 93-5 for description.

Figure 1-1. Method of repair guide for bituminous pavement rehabilitation.

tages of portland cement concrete recycling. The construction aggregate can be used for portland cement concrete pavements, Econocrete, cement-treated base, and aggregate base. Figure 1-2 presents types of distress that may be corrected by portland cement concrete recycling. Other repair methods are shown for comparison purposes.

Pavement Distress[a]	Severity Level[b]	Remove and Replace With PCC	Remove and Replace With New PCC	Overlay	Seal Cracks	Slab Jacking	Cold Milling
Blow Up	L	X	X				
	M	X	X				
	H	X	X	X			
Corner Break	L				X		
	M				X	X	
	H	X	X	X		X	
Longitudinal, Transverse, and Diagonal Cracks	L				X		
	M				X		
	H	X	X	X	X		
Durability ("D") Cracking	L				X		
	M	X	X	X			
	H	X	X	X			
Joint Seal Damage	L				X		
	M				X		
	H				X		
Patching, Small (Less than 5 S.F.)	L						
	M		X				
	H		X				
Patching, Large (Over 5 S.F.) and Utility Cut	L						
	M		X	X	X		X
	H		X	X			
Popouts		X	X	X			
Pumping					X	X	
Scaling, Map Cracking, and Crazing	L						
	M	X	X				
	H	X	X				
Settlement or Faulting	L						X
	M					X	X
	H	X	X			X	X
Shattered Slab/Intersecting Cracks	L						
	M	X	X	X			
	H	X	X	X			
Shrinkage Cracks					X		
Spalling (Transverse & Longitudinal Joint)	L						
	M		X				
	H	X	X	X			
Spalling (Corner)	L				X		
	M	X	X				
	H	X	X				

a Detail description given in Air Force Regulation AFR 93-5, "Airfield Pavement Evaluation Programs," 18 May 1981.
b L = Low, M = Medium, H = High.

Figure 1-2. Method of repair guide for portland cement concrete rehabilitation.

CHAPTER 2
SURFACE RECYCLING OF PAVEMENTS

2-1. General.

When a pavement is structurally sound and rehabilitation is needed to correct a surface problem, surface recycling should be considered. The three surface recycling processes discussed in the following paragraphs are rejuvenating, heater-planing-overlaying, and cold milling. The basic procedures for surface recycling are shown on the flow chart in figure 2-1.

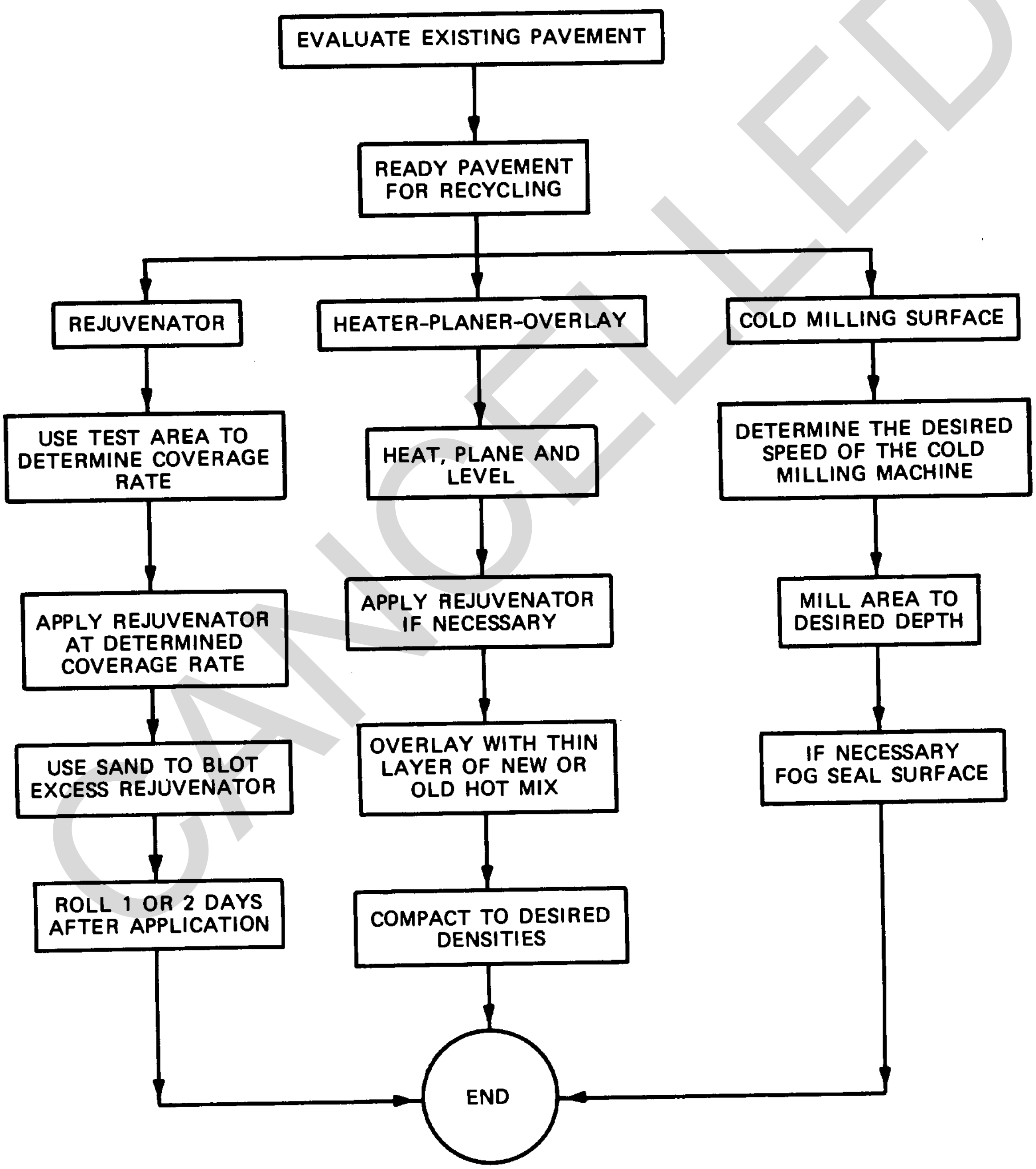

Figure 2-1. Surface recycling flow chart.

2-2. Equipment.

The major pieces of equipment required for surface recycling techniques are conventional asphalt distributor for rejuvenating, heater-planer and motor grader or self-contained heater-planer-paver, broom, trucks, and front-end loader for heater-planing-overlaying, pavement milling machine, broom, and trucks for cold milling.

2-3. Rejuvenating.

The application of a chemical rejuvenator provides penetration of a chemical into bituminous pavement which plasticizes the binder. Rejuvenators can be sprayed directly on the surface of a bituminous pavement, as in figure 2-2, or they can be used in conjunction with heater-planing-scarifying and cold milling recycling processes.

Figure 2-2. Asphalt distributor applying rejuvenator.

a. Properties of rejuvenators. Some of the properties of rejuvenators are described below.

(1) The application of a rejuvenator to a bituminous pavement partially restores its original asphalt properties. However, for a rejuvenator to be successful, it must penetrate the pavement surface and soften the asphalt rejuvenator, the weather conditions, and the permeability of the pavement surface.

(2) When a rejuvenator is applied to a pavement in which the asphalt binder is oxidized, it will retard the loss of surface fines and reduce the formation of additional cracks. Application of a rejuvenator will also reduce the skid resistance of the pavement for up to 1 year. While this reduction in skid resistance should not be significant for parking aprons and taxiways, it may be significant for runways or other areas where high aircraft speeds are likely to occur. Use caution; be sure to have a full-time person on the job who is experienced in applying rejuvenators.

(3) A rejuvenator should not be applied to a bituminous pavement having an excess of binder on the surface such as that found in slurry seal, porous friction course, or bituminous surface treatment. When excessive binder is on the surface, the rejuvenator will soften the binder and cause the surface to become tacky and slick.

(4) The amount of air voids in the bituminous mixture being rejuvenated should be at least 5 percent to ensure proper penetration of the rejuvenator into the pavement. However, if the voids are less than 5 percent, the rejuvenator may fill the voids and thus cause an unstable mix.

(5) Care must be used in selecting a rejuvenator. Some rejuvenators perform satisfactorily, but many do not. The rejuvenator selected for use should have a proven record of satisfactory performance. However, if performance data on a particular rejuvenator are not available, the rejuvenator should be applied to a test area on the pavement and evaluated over some period of time to determine its potential performance.

(6) It is desirable to change the properties of the asphalt in the top approximate % inch of material so that the asphalt cement approaches its original properties. Test results have shown that the viscosity test is more effective in determining a change in asphalt properties than the penetration test. Although application of a small amount of rejuvenator will be reflected by the viscosity test, the penetration test may indicate very little or no change in asphalt property.

(7) Rejuvenators should be applied in hot weather, above 70 degrees F, so that the rejuvenator will penetrate more deeply into the asphalt pavement and will cure sooner.

b. Application of rejuvenators. When applying a rejuvenator, the following must be considered.

(1) The asphalt distributor is the key piece of equipment used to apply asphalt rejuvenators. It is essential that the distributor is in proper operating condition when rejuvenators are applied to ensure that the rate of application is uniform. Figure 2-2 shows a distributor properly applying a rejuvenator to an asphalt concrete pavement. An inspection of the distributor should ensure that:

(a) The distributor has a circulating tank so that the rejuvenator can be thoroughly mixed prior to spraying.

(b) The motor is in proper running condition so that it does not misfire when accelerating and cause varying rates of rejuvenator to be applied.

(c) The size of the spray nozzles is selected so that a smooth consistent spray is obtained over the range of desired application rates.

(d) All spray nozzles are the same size and are set at the same angle with the spray bar.

(e) The spray bar is at the correct height to provide either a double or triple overlap.

(f) The application rate is checked to verify proper calibration.

(2) Before rejuvenator is applied to the pavement, several test sections should be constructed and the rejuvenator should be applied to the sections at various rates to determine the proper application rate. Generally, the application rate should not exceed that which will allow the rejuvenator to penetrate the pavement within 24 hours.

(3) The amount of rejuvenator needed to properly modify the asphalt binder may not be the same amount needed to penetrate the asphalt pavement. The determinations made from the test sections should dictate the amount of rejuvenator that can penetrate the asphalt pavement, and this amount should never be exceeded. The optimum benefit will be obtained by applying the maximum rate that will penetrate the pavement.

(4) When rejuvenator is applied to the pavement, clean dry sand should be available to blot areas that received too much rejuvenator. The sand should be evenly spread over these areas, broomed into a pile, and removed. Rolling the pavement surface 1 or 2 days after rejuvenator has been applied may help to knead and to close hairline cracks.

