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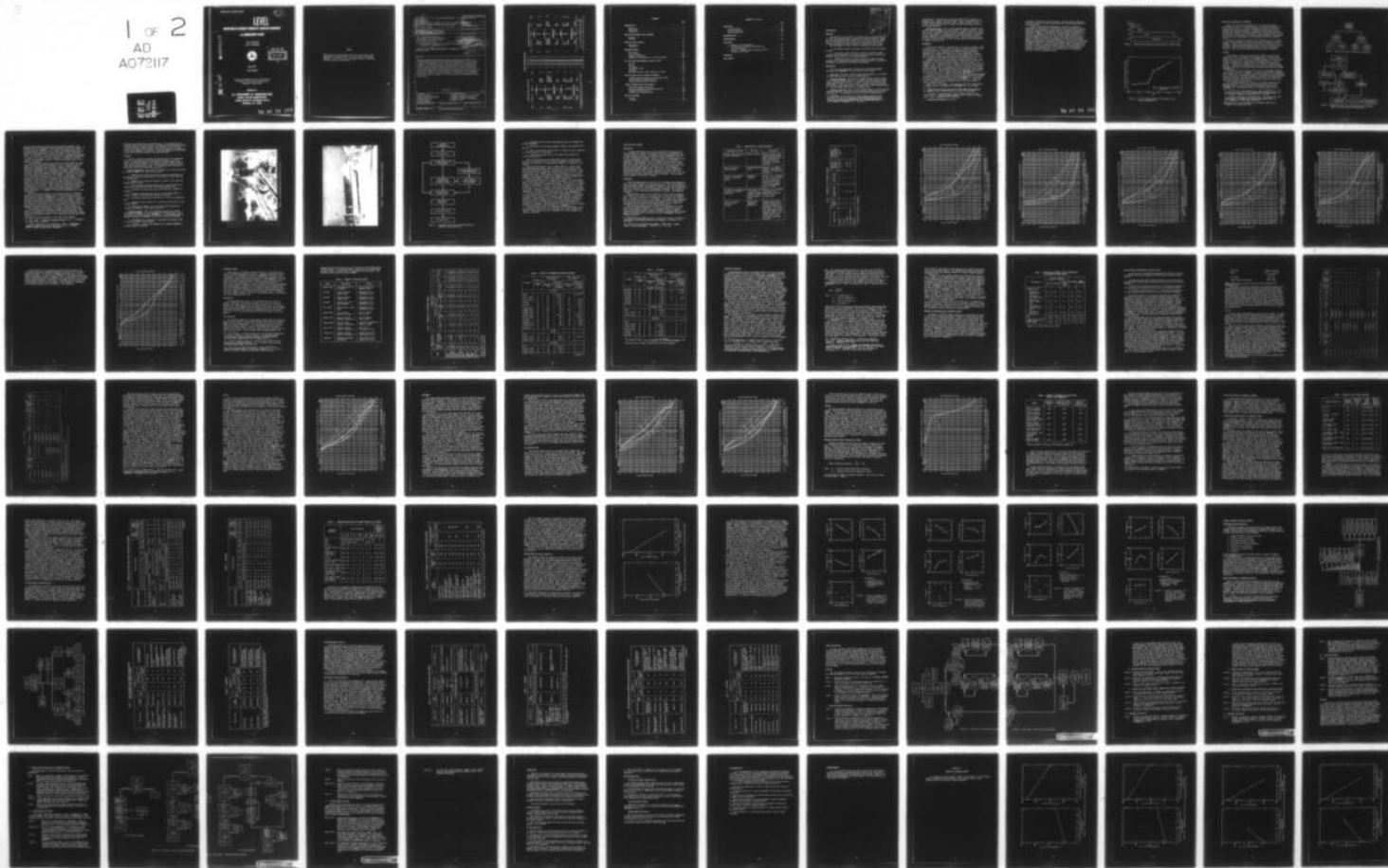
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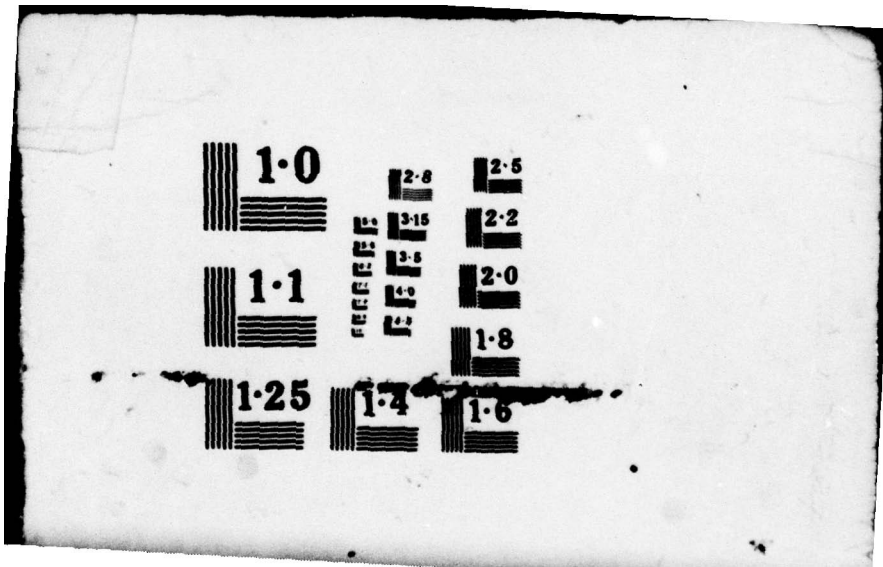
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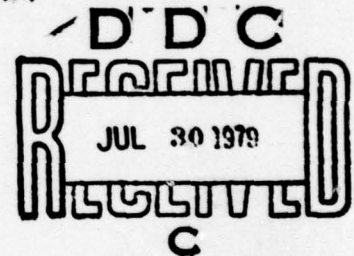
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# LEVEL

## RECYCLING OF ASPHALT CONCRETE AIRFIELD PAVEMENT

### - A LABORATORY STUDY

R. B. Brownie  
M. C. Hironaka



May 1979

Final Report

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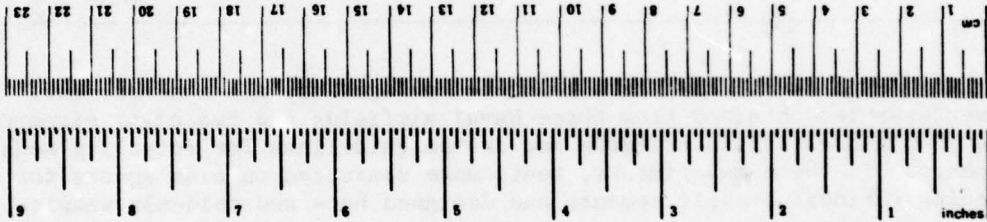
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<p>16. Abstract  ↓  Laboratory experiments have been conducted on aged asphalt concrete (AC) pavement samples obtained from three Naval airfields and two civil airports to develop and establish criteria and design guidelines for recycling such pavements. In these experiments, tests were conducted on nine agents for softening residual asphalt cements and designed hot- and cold-mix samples. It was found that aged AC pavement materials can be recycled to meet FAA and Navy specifications for new pavement surfaces and base courses by hot-mix recycling procedures and new base courses by cold-mix recycling procedures. Based on the results of this investigation, criteria and design guidelines for recycling aged AC pavements by hot-mix and cold-mix procedures have been established.  ↑</p> <p style="text-align: center; font-size: 2em;">391 111</p> <p style="text-align: right;">JUB</p>			
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## METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures				Approximate Conversions from Metric Measures			
Symbol	When You Know	Multiply by	To Find	Symbol	When You Know	Multiply by	To Find
<b>LENGTH</b>							
in	inches	2.5	centimeters	mm	millimeters	0.04	inches
ft	feet	30	centimeters	cm	centimeters	0.4	inches
yd	yards	0.9	meters	m	meters	3.3	feet
mi	miles	1.6	kilometers	km	kilometers	0.5	miles
<b>AREA</b>							
sq in	square inches	6.5	square centimeters	cm <sup>2</sup>	square centimeters	0.16	square inches
sq ft	square feet	0.09	square meters	m <sup>2</sup>	square meters	1.2	square yards
sq yd	square yards	0.8	square meters	m <sup>2</sup>	square kilometers	0.4	square miles
sq mi	square miles	2.6	square kilometers	km <sup>2</sup>	hectares (10,000 m <sup>2</sup> )	2.5	acres
<b>MASS (weight)</b>							
oz	ounces	28	grams	g	grams	0.035	ounces
lb	pounds (2000 lb)	0.45	kilograms	kg	kilograms	2.2	pounds
		0.9	tonnes	t	tonnes (1000 kg)	1.1	short tons
<b>VOLUME</b>							
tblsp	tablespoons	5	milliliters	ml	milliliters	0.03	fluid ounces
fl oz	fluid ounces	30	milliliters	l	liters	2.1	pints
c	cups	0.24	liters	m <sup>3</sup>	cubic meters	1.06	quarts
pt	pints	0.47	liters	m <sup>3</sup>	cubic meters	0.26	gallons
qt	quarts	0.95	liters	m <sup>3</sup>	cubic meters	35	cubic feet
gal	gallons	3.8	liters	m <sup>3</sup>	cubic meters	1.3	cubic yards
cu ft	cubic feet	0.03	cubic meters				
cu yd	cubic yards	0.76	cubic meters				
<b>TEMPERATURE (exact)</b>							
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature



\* 1 m = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10.286.

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## INTRODUCTION

### Objective

The purpose of this study is to develop criteria and guidelines for the reuse of existing asphalt concrete (AC) airport pavements. These criteria and guidelines are intended for recycling of aged AC pavement material by hot-mix procedures for new surface or base courses and cold-mix procedures for new stabilized or unstabilized base courses.

The development of these criteria and guidelines was based on:

1. A literature review, interviews, and observation of recycling projects.
2. A laboratory study of hot-mix recycling of aged AC airport pavements from three Naval air stations and two civilian airports into surface or base courses for new airport pavements.
3. A laboratory study of cold-mix recycling of aged AC airport pavements into stabilized and unstabilized base courses by the addition of granular base material and chemical stabilizers.

### Definitions

The following definitions as presented by the Federal Highway Administration (REFERENCE 1\*) will be used in this report.

**Recycling:** The reuse, usually after some processing, of a material that has already served its first-intended purpose.

**Hot-mix recycling:** One of several methods where the major portion of the existing pavement structure - including in some cases the underlying, untreated base material - is removed, sized, and mixed hot with added asphalt cement at a central plant. The process may also include the addition of new aggregate or a softening agent. The finished product is a hot-mix asphalt base, binder, or surface course.

**Cold-mix recycling:** One of several methods where the entire existing pavement structure - including in some cases the underlying, untreated base material - is processed in-place or removed and processed at a

\*1. Department of Transportation, Federal Highway Administration. FHWA Notice N 5080.64: Initiation of National Experimental and Evaluation Program (NEEP) Project No. 22 - Pavement Recycling, by H. A. Lindberg. Washington, D.C., Jun 1977.

central plant. The materials are mixed cold and can be reused as an aggregate base. Asphalt, portland cement, lime, or other materials can be added during mixing to provide a base of higher strength. This process usually requires that an asphalt surface course be placed over the recycled material.

Surface recycling: One of several methods where the surface of an existing asphalt pavement is planed, milled, or heated in place. In the latter case, the pavement may be scarified, remixed, relaid, and rolled. Additionally, asphalts, softening agents, minimal amounts of new asphalt hot-mix, aggregates, or combinations of these may be added to obtain desired mixture and surface characteristics. The finished product may be used as the final surface or may, in some instances, be overlaid with an asphalt surface course.

### Background

Recycling of asphaltic concrete is not a new idea or process. Most recycling prior to 1973 was cold recycling, or the pavement material was crushed and used as a replacement for aggregate base or subbase. Increasing fuel costs, along with the costs of transporting virgin aggregate over long-haul distances, have caused engineers to examine other sources of materials. Concurrent with increased fuel costs, the price of asphalt binder materials has more than doubled since 1973.