2-4. Heater-planing-scarifying.

a. Heater-planing. Heater-planing consists of heating the surface of a bituminous concrete pavement and planing the surface to the desired grade. In recent years, the cold-milling operation has essentially replaced heater- planing for airfield work.

b. Planing operation. The planing operation may require one or more passes of the equipment to obtain the desired depth of cut. The equipment used to plane a pavement varies considerably. Some of the equipment, as shown in figure 2-3, is self-contained so that one piece of equipment can heat, plane, scarify, or add binder and hot mix. Other equipment is not self-contained. In fact, often planing and scarifying are done with several pieces of equipment, such as a heater which can heat and scarify, a planer, which usually is a motor grader, a distributor to add binder material, and a laydown machine. A heater-planer with scarifying teeth followed by a grader is shown in figure 2-4. Usually, when planing and scarifying are required, several passes may be necessary to plane the pavement to the desired depth before scarification. The planed pavement is then reheated and scarified to a depth of¾ to 1 inch. Some planers use direct flame to heat the pavement surface, and others use radiant heat. The heater in figure 2-4 uses direct flame for heat, and the heater in figure 2-3 uses radiant heat.

c. Planing pavement. Caution should be used when planing an existing pavement to a desired grade. Since the planing operation usually consists of removing the heated material to a design grade, an experienced operator is required. Two to three passes of the heater and planer may be necessary in some areas to obtain the desired grade.

d. Removed material. The removed material can be used best while hot to provide a low-quality bituminous mixture where a low-quality mix is acceptable. Kerosene or other solvents are often mixed with the removed material to form a cold mix that can be stockpiled. Often, the quantity of material removed is so small that it is impractical to use the planed material. Also, once the material cools and hardens, it is difficult to reuse.

e. Scarifying process. Scarifying the pavement surface prior to overlay can minimize some existing pavement problems such as bonding if the pavement surface has become polished over a period of years from the action of traffic. In this case, the surface can be scarified to promote a good bond between this existing polished surface

Figure 2-3. Self-contained heater-planer.

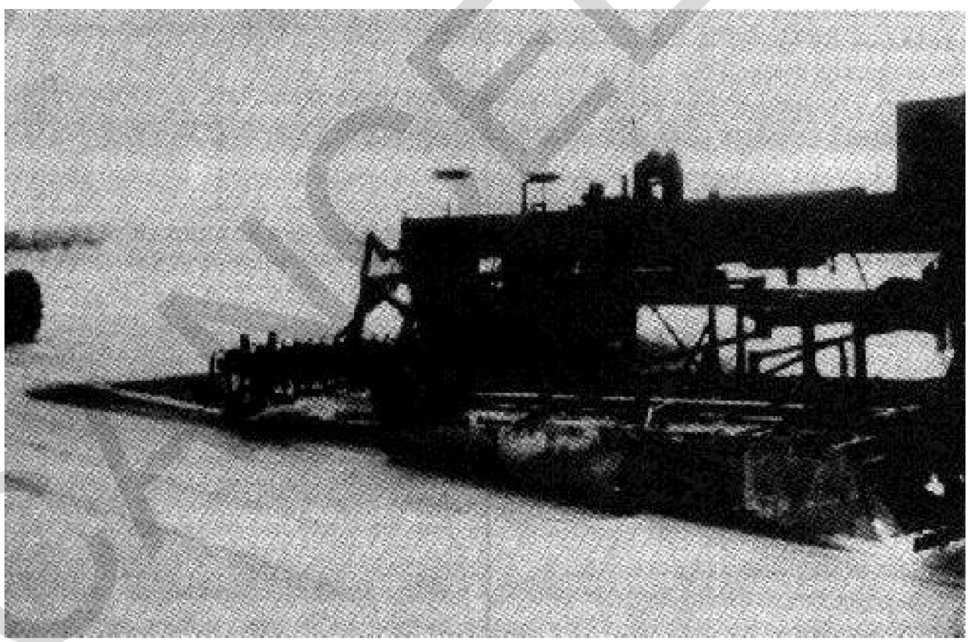

Figure 2-4. Heater with scarifying teeth followed by grader.

and an overlay. Scarification also breaks up the crack pattern and reduces the amount of reflective cracks that will appear in the overlay. Scarifying the top ¾ to 1 inch of the surface allows additional asphalt binder or rejuvenating agent to be added to the scarified material. This procedure is often used to maintain secondary roads to provide a tight waterproof surface. In most instances, the scarification process is followed by a bituminous concrete overlay.

f. Quality. The quality of mixes obtained by heating and scarifying existing pavements is difficult to control. The quality of the scarified and rejuvenated mixture depends on the depth of scarification, time of heating, amount of rejuvenator added, and amounts of compaction. When no overlay is applied in conjunction with the scarified material, it is necessary that the heated material be rolled immediately after being heated and scarified to ensure that a satisfactory density is obtained. Scarifying, rejuvenating, and compacting a surface without the addition of an overlay may cause an excess of coarse aggregate on the surface. This coarse aggregate makes the scarified material difficult to compact and results in a surface that tends to ravel. The scarifying, rejuvenating, and compacting procedure should only be used to improve the surface of mixtures on secondary roads.

g. Overlay approach. An overlay in conjunction with scarifying the pavement is recommended. The overlay may be added prior to compaction of the scarified material and both layers compacted simultaneously, or the scarified material may be compacted prior to addition of the overlay. To ensure better bond and better overall density, it is recommended that the overlay be placed immediately after scarifying the surface and the entire depth of material compacted. Although this scarification and overlay approach has been used on airfields, generally other alternatives should be selected.

h. Asphalt. The asphalt sampled from the scarified and rejuvenated material should show an improvement in properties over the existing asphalt properties. Generally, the penetration of the recovered asphalt binder should be 40 to 70. The amount of binder material added should not cause the voids in the compacted mixture to become overfilled and thus create an unstable mixture. To determine when a mixture is unstable, samples of the mixture should be obtained and compacted at 250 degrees F using the standard compaction effort for the job. When the voids of the compacted samples are less than 3 percent, the mixture should be considered unstable, and the amount of rejuvenator should be reduced.

i. Pollution. Pollution caused by smoke from the heating of the asphalt surface may be a problem. But the amount of smoke can usually be controlled within an acceptable range on most asphalt mixtures. However, heating of pavements that have numerous sealed cracks will present a problem since the sealer material usually causes an increase in the amount of smoke during the heating operation.

2-5. Cold milling.

a. Milling process. The milling process, which does not use heat, is used to mill a bituminous or portland cement concrete pavement to a desired depth. The milling equipment, which can remove up to 4 inches of bituminous mixture in one pass, uses sensors that follow a stringline grade reference and slope control to directly control the finished grade (fig 2-5). Since no heat is needed, the pollution problem caused by burning bitumen is eliminated. However, a problem with dust may occur, but this problem can usually be solved by spraying a small amount of water onto the pavement in front of the machine. The milling machine can be used during all weather conditions to produce a smoother grade.

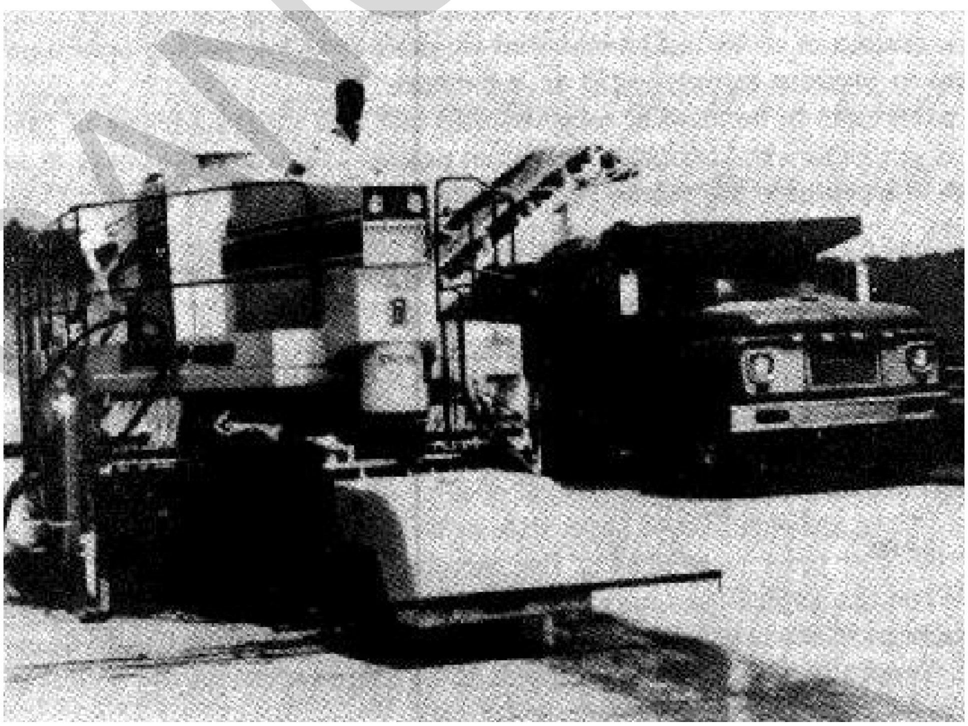

Figure 2-5. Pavement cold-milling machine in operation.

b. Cutting teeth. The cutting teeth on the milling machine are a high maintenance item and must be replaced often. The teeth may last 1 or 2 days, depending on hardness of the material being milled and the number of operation hours per day. The cutting teeth can be adjusted to provide a range of surface textures from smooth to very rough. When all the teeth are in position, the finished surface texture is smooth. By removing some of the teeth, the surface texture can be made rougher. When the milled surface is used for a riding surface, a rougher surface texture provides better skid resistance; however, the rougher surface also causes more tire wear.

c. Milling versus heater-planing. The reasons for milling are similar to those for heater-planing. The milling can remove bituminous or portland cement concrete pavement from bridges to avoid exceeding the maximum dead load. Also, areas adjacent to curbs, manholes, and other structures can be milled before an overlay is applied so that the overlay thickness can be maintained adjacent to these structures. One advantage the pavement milling machine has over the heater-planer is its ability to remove portland cement concrete pavement. This is particularly advantageous when milling a pavement that has some portland cement concrete along with the bituminous material that must be planed or removed, such as in areas adjacent to manholes or patches. The most extensive use of the milling machine is in pavement recycling. The removed materials can be mixed with new aggregate and new asphalt to produce recycled cold mix or recycled hot mix.

d. Milled surface. Occasionally, when a pavement surface has been milled, the surface is used as the riding surface for a period of time. For instance, when a pavement does not have adequate skid resistance but no immediate funds are available to overlay this pavement, one alternative is to mill the surface to give it a rough surface texture and thereby provide adequate skid resistance until it can be overlaid or otherwise repaired. An excessive amount of material should not be removed because the pavement structure would be weakened. It is recommended that the pavement be overlaid as soon after the milling as possible. Raveling may become a problem with asphalt concrete pavements after the milling process. On airfields, raveling could result in foreign object damage (FOD) to the aircraft. Therefore, an overlay should be applied immediately after the milling operation in most cases.

e. Milled material. The material obtained from milling operations can be used in pavement construction. The milled material can be stockpiled, but care must be exercised not to stockpile it too high, especially in hot weather, since the asphalt concrete material will have a tendency to bond thus making it difficult to use. In most cases, the material should not be stockpiled over 10 feet. The milled material can be used for producing recycled cold mix, recycled hot mix, and other mixes. Occasionally, this milled material can be used to surface secondary roads that otherwise would not be surfaced. In this case some additional binder material, such as asphalt emulsion or rejuvenator, is usually added to rejuvenate the old asphalt or improve binding qualities. This milled material, mixed with asphalt emulsion, can also be used as a base course for high-quality pavements. The material can be mixed in place or removed and plant-mixed to produce a satisfactory base course. For high-quality airfield pavements, this base course should be overlaid with the minimum amount of asphalt concrete mixture required by design. The hot mix and cold mix prepared from materials obtained by milling are discussed in chapters 3 and 4.

f. Gradation. The gradation of the milled material obtained from the milling operation is important when the material is to be used to produce recycled cold or hot mixes.

(1) When the material is to be used in recycled cold mix, the maximum size of the milled material, which is a conglomeration, of aggregate and asphalt, should not exceed 1½ inches. However, a small amount of material larger than 1½ inches is acceptable if it can be removed by screening prior to mixing. Generally, the milled material, without additional virgin aggregates, is used to produce recycled cold mix.