Disposal of solid waste has become a problem in many areas. Lack of suitable landfill sites, particularly in urban areas, has led to the development of contractor-operated pavement recycling centers. For example, in the Los Angeles area a contractor has set up yards to receive pavement rubble. When a sufficient stockpile of material is obtained, a portable crushing plant is brought in to process the material into base course gradation. Approximately 600,000 tons of material were recycled this way in 1977. The Los Angeles County Road Department has written a special specification for recycled base course (REFERENCE 2\*).

Hot-mix recycling of asphalt concrete has been spurred by development of equipment that can effectively heat asphalt materials without burning them and with acceptable pollution control (REFERENCE 3\*). The amount of hot mix recycled is increasing yearly (see FIGURE 1). Almost all hot-mix recycling has been on highway projects with little work on airport pavements thus far.

While the cost of asphalt paving materials has been rising (shown in FIGURE 2 based on information from REFERENCE 4\*), an increased

\*2. Standard Specifications for Public Works Construction, 1976 ed. Los Angeles, Calif., Building News, Inc., Oct 1976, pp 68-69.

3. Department of Transportation, Federal Highway Administration. Report IP 75-5: Recycled Asphalt Concrete, by H. Proudly, G. Gregory, and J. Hodge. Washington, D.C., Sep 1975.

4. Engineering News-Record, 1970-1977.

awareness of the need to preserve natural resources and the imposition of stricter pollution control regulations have reinforced the effort to recycle materials.

As part of the present investigation, a review of literature, interviews, and observation of recycling projects were made to provide background for preparation of guidelines for construction operations in recycling. Samples of aged asphalt concrete pavements from Naval Air Stations and commercial airports were obtained to provide material for laboratory investigations of hot-mix recycled asphalt concrete and cold-mix asphaltic concrete base course. The investigations included the use of additional asphalt and aggregate and the use of softening agents, portland cement, and asphalt emulsions. The quality of laboratory mixtures was generally evaluated using conventional test procedures such as Marshall stability, California Bearing Ratio (CBR), unconfined compression, gradation, Atterberg limits, viscosity, and penetration tests. Criteria for recycling mixtures were developed from the information obtained in the investigation of recycling projects and laboratory testing of recycled pavement mixtures.



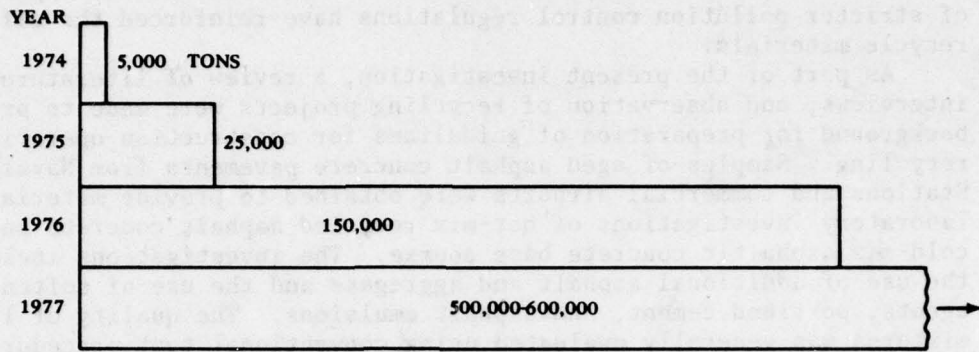


FIGURE 1. QUANTITIES OF RECYCLED HOT-MIX PRODUCED IN RECENT YEARS.