(2) When the milled material is to be used in recycled hot mix, the gradation of the milled material after extraction of the asphalt cement is important. Very little breakdown of the aggregate should occur during the milling operation. It is important that the maximum size of the material as milled does not exceed 1½ to 2 inches to ensure that it will break up and satisfactorily mix with the new materials in the production of recycled hot mix. Some filler material passing the No.200 sieve will be manufactured during the milling operation. Depending on the aggregate type, 1 to 3 percent additional filler may be manufactured. One of the problems in designing a recycled mixture is not to exceed the maximum amount of filler allowed. Generally, new aggregates that are to be added to a recycled mixture are required to have little or no filler. Therefore, washing of new aggregate is often required to remove the filler prior to producing the recycled mixture.

g. Base course. When the asphalt pavement material is to be removed down to the base course, care should be taken to prevent damage to the base course. Any damage to the base course should be corrected prior to placing the recycled mixture. Generally, approximately ½ inch of asphalt mixture should be left in place to prevent damage to the base course by the milling equipment or by rain.

CHAPTER 3
RECYCLED COLD-MIX ASPHALT CONCRETE

3-1. General.

When a pavement has deteriorated to a point that the thickness of a conventional overlay required to satisfactorily provide a solution to the problem is not economical or is prohibited by existing grades, the use of recycled cold mix should be considered. A recycled cold mix involves the reuse of the existing pavement structure by reprocessing it and adding a binder to it without the use of heat. The binder is usually lime, portland cement, or asphalt. This chapter will address the use of asphalt as the binder in recycled cold mixes. Recycled cold mix in conjunction with a hot mix overlay can often be used to repair an existing pavement at lower cost than with a conventional overlay. The basic process is shown on the flow chart in figure 3-1.

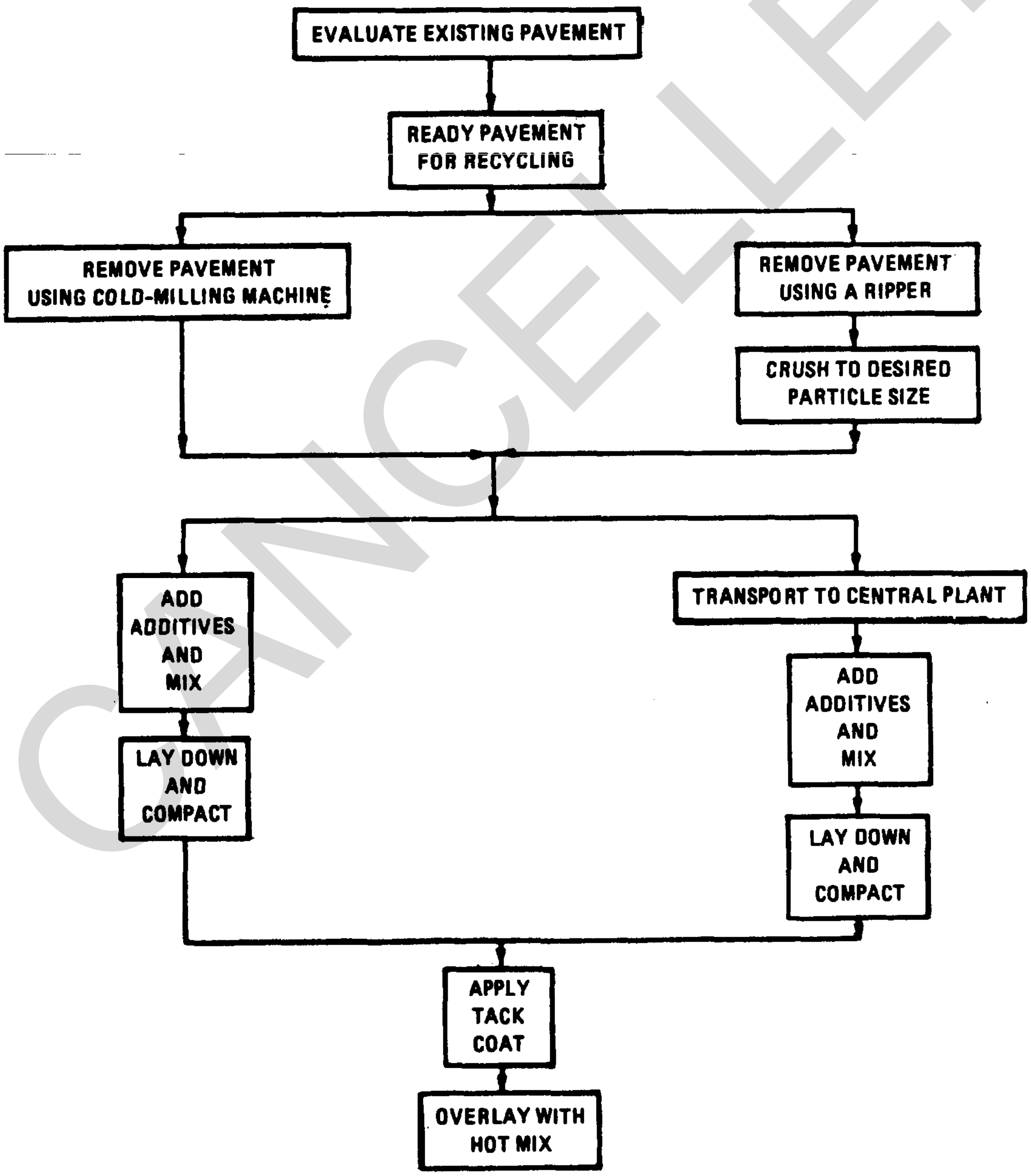

Figure 3-1. Cold-mix recycling flow process.

3-2. Equipment.

The equipment required for pavement removal and crushing is either conventional equipment for ripping and crushing or a cold-milling machine. For mixing and placing, a mix-in-place travel plant or a central plant and a conventional paver are required. The required equipment includes a distributor, trucks, brooms, rollers, and front- end loaders.

3-3. Pavement design.

The structural design of pavements using recycled cold-mix asphalt should be the same as that for the asphalt stabilized materials as provided in TM 5-825-2/AFM 88-6, chapter 2. The recycled cold mix should provide a structure whose performance is equal to that of the asphalt-stabilized material. Mixture design for recycled cold-mix asphalt concrete is important to ensure proper material proportions and to obtain maximum field density. When no new aggregates are to be added to the reclaimed materials, the mix design should be performed on the reclaimed materials as recovered. The maximum-size particles of the reclaimed asphalt concrete should not exceed the requirement, which is usually 1.5 inches. When new aggregates are to be added, the design should be performed on the desired mix of reclaimed aggregate and new aggregate.

3-4. Mix design.

Development of the mix design accomplishes two objectives: *(a)* determines the amount of new binder and rejuvenator required to obtain a durable and stable mixture, and *(b)* fixes the amount of moisture needed to provide maximum density.

a. Rejuvenator. A rejuvenator can be used in place of new asphalt in some instances to improve the old asphalt properties. A thorough blending of the rejuvenator and oxidized asphalt does not immediately occur when mixing the recycled cold mix. In fact, the rejuvenator initially coats the old asphalt and with time, probably months, will penetrate the old asphalt binder and produce an improved binder. During the first few months, the recycled cold mix may be unstable because of the film of rejuvenator around the oxidized asphalt and aggregate. After the rejuvenator penetrates the old asphalt and the binder material becomes more homogeneous, the recycled cold mix should perform satisfactorily. Because of the initial instability and increased costs created by rejuvenators, asphalt emulsions are usually used in recycled cold mixes.

b. Asphalt content. The amount of new asphalt needed in the recycled cold mix should be determined by conducting a conventional hot-mix design on the recovered aggregate. The laboratory density obtained in the hot-mix design is approximately equal to the maximum density that will be obtained in the field under traffic. The amount of asphalt added should be varied by 0.5 percent increments from 0 percent to the high side of optimum asphalt content. The samples should be compacted by the required effort, either 50 blows for low-pressure tires or 75 blows for high-pressure tires, and determinations should be made for density, stability, flow, voids total mixture, and voids filled with asphalt. These determinations should be plotted and curves drawn to select the optimum asphalt content. The optimum additional asphalt will often be between 0 and 1 percent. When the optimum additional asphalt to be selected is 0 percent, no additional asphalt should be added since it may cause the mixture to become unstable. When no asphalt is needed, only water should be added to lubricate the mixture so that the needed density can be obtained in the field.

c. Compacted samples. After the optimum asphalt content has been determined, samples should be made at the optimum asphalt content with varied water contents. These samples should then be compacted at room temperature using the same compaction effort as that used to determine optimum asphalt content. Next, the dry density for each of the compacted samples should be determined, a moisture/density curve should be plotted, and the moisture content that provides maximum dry density should be selected as the optimum moisture content. A design example is given in paragraph B-l.

3-5. Removal of in-place material.

The material to be used in the recycled cold mix can be removed from the in-place pavement by a number of methods. Two of the more common methods are identified. As discussed in paragraph 2-5, milling machines can be used to remove existing materials. When a milling machine is used, the existing asphalt pavement can be removed to any desired depth. Generally, the particle size of the removed material is satisfactory, and no further crushing is necessary. Another procedure for removing the pavement involves using a ripper tooth to remove the asphalt concrete (fig 3-2). When a ripper tooth is used, the asphalt concrete is removed full depth since there is no way to control the depth of material removed. When the asphalt concrete is removed by ripping, it must be further broken down by crushing in place with a pulverizer or other equipment or be carried to a crusher (fig 3-3). When this method is used, a significant amount of base repair will be required. While the old pavement is being removed, consideration should be given to drainage of the area to prevent unnecessary delays caused by rain. The exposed surface should be sloped to promote good drainage, and outlets or other means should be provided to prevent the ponding of water.

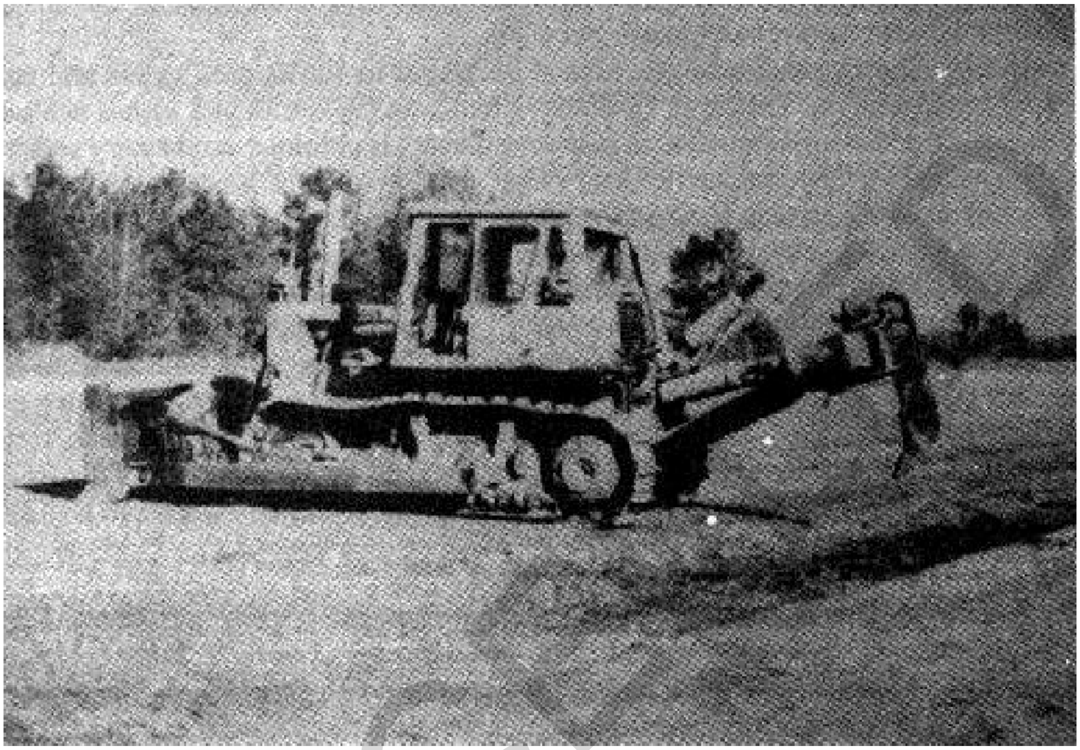

Figure 3-2. Pavement ripper attached to bulldozer.

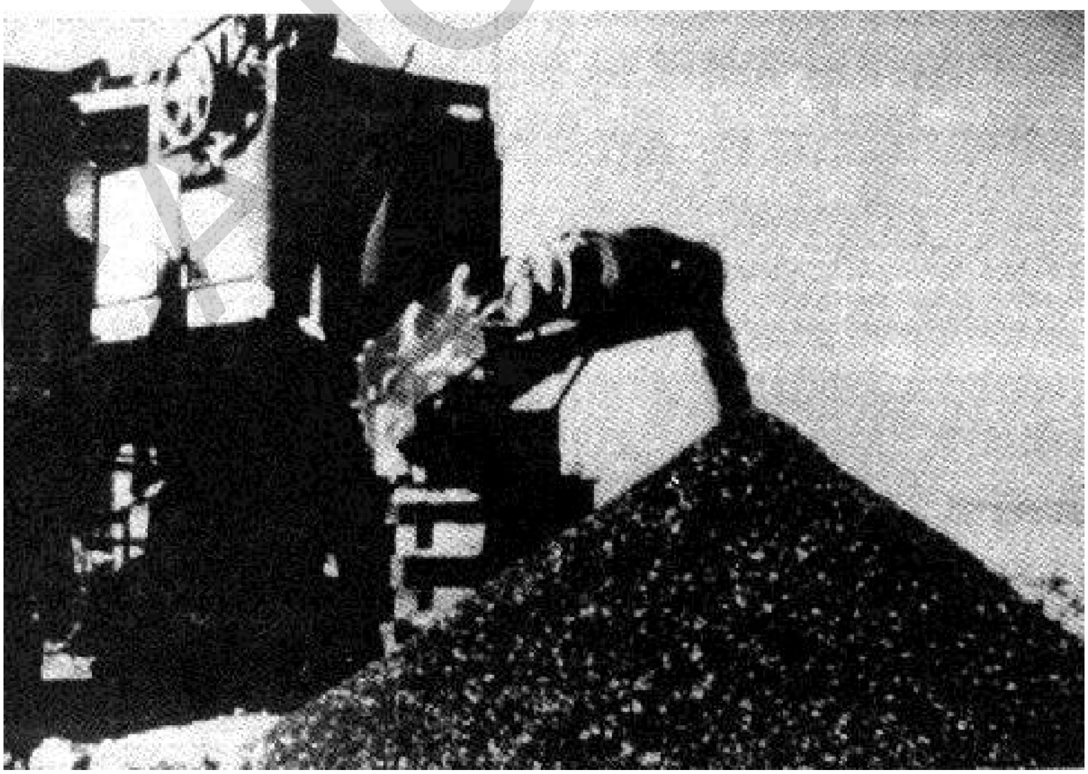

Figure 3-3. Old asphalt concrete pavement after crushing.

3-6. Construction.

After the asphalt concrete has been broken down to the desired particle size, it can be mixed with asphalt or other stabilizers and water in place or at a central plant. The in-place mixture produced by a travel plant is less expensive than the mixture produced at a central plant, but control of the quality is not as good. Either type of plant should be acceptable as long as the contractor can demonstrate that material meeting the specification requirements can be produced. To meet the specification requirements, the contractor must be able to control the amount of additional asphalt and water as well as the mixing time.

a. Recycled cold mix. The recycled cold mix should be placed to the desired grade and compacted to meet the minimum density requirements. The layer thickness should not be less than 2 inches compacted nor greater than 4 inches compacted. In order to ensure that satisfactory density is obtained, a vibratory roller and a pneumatic- tired roller should be available. The pneumatic-tired roller should weigh at least 20 tons and be capable of tire inflation pressures of at least 90 pounds per square inch.

b. Density. Since it is difficult to establish a laboratory density for comparison with field density, the theoretical maximum density (TMD) should be used to establish field density requirements. The theoretical maximum density is that density at which there would be zero air voids in the mixture. At least 86 percent of the theoretical maximum density should be obtained in the field to ensure that the voids in the field mixture are not excessive.

c. Cure time. Each layer of recycled cold mix should be allowed time to cure prior to being overlaid. The time needed to cure depends on many things such as air temperature, wind, type of asphalt used, layer thickness, and humidity, but as a general rule each layer of recycled cold mix should be allowed to cure for 10 days before being overlaid.

3-7. Field density measurements.

The field density should be determined from cores removed from the in-place pavement. With some mixes it will be difficult to obtain undamaged cores prior to curing the cold mix for a few days. When cores cannot be obtained within 24 hours of paving, other methods of obtaining samples should be considered. For example, ice placed on the sample locations for 1 to 2 hours prior to coring samples will cool the material and reduce damage caused by heat developed during the coring operation. Another approach is to use a concrete saw to cut small cubes from the pavement. Nuclear density gages can be used to obtain an indication of density, but actual samples should be taken to determine acceptability of the density of the in-place mixture.

CHAPTER 4
RECYCLED HOT-MIX ASPHALT CONCRETE

4-1. General.

Recycled hot-mix asphalt concrete should be considered as an alternative anytime a conventional overlay reconstruction is anticipated. Recycling will create a greater savings in material cost and total job cost than that for a conventional overlay or reconstruction on many jobs. Performance of recycled hot mix should be considered equivalent to that expected with conventional hot mix. Recycled hot mix can be used to construct bituminous base, intermediate, and surface courses.

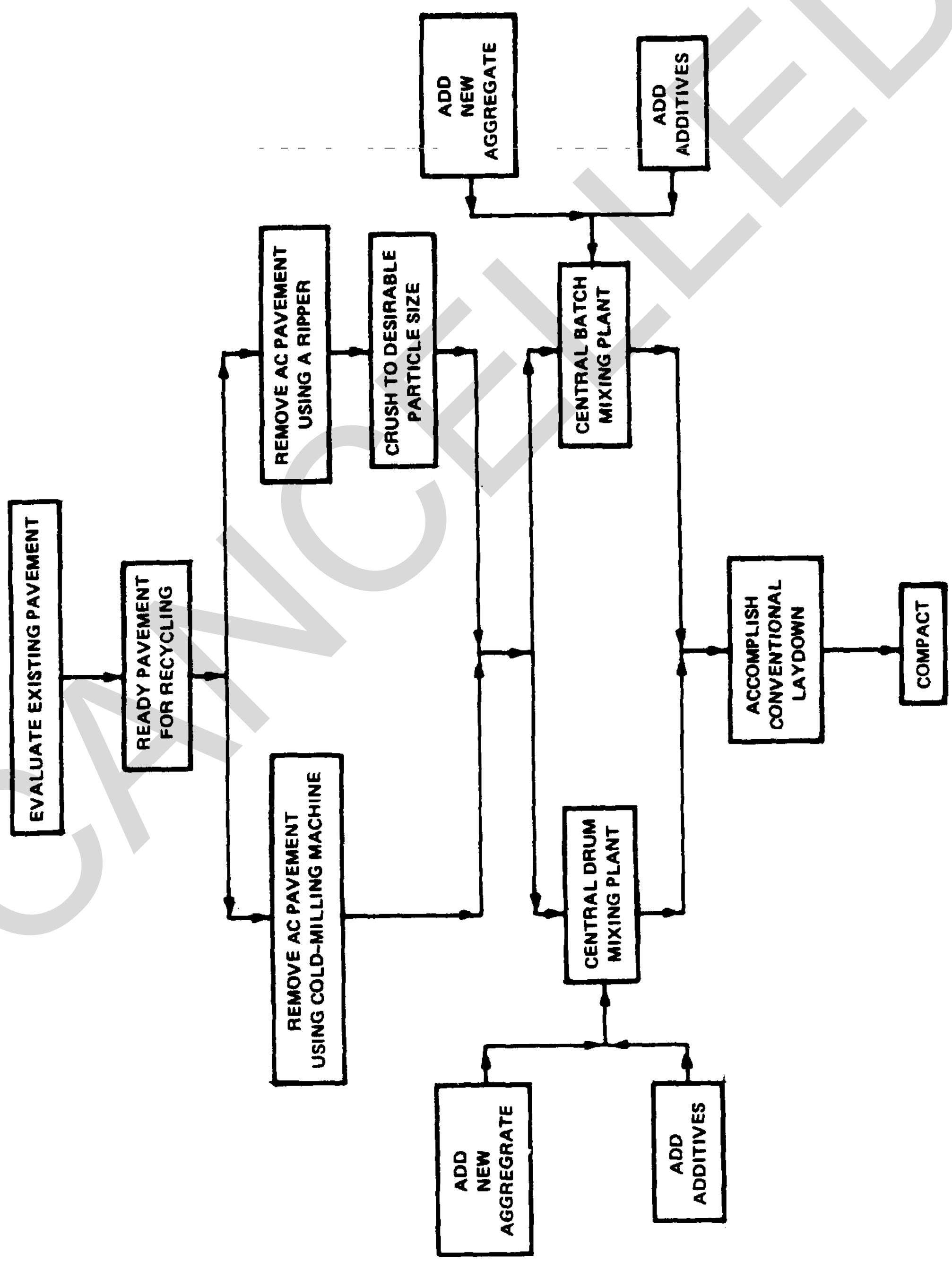

Figure 4-1. Hot recycling process.

4-2. Equipment.

The equipment required for pavement removal and crushing will include either conventional equipment for ripping and crushing or a cold-milling machine. A batch or drum plant, either designed or modified to mix recycled materials is also required. Placement is with a conventional paver, and trucks, front-end loader, and asphalt distributor are also required.

4-3. Recycling hot-mix procedures.

Recycling hot mix consists of removing the existing pavement; crushing the reclaimed mix, if necessary; mixing the reclaimed mix with virgin aggregate, virgin asphalt, and recycling agent; and placing the recycled mix by the same procedures as those used for a conventional mix (fig 4-1).

4-4. Removal and sizing.

The asphalt concrete pavement should be removed by a cold-milling machine or with a ripper tooth and crushed. The cold-milling machine is a self-propelled, power-operated planing machine capable of removing, in one pass, a layer of bituminous material up to 12 feet wide and 2 to 4 inches deep. The equipment should be capable of establishing grade control by referencing from existing pavement or from independent grade control and should have a positive means of controlling transverse slope elevations. The equipment should have an effective means of preventing dust from the operation from escaping into the air. The milled material should pass through a 2-inch sieve. The teeth on the cutting drum must be in satisfactory condition at all times to prevent shearing off chunks of the asphalt concrete and creating oversize particles or a rough surface. If oversize particles are present, they should he removed by screening.

4-5. Virgin aggregates.