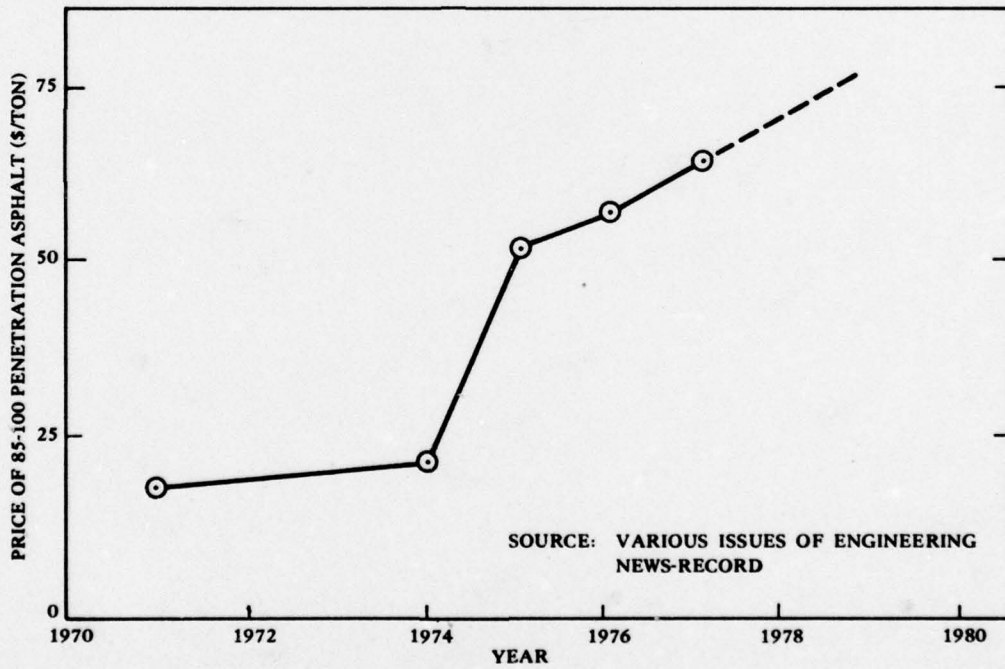


FIGURE 2. COST OF ASPHALT CEMENT IN LOS ANGELES, CALIF. (BASED ON REFERENCE 4).

## RECYCLING EQUIPMENT AND PROCEDURES

Again, the three basic categories for recycling AC pavements, defined earlier, are (1) surface recycling, (2) hot-mix recycling, and (3) cold-mix recycling. In this investigation hot-mix and cold-mix pavement recycling are emphasized. Equipment and procedures for performing such hot-mix and cold-mix recycling operations are described in this section. Surface recycling methods, which include planing, milling, and heating of the surface of an existing asphalt pavement, are outside the scope of this investigation and, therefore, will not be included herein.

In general, recycling operations could take place either on-grade (in-place) or off-grade at a remote central processing plant as shown in FIGURE 3. In-place processing usually involves a cold-mix recycling procedure; central plant processing usually involves a hot-mix recycling procedure. The construction equipment and procedures required for in-place as well as central plant processing are shown in FIGURE 3.

### Hot-Mix

All equipment, except the hot-mix plant required for recycling operations, can be the standard road-building type. Bulldozers with ripper teeth can be used for initial pavement breakup. Heavy bulldozers, rollers, and compactors can break up the pavement further. Front end loaders and dump trucks, respectively, can perform the loading and hauling. A conventional crushing plant can crush the broken pavement material. Conventional equipment can also be used to rework and compact the base course and to place and compact the recycled bituminous hot-mix (REFERENCE 5\*).

The operational steps for hot-mix recycling of pavements through a central plant are shown in FIGURE 4. The major steps include preparing the pavement area to be recycled by cutting the boundaries of the pavement area, removing and crushing the pavement, processing the crushed material through a hot plant, and replacing the recycled mix. The operational steps involving the processing of the material through a hot plant are the primary topics of this section.

Two different methods are available for hot-mix recycling of AC pavement material: (1) the modified dryer drum mixer and (2) the Maplewood process\*\* used with modified conventional batch plants (REFERENCE 6\*). The modified versions of the dryer drum mixer by

\*5. Air Force Civil Engineering Center. Report AFCEC-TR-76-7: Use of Recycled Materials in Airfield Pavements Feasibility Study, by R. J. Lawing. Tyndall Air Force Base, Fla., Feb 1976.

6. Minnesota Department of Transportation. Investigation No. 646: Progress Report on Maplewood, Minnesota Recycling Project, by R. C. Ingberg. St. Paul, Minn., Nov 1976.

\*\*Maplewood Process was developed by the Minnesota Department of Transportation, Maplewood, Minn.