Virgin aggregates are added to the recycled hot mix for a number of reasons.

a. Pollution control. Without the addition of new aggregate, air pollution during mix production for most plants would exceed the allowable levels. With the addition of new aggregate, an aggregate shield can be used to prevent the flame from having direct contact with the reclaimed asphalt pavement (RAP) and causing the burning of the asphalt in the reclaimed asphalt pavement, which is the main source of air pollution in hot recycling.

b. Gradation. The gradation of the aggregate in the existing mix can be improved by adding virgin aggregates. Many times existing pavements do not contain the desired aggregate gradation, and if they do contain a satisfactory gradation, it may be changed during the milling or crushing operation. Therefore, the addition of new aggregate allows the gradation of the recycled mix to be modified to an acceptable range.

c. Aggregate quality. Many times the quality of the aggregates in an existing mix is not acceptable, even though the gradation is satisfactory. One cause of poor quality in an aggregate blend is the use of an excessive amount of natural rounded sand. Rounded sand is a poor aggregate for asphalt concrete, but because of its abundance and low cost, it is often used in excess in asphalt concrete mixtures. The addition of a new high-quality aggregate can reduce the percentage of rounded sand in the mixture and thus improve the overall quality of the mix. The amount of natural sand added to a recycled mixture should not exceed 15 percent of the new aggregate for airfields.

d. Excess filler material. Existing asphalt concrete pavements were generally constructed with the amount of filler material passing the No.200 sieve near or above the maximum allowed by specifications. The amount of filler in the reclaimed mixture most often varies between 8 and 12 percent whereas the maximum amount of filler allowed is 6 percent. During the milling or crushing operation approximately 1 to 3 percent additional filler will be manufactured. Thus, in order to control the amount of filler, the new aggregates must be limited to very little or no filler. The virgin aggregates may have to be washed to minimize the amount of filler material. In addition, the percent of virgin aggregate in the recycled mixture may have to be adjusted to help control the filler content.

e. Asphalt binder. The asphalt binder in existing pavement is usually oxidized and requires some modification during recycling to produce an acceptable asphalt binder and mixture. If no new aggregate is added to the mix, the addition of asphalt or recycling agent needed to produce satisfactory asphalt cement properties may result in a mixture that is too rich. The asphalt cement content of the existing pavement mixture is generally near the optimum asphalt content; hence, the addition of more asphalt cement or recycling agent may result in an excessive asphalt content. If the existing asphalt binder is not modified with a low viscosity asphalt or recycling agent, a brittle mixture will be produced.

4-6. Mix design.

The mix design is conducted to determine the percentages of reclaimed asphalt mixture, each new aggregate, recycling agent, and asphalt cement to be used in the mixture. The amount of reclaimed mixture used in a recycled mixture is usually based on the amount of reclaimed materials available, the desired physical properties of the recycled mix, requirements of the aggregate gradation, economical considerations, and the type of asphalt plant. A drum mixer can prepare recycled asphalt mixtures using up to a maximum of 70 percent reclaimed mixture. However, in order to ensure that the quality of the mix is controlled, the amount of reclaimed asphalt concrete used in the production of recycled hot mix should not exceed 60 percent. When a modified batch plant is used to produce the recycled mixture, the maximum amount of reclaimed materials that can be added to the mixture generally varies between 50 and 60 percent because at least 40 to 50 percent new superheated aggregate is needed to obtain sufficient heat transfer to the reclaimed asphalt pavement material. The selection and evaluation criteria for the new and old aggregate are the same as those for new hot mixes.

a. Percentage of aggregate. The first step in the mixture design is to determine the percentage of each new aggregate and reclaimed asphalt concrete that should be used. The amount of reclaimed asphalt concrete that can be practically recycled is determined, as discussed in paragraph 4-6. The gradation of the aggregate extracted from the reclaimed asphalt and the gradations of the new aggregates are then determined. The percentage of each aggregate to be used in the recycled mixture is then selected so that the blended gradation of all aggregates used, including the aggregate in the reclaimed asphalt concrete, meets the specification requirements.

b. Type of binder. The second step is to determine the type of binder or recycling agent to be used in the mixture. A recycling agent is usually required to modify the oxidized asphalt binder. When the penetration of the old asphalt binder is more than 10 percent and the amount of reclaimed asphalt concrete used in the recycled mixture is below 50 percent, the existing asphalt binder can usually be modified with an asphalt cement such as AC-2.5 (ASTM D3381). In this case, no recycling agent would be needed. When the amount of reclaimed asphalt concrete used in the mixture exceeds 50 percent, or when the penetration of the existing asphalt binder is less than 10 percent, a recycling agent is generally needed. For many jobs it will be necessary to use an asphalt cement and a recycling agent to properly modify the existing asphalt at optimum asphalt content.

c. Preparation. The third step consists of preparing recycled mixtures at various asphalt contents with 0, 0.5, and 1.0 percent recycling agent, if a recycling agent is being used. The following data should be plotted for each recycling agent content being evaluated: (1) density versus additional asphalt content, (2) stability versus additional asphalt content, (3) flow versus additional asphalt content, (4) voids in the total mix versus additional asphalt content, and (5) voids filled with asphalt versus additional asphalt content. These graphs, with the exception of stability, take the same shape as those developed when conducting a mix design for conventional hot-mix asphalt concrete. The plot of stability versus additional asphalt content generally indicates the highest stability at 0 percent additional asphalt and a reduction in stability as the asphalt content is increased. The optimum asphalt content should be determined by averaging the asphalt contents at the peak of the density curve, middle of the voids in the total mixture requirements, and middle of the voids filled with asphalt requirements. The requirements for voids in the total mix, voids filled with asphalt, stability, and flow are the same as those for conventional hot-mix asphalt concrete. Mixtures at optimum asphalt content for each recycling agent content should be prepared and the asphalt recovered from these mixtures. The penetration of the recovered asphalt should be a minimum of 60 percent of the desired original asphalt penetration for the area in which the mixture is to be used. The amount of recycling agent should be selected so that the recovered asphalt penetration meets the desired limits. It is important that the penetration of the recovered asphalt be measured during plant production and that adjustments be made if necessary to ensure proper asphalt consistency. Paragraph B-2 gives a design example of a hot-mix design for a recycled asphalt concrete pavement.

4-7. Recycling hot-mix quality control.

Most recycled asphalt concrete is produced with a drum mixer designed or modified to produce recycled mixtures. Modified batch plants have also been used successfully to produce recycled hot mix.

a. Drum mixer. when a drum mixer is used for recycling, the new aggregate is added at the high side of the drum near the flame (fig 4-2). The aggregate absorbs much of the heat from the burner and acts as a shield to protect the reclaimed asphalt concrete, new asphalt binder, and recycling agent. The reclaimed asphalt concrete is added to the drum near the midpoint followed by the recycling agent and new asphalt. The flights inside the drum should be in good condition so that the veil of new aggregate will properly protect the asphalt materials from heat damage. The final recycled mixture is generally heated to between 260 and 290 degrees F to produce a mixture that can be compacted to meet density requirements. Pollution is sometimes a problem, but generally the mix design can be modified by lowering the percent of reclaimed asphalt pavement to bring pollution within an acceptable range.

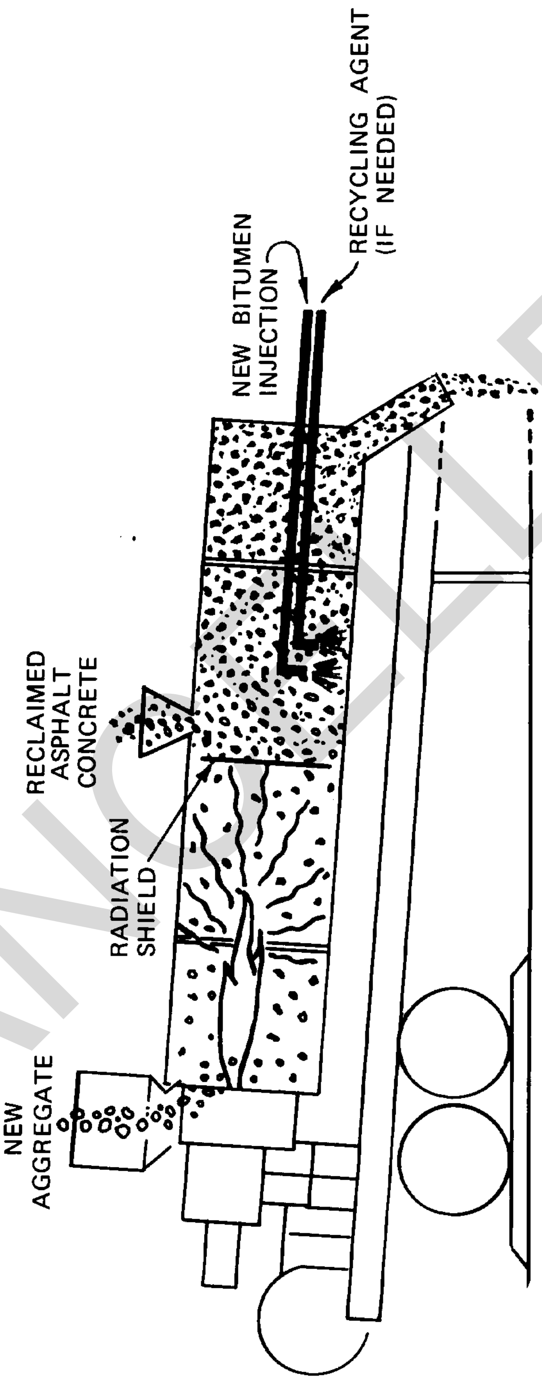

Figure 4-2. Recycling hot-mix production in a drum mixer.

b. Batch plant. Batch plants have also been modified so that recycled mixtures can be produced (fig 4-3). The modification consists of adding a feeder and conveyor to carry the reclaimed asphalt pavement directly to the weigh bucket. The new aggregate that passes through the dryer is usually superheated to between 500 and 600 degrees F so that when the materials are blended, the resulting temperature is suitable for mixing and compaction. An increase in the amount of reclaimed asphalt concrete used in the mix would require an increase in the new aggregate temperature. Also, additional moisture in the new aggregate or reclaimed asphalt pavement stockpiles will require additional heat. Therefore, to save energy both stockpiles should be kept as dry as possible,

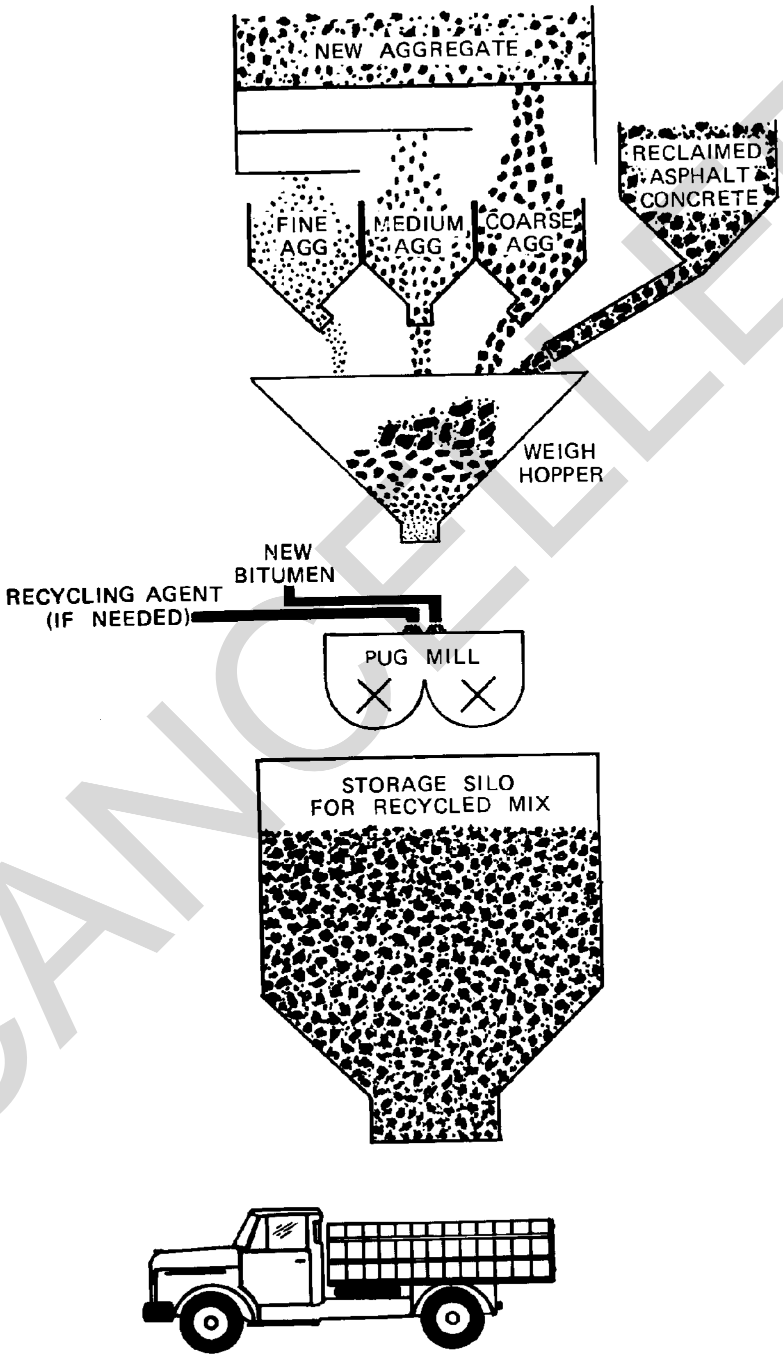

Figure 4-3. Recycling hot-mix production in a batch plant.