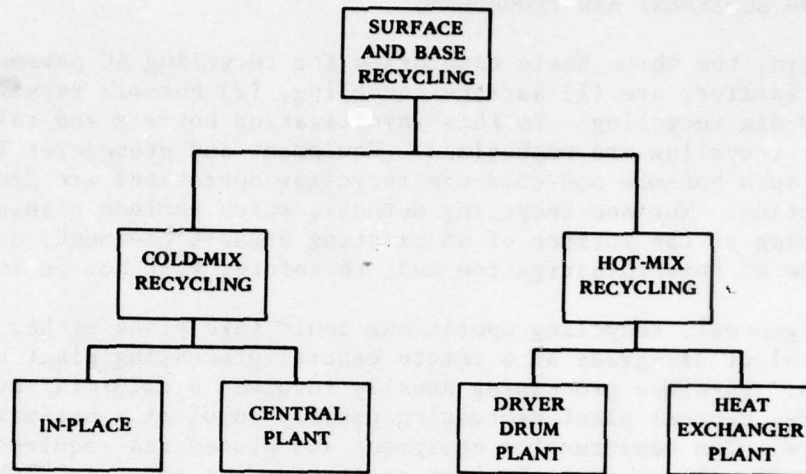


FIGURE 3. COLD-MIX AND HOT-MIX RECYCLING ALTERNATIVES.

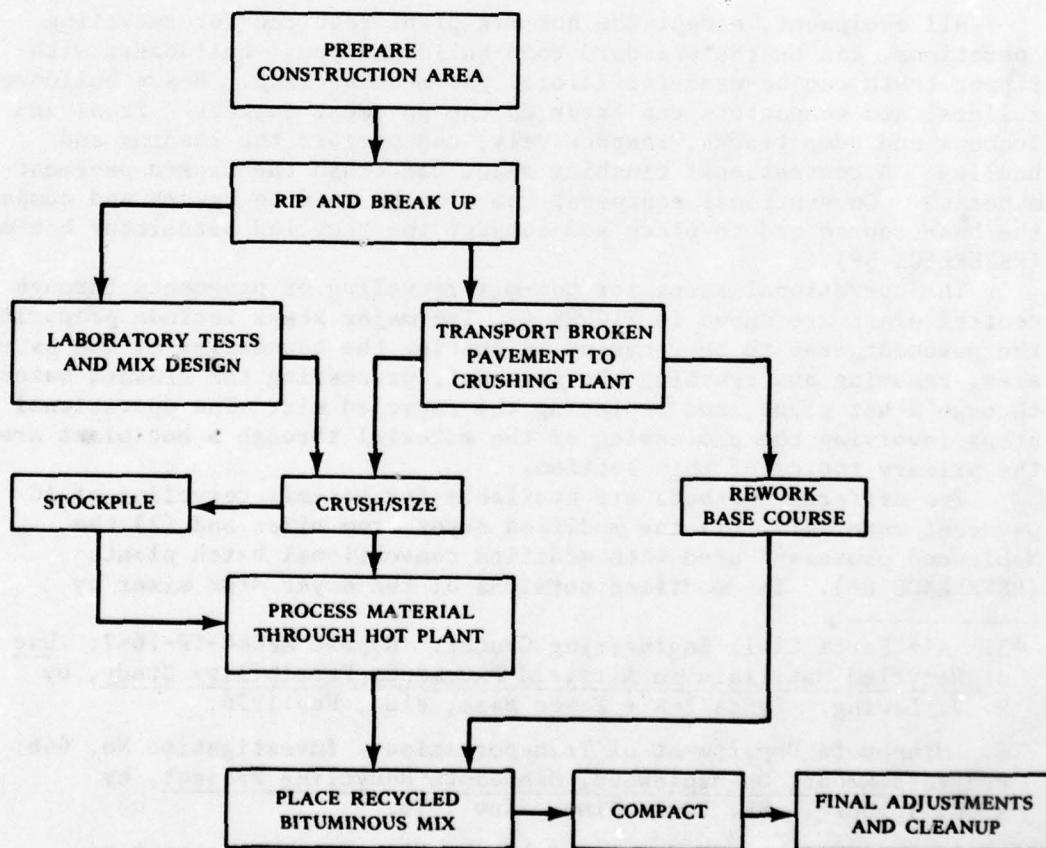


FIGURE 4. OPERATIONAL STEPS FOR HOT-MIX RECYCLING OF PAVEMENTS THROUGH A CENTRAL PLANT (AFTER REFERENCE 5).