c. Stockpiling. Prior to production of recycled asphalt concrete, the stockpile of reclaimed materials should be inspected to ensure that no significant segregation of material exists. Many pavements have been patched during their lives causing variation in the type of materials at various locations in the pavements. Therefore, the materials should be removed from the pavement and stockpiled in such a way to ensure proper mixing of these localized materials with the other reclaimed materials. When the asphalt pavement is removed in two lifts, the properties of the material in the top lift will probably vary from the properties of the materials in the bottom lift. In this case, the materials should be stockpiled separately, or some acceptable procedure for blending these materials must be used.

d. Cold feeds. In order to remove all material larger than 2 inches a screen should be placed over the bin or cold feeder from which the reclaimed materials will be fed to the plant. when conglomerations of asphalt and aggregate exceed this size, they will not break down enough in the asphalt plant to produce a homogeneous mixture. Consequently, these oversize pieces may cause problems with pulling and tearing of the mat during the lay- down operation.

e. Control testing. During production of recycled asphalt concrete, a number of tests must be conducted to ensure that a satisfactory product is produced. The tests used to evaluate recycled mixtures are the same tests used to evaluate conventional hot mix. These tests evaluate material properties such as, Marshall stability, flow, laboratory density, voids in the total mixture, voids filled with asphalt, aggregate gradation, asphalt content, temperature, and field density. Penetration of the recovered asphalt cement is another property that is needed to evaluate recycled mixtures during production.

4-8. Laydown of recycled hot mix.

There should be no difference between the laydown of recycled hot mix and the laydown of conventional hot mix. The recycled mixture may appear to be a little more oily, which is probably due to recycling agent, but this condition is normal.

4-9. Excess reclaimed asphalt pavement.

All excess reclaimed asphalt pavement should be stockpiled for use on other Government projects. If the ownership of excess reclaimed asphalt pavement is transferred to the contractor, credit should be given to the Government for its value.

CHAPTER 5
RECYCLING OF PORTLAND CEMENT CONCRETE

5-1. General.

This chapter provides information and instruction for the preparation of contract specifications and construction operations involving the recycling of portland cement concrete as aggregates in road and airfield pavements. As shown in figure 1-2, portland cement concrete recycling or other methods may correct many types of pavement distress.

5-2. Recycling portland cement concrete procedure.

Existing portland cement concrete when removed as unwanted pavements and structural elements is usually wasted and disposed of outside the project limits. However, the contractor may be given the option of recycling these materials as construction aggregates for portland cement concrete pavement (PCCP), Econocrete, cement- treated base (CTB), and aggregate base (AB). The basic process is shown in the flow chart of figure 5-1. The first step involves preparing the existing pavement or other structural elements for fracturing into pieces of manageable size for the available equipment. The pavement is broken by fracturing with a pavement breaker, scarifying, ripping, or jackhammering. The broken concrete is then hauled to the crushing plant where it is crushed and sized according to specification requirements. The aggregates are then reused directly from the crushing plant or stockpiled for future use. Some of the advantages and disadvantages of recycling portland cement concrete are given in table 1-1.

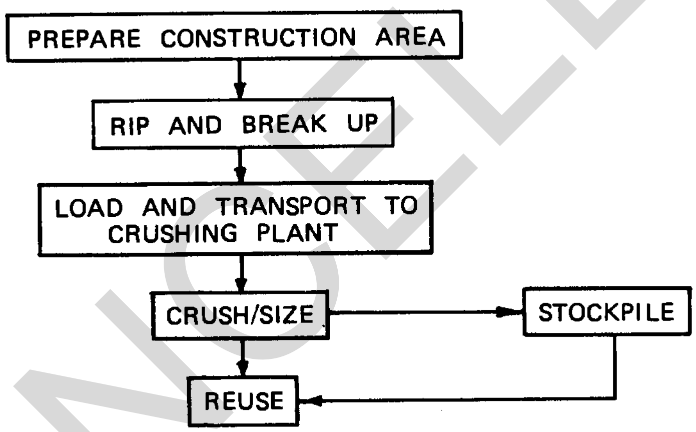

Figure 5-1. Recycling portland cement concrete flow process.

5-3. Sources for recycled aggregates.

Aggregates can be produced from the breakup and crushing of existing portland cement concrete pavement and structural elements.

a. Pavement. where an asphalt concrete surface is present on an existing rigid pavement, the asphalt concrete must be removed before the old portland cement concrete pavement is broken up. It is intended that all of the asphalt concrete be removed; however, isolated areas of asphalt concrete up to 1 inch in thickness and small asphalt concrete patches will be considered acceptable. The old portland cement concrete pavement should be removed in a manner that excludes subbase and subgrade material to the maximum extent practicable.

b. Structures. It is the intention of this operation to produce the maximum amount of salvage portland cement concrete that can be crushed, stockpiled, and accepted as aggregate in new portland cement concrete. All reinforcing steel should be removed from the salvaged concrete either prior to or during the crushing operation.

5-4. Excess recycled aggregates.

All excess recycled aggregate should be stockpiled for use on other Government projects. If the ownership of the excess recycled aggregate is transferred to the contractor, credit should be given to the Government for its value.

5-5. Equipment.

In general, equipment and procedures to handle the crushed portland cement concrete are the same as those for typical aggregates. However, equipment and procedures used to break up, crush, and process existing portland cement concrete for reuse as construction aggregates are unique to the recycling process and, therefore, will be described. Since the major source of recycled concrete is old rigid pavement, most of the pieces of equipment are involved with this operation. Even the equipment used in the recycling process is the type that can be considered standard in heavy construction.

a. Breakup equipment. Equipment that has been used successfully to break up existing portland cement concrete pavement includes the following:

(1) Diesel pile-driving hammer mounted on a motor grader that punctures the pavement on a 1- to 2-foot grid pattern (fig 5-2).

(2) Concrete pavement breakers of various types.

(3) Rhino-horn-tooth-ripper-equipped hydraulic excavator frequently employed to dislodge and expose the reinforcing steel after the pavement has been fractured by one of the pieces of equipment described in (1) and (2) above (fig 5-3). The exposed steel is then cut manually with a cutting torch or shears.

Figure 5-2. Diesel pile-driving hammer puncturing the old pavement.

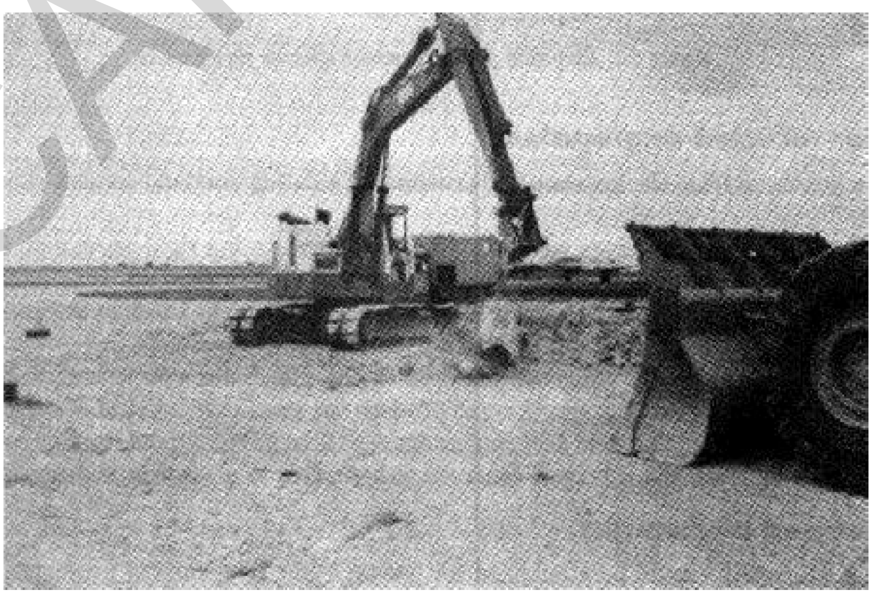

Figure 5-3. Rhino-horn-tooth-ripper-equipped hydraulic excavator.

(4) Old concrete structural elements broken down into manageable pieces by a combination of jackhammers and demolition balls.

b. Transport equipment. Cranes and front-end loaders are then used to load the rubble concrete into dump trucks for hauling to the crushing plant.

c. Crushing equipment. The crushing plants are either a portable type and located on the job site or a stationary plant situated at an existing pit or quarry.

5-6. Crushing process.

The crushing process consists of breaking the fractured concrete pieces to the required sizes and then stockpiling.

a. Crushing and screening. The salvaged concrete is brought to the crushing plant where it is reduced to the maximum size called for in the specifications. The equipment used to crush and size the existing concrete is also a common type used in the construction industry. The crushing equipment should include jaw or cone crushers. The preferred sequence of equipment utilization consists of a primary jaw crusher which breaks the material down to a maximum size of about 3 inches. The secondary cone crusher then breaks the particles down to the maximum size required which, depending upon specification, may vary between ¾ and 2 inches. A hammermill secondary crusher should not be used because of the excess amount of fines such a unit produces. After crushing, the material is separated over appropriate screens and stockpiled separately. A 3/8-inch screen is normally used to separate the coarse from the fine aggregates. The coarse aggregates may be split between fractions under and over ¾ inch. Another screen should be used to scalp off particles above the maximum size specified.

b. Stockpiling. The stockpiling should be accomplished in a manner that will prevent segregation and contamination by foreign materials. Each size of aggregate should be stored separately in free-draining stockpiles. Vehicles for stockpiling or moving aggregates should be kept clean of foreign materials. Processing equipment shall include a means by which excessive fines can be controlled so that no more than 5 percent of the fine aggregate passes the No.200 sieve.

c. Aggregate preparation. Usually it is not necessary to wash the crushed recycled aggregates unless they are contaminated with base or subbase material. State laws governing pollution control must be observed in the crushing operation.

d. Reinforcing steel. Any reinforcing steel not removed previously must be separated from the recycled concrete after it is processed through the primary crusher. The pieces of reinforcing steel should be removed either by electromagnet, suspended above the conveyor belt leading from the primary crusher, or removed manually. The steel will be the property of the contractor and must be removed from the project.

5-7. Evaluation and testing.

These aggregates must meet the requirements for normal aggregates. The recycled portland cement concrete aggregates will be subjected to all tests used to evaluate new aggregates as specified.

5-8. D-crack concrete pavement recycling.

The deterioration of concrete pavement through D-cracking is a fairly widespread phenomenon. D-cracking occurs adjacent to joints and is caused by alkali aggregate reaction and freeze-thaw problems. In order to alleviate the problem, all recycled aggregates from an existing pavement that has experienced this type of deterioration must pass the ¾-inch sieve if they are to be used as aggregates for a new portland cement concrete pavement. Experience has shown that crushing the reclaimed portland cement concrete to pass through the 3/4 inch sieve prevents D-cracks from reoccurring in the recycled pavement.

5-9. Fine aggregates.

To improve workability of a new portland cement concrete pavement using recycled concrete, natural sand can be added to the fine aggregates. But when two or more types of fine aggregates are used, each must be stockpiled separately.

5-10. Utilization of recycled aggregates.

Once the old portland cement concrete has been crushed and stockpiled, and the quality has been found to be satisfactory for its intended use, the material will then be treated as any other aggregate. An applicable document to use as a guide from that point is TM 5-822-7/AFM 88-6, chap 8.

APPENDIX A
REFERENCES

Government publications

Departments of the Army and the Air Force

TM 5-822-7/AFM 88-6, Chap. 8	Standard Practice for Concrete Pavements
TM 5-822-8/AFM 88-6, Chap. 9	Bituminous Pavements Standard Practice
TM 5-825-2/AFM 88-6, Chap. 2	Flexible Pavement Design for Airfields

Nongovernment publications

American Society for Testing and Materials (AS TM), 1916 Race Street, Philadelphia, PA 19103

D 3381-83	Viscosity—Graded Asphalt Cement For Use in Pavement Construction

APPENDIX B
EXAMPLES OF COLD-MIX AND HOT-MIX RECYCLING PROGRAMS

B-1. Cold-mix recycling problem.

The middle 50 feet of an airfield taxiway is to be removed to a full depth (3 to 5 inches), replaced with a recycled cold mix, and overlaid with 3 inches of new hot mix. The design mix must be developed for the recycled cold mix.

a. *Step 1.* Obtain samples of the in-place pavement (use jackhammer or other acceptable means).

b. *Step 2.* Run an extraction on the old asphaltic pavement to determine the following:

(1) *Asphalt content.* Use the determination of the existing asphalt content as a guide to calculate how much, if any, additional asphalt binder will be needed.

(2) *Asphalt penetration.* Perform a penetration test to determine if the existing asphalt has become so brittle that it needs rejuvenating. If possible, avoid using a rejuvenator with recycled cold mixes. Until the rejuvenator penetrates the old asphalt, the mix is unstable and could remain unstable for as long as 2 months. Generally, a slow-set asphalt emulsion is preferred for cold-mix recycling.

c. *Step 3.* Prepare a set of samples varying the amounts of asphalt emulsion added, and compact at 75-blow compaction effort at a temperature of 250 degrees F. Vary the amount of asphalt emulsion added from 0 to 2.5 percent in 0.5 percent increments. This range will generally be large enough to bracket the optimum amount of emulsion to be added.

d. *Step 4.* Test the samples obtained in step 3 for stability, flow, unit weight, percent voids total mix, and percent voids filled with asphalt. Record the test results in plots similar to those shown in figure B-1. The plots in figure B-1 are used to determine the optimum asphalt emulsion to be added.

e. *Step 5.* Using figure B-1 and the procedure outlined in TM 5-822-8/AFM 88-6, chap 9, and TM 5-825-2/AFM 88-6, chap 2, select the preliminary optimum asphalt emulsion to be added as follows:

Determination of Optimum Bitumen Content

Selection Point	Asphalt Emulsion Added
Peak of stability curve	0.5 percent
Peak of unit-weight curve	1.0 percent
4 percent voids in total mix	1.0 percent
~~75 percent total voids filled with asphalt~~	~~0.0 percent~~
Average	0.6 percent

f. *Step 6.* Determine the optimum water content by preparing a set of samples of various water contents (0.6 percent added asphalt emulsion held constant) using the 75-blow compaction effort at the approximate temperature at which the reclaimed asphalt concrete will be during construction.

g. *Step 7.* Using the data obtained in step 6, plot the dry density versus the water content, as shown in figure B-2. Pick the peak of the curve to obtain the optimum water content. For the example, the optimum water content is 2 percent.

h. *Step 8.* Adjust mix during laydown operations as needed.

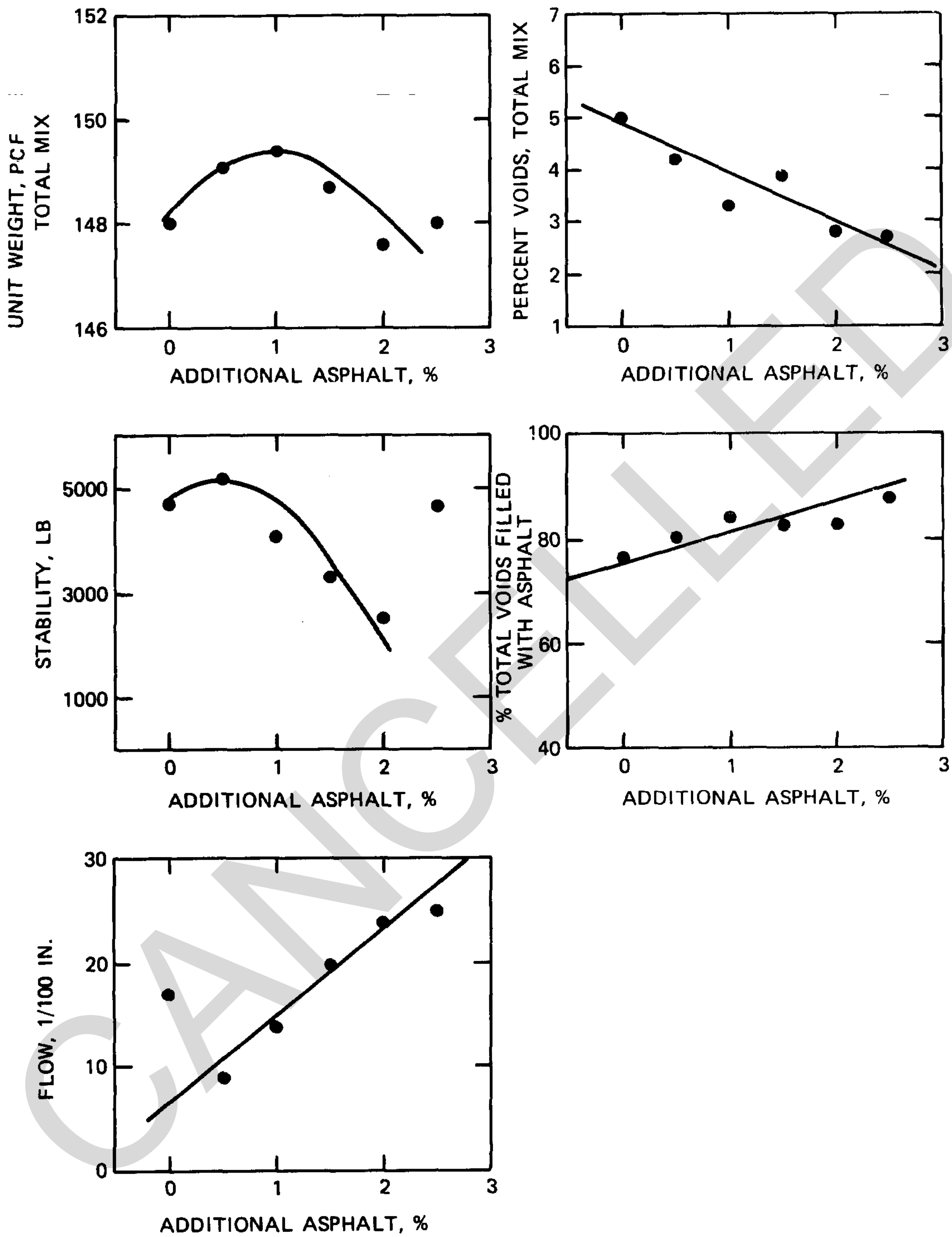

Figure B-1. Recycled cold-mix design using asphalt emulsion.

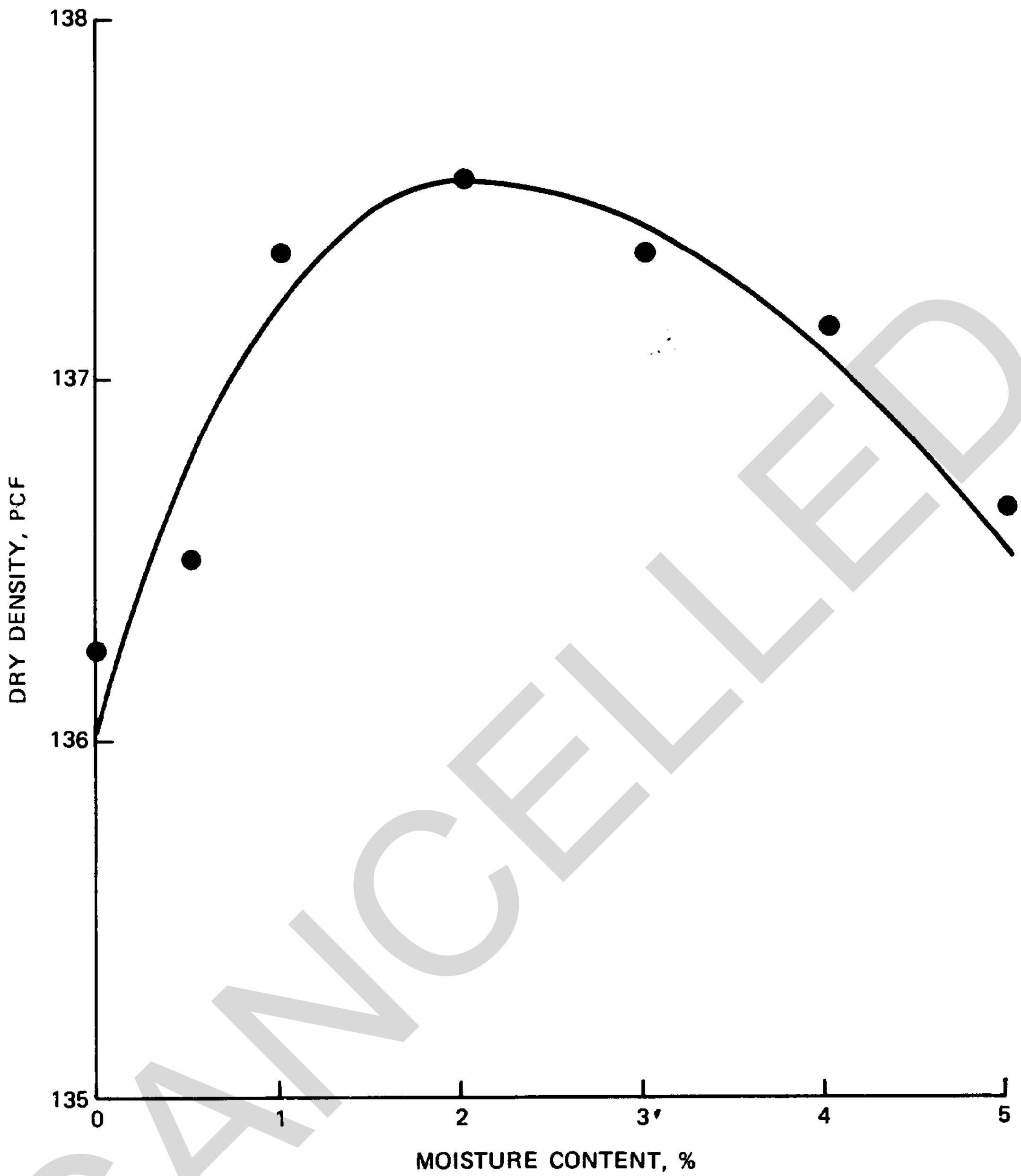

Figure B-2. Determination of optimum moisture for cold-mix design.

B-2. Hot-mix recycling problem.

The middle 75 feet of a runway is to be removed full depth (3 inches) and replaced with a recycled asphalt mixture containing 50 percent reclaimed asphalt pavement. Develop the design mix.

a. Step 1. Obtain samples of the in-place pavement (use jackhammer or other acceptable means) along with samples of the new aggregates to be used and the new asphalt and recycling agent, if needed.

b. Step 2. Run sieve analyses on all aggregates including aggregate extracted from sample of the in-place asphalt mixture. If an adequate history upon which to evaluate the new aggregate is not available, use the standard tests as outlined in TM 5-822-8/AFM 88-6, chap 9, and TM 5-825-2/AFM 88-6, chap 2. The history of the performance of the old aggregate should suffice for its evaluation. The aggregate gradations are shown in table B-1.

Table B-1. Aggregate gradations

Sieve Size	Percent Passing: Reclaimed Asphalt Pavement	New Coarse Aggregate	New Fine Aggregate	New Natural Sand
3/4 in	100	100	100	100
1/2 in	95	95	100	100
3/8 in	83	75	100	100
No. 4	63	12	100	98
No. 8	52	2	79	95
No. 16	40	0	57	89
No. 30	29	0	42	77
No. 50	21	0	30	48
No. 100	12	0	18	12
No. 200	6.0	0	8.0	4.5

c. Step 3. Determine the percentage of each aggregate to be used so that the gradation requirements for the blend are satisfied. The gradation requirements for this job are outlined in table B-2. The gradation requirements for recycled hot mix are the same as those for new mixtures. Through trial and error it was determined that a blend using 50 percent reclaimed asphalt materials, 24 percent coarse aggregate, 19 percent fine aggregate, and 7 percent natural sand would satisfy the gradation requirements (table B-2).

Table B-2. Gradation of recycled mixture

Sieve Size	Percent Passing	
	Specifications	Recycled Mixture
3/4 in	100	100
1/2 in	82–96	95
3/8 in	75–89	86
No. 4	59–73	60
No. 8	46–60	48
No. 16	34–48	37
No. 30	24–38	28
No. 50	15–27	20
No. 100	8–18	10
No. 200	3–6	4.8

d. Step 4. Conduct a penetration test on the recovered asphalt. A penetration test on the asphalt recovered from the in-place asphalt mixture indicated that the asphalt penetration was 10 percent. The target penetration for this example (mild climate) is 50. Because of the low penetration, it will be necessary to use a low-viscosity asphalt cement AC-2.5) and possibly an asphalt recycling agent.

e. Step 5. Prepare a set of samples with various asphalt contents with no recycling agent and a set of samples at various asphalt contents with 0.5 percent recycling agent. The added asphalt content should be varied from 2.5 to 4.0 percent for the samples with no recycling agent and from 1.5 to 3.0 percent for the samples with 0.5 percent recycling agent. Figure B-3 shows the properties of the mixtures with various added asphalt contents and 0.5 percent recycling agent. Figure B-4 shows the properties of the mixtures at various asphalt contents with no recycling agent.

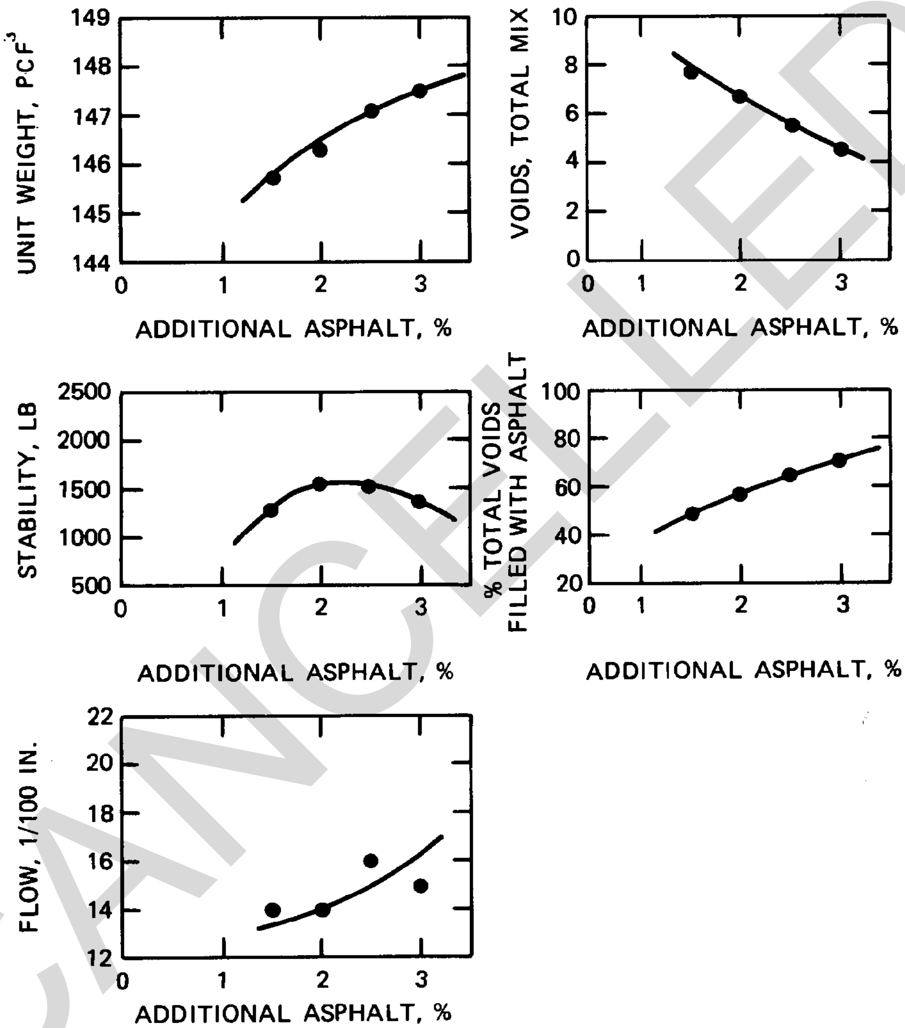

Figure B-3. Recycled asphalt concrete mix design for recycled hot mix; AC-2.5 asphalt binder and 0.5 percent recycling agent.

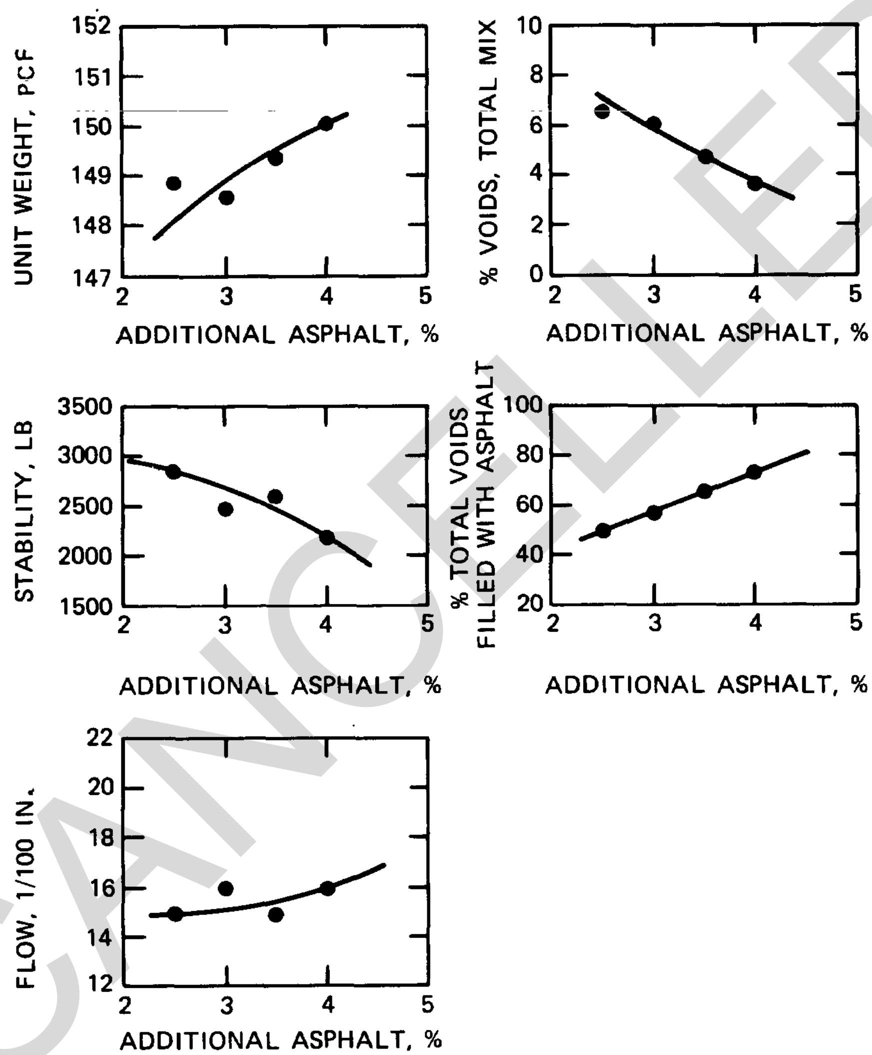

Figure B-4. Recycled asphalt concrete mix design for recycled hot mix; AC-2.5 asphalt binder with no recycling agent.

f. Step 6. Select the optimum asphalt content for the mixture with no recycling agent and for the mixture with 0.5 percent recycling agent. The optimum asphalt content and mixture properties for the two mixtures, as well as the penetration of the asphalt cement recovered from these two mixtures, are listed in table B-3.

Table B-3. Asphalt mixture properties at optimum asphalt content

Property	Mixture With No Recycle Agent	Mixture With 0.5% Recycle Agent
Optimum asphalt content, percent	4.0	3.0
Density, pcf	150.1	147.5
Stability, lb	2200	1450
Flow, 0.01 in.	16	16
Voids total mix, percent	3.9	4.5
Voids filled with asphalt, percent	75	72
Penetration of recovered asphalt binder, 0.1 mm	40	90

g. Step 7. Select a preliminary mix design to provide penetration of recovered asphalt binder to be approximately 50 by interpolating between penetration values of 40 and 90 as determined in step 6. The change in penetration with a change in recycling agent is not linear, but for the preliminary mixture design a linear interpretation is sufficient. The properties at optimum asphalt and recycling agent contents are presented in table B-4.

h. Step 8. At start-up of plant operations, modify the mix design to suit field conditions. The properties of the asphalt binder can be adjusted without changing other mix properties significantly by increasing the amount of recycling agent slightly and decreasing the amount of asphalt cement by the same amount or vice versa. Failure to modify mix design to meet field conditions may result in an unsatisfactory mix.

Table B-4. Mixture properties at optimum asphalt and optimum recycling agent content

Property	
Optimum recycling agent content, percent	0.1
Optimum added asphalt content, percent	3.8
Density, pcf	149.6
Stability, lb	2050
Flow, 0.01 in.	16
Voids total mix, percent	4.0
Voids filled with asphalt, percent	74
Penetration of recovered asphalt binder, 0.1 mm	50

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