Barber-Greene Company, Boeing Construction Equipment Company, Iowa Manufacturing Co. (Cedarapids), CMI Corporation, and RMI are examples of the first type of equipment. In the dryer drum mixing process, the pavement material being recycled is heated in the dryer drum along with additional virgin aggregate, if used, and asphalt cement, softening agent, or both added. In the Maplewood process, new aggregate amounting to at least 50% of the total mix is heated to a temperature high enough to produce an acceptable mix when combined in the pugmill with cold, crushed, recycled asphalt concrete. Additional asphalt cement is also added in the pugmill.

Since about 1970, hot-mix recycling has evolved rapidly with development of the prototype RMI Thermomatic Plant.\* This plant, and the associated recycling process covered in a patent, demonstrated the feasibility of hot-mix recycling within economic and environmental constraints (REFERENCE 7\*\*). Subsequent development of modified Boeing and Barber-Greene dryer-drum mixing plants has added impetus to hot-mix recycling. Another development of RMI Company is the split-feed, direct-fired drum mixer-type plant called the "Gemini." This plant is purported to solve problems encountered with the earlier RMI Thermomatic, such as caking of the mix on the heat exchanger tubes and low production. In the Gemini, coarse material is introduced into the mixer at the end nearest the flame, and fine portions are added farther down the mixer, resulting in less burning of asphalt binder and lowering the possibility of producing air pollutants. Other equipment manufacturers known to be developing plants for use in recycling are CMI Corporation, Standard Steel Corporation, and Iowa Manufacturing Company (manufacturer of Cedarapids plants). In FIGURE 5, a CMI plant in Oklahoma City is shown in operation.

Dryer-drum mixers produced by the Boeing Construction Equipment Company have been used on several 1977 recycling projects in Arizona, Texas, Oregon, and Utah (REFERENCE 8\*\*). At each of these projects, adjustments and changes in components were made to produce an acceptable mix while simultaneously meeting air pollution requirements. Some of the modifications included relocation of the burner, installation of a heat shield to reduce direct contact of the flame with recycled material being processed, and relocation of the asphalt injection pipe. In FIGURE 6, a modified Boeing plant in Arizona is shown in operation.

The Maplewood process requires a separate cold feed to the weigh-hopper of a conventional batch plant for the recycled material. The cold, recycled material is then mixed in the pugmill with heated virgin aggregate and additional asphalt. This system avoids pollution problems

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\*Developed by Robert Mendenhall of Las Vegas Paving Company.

\*\*7. RMI. Report: Recycling of Asphalt Concrete, by R. L. Mendenhall. Las Vegas, Nev., Jan 1977.

8. Arizona Department of Transportation. Report: Recycling of Asphaltic Concrete - Arizona's First Project, by J. A. McGee and A. J. Judd. Safford, Ariz., undated.

associated with heating of recycled materials. One problem noted at a permanent batch plant installation in Los Angeles, which had been modified to a Maplewood heat transfer process, was burning of the cloth bag filters in the dust control system. This was attributed to overheating of the virgin aggregate in the drier. Limiting temperatures to 425°-475°F in the drier solved the problem of the bags igniting.

### Cold-Mix

Cold-mix recycling of pavement and base material can be performed in-place or the material can be removed and processed at a central plant. A stabilizing agent such as asphalt, portland cement, lime, or other material may be added to the recycled material and mixed cold to form a new stabilized base course. A new wearing surface is generally required over this new stabilized base course.

Steps in Recycling. The operational sequence for cold-mix recycling is shown in FIGURE 7; the major steps include:

1. Preparing the construction area by cutting the boundaries of the area to be recycled and lowering all structures to below the depth to be pulverized.
2. Ripping or scarifying the pavement to break it into pieces no larger than 4-5 inches.
3. Pulverizing the broken pavement pieces to specifications and mixing with a predetermined amount of existing aggregate base.
4. Windrowing of pulverized mixture and reworking of subbase if required.
5. Adding of cementing agent such as lime, portland cement, or asphalt to stabilize the pulverized mixture, if desired.
6. Grading and compacting of the mixture to form a new stabilized base.
7. Applying a tack or prime coat as required and placing of a new wearing surface.
8. Adjusting the height of all structures where required and cleaning and dressing of the construction area.

Equipment Needed. All of the equipment required for cold-mix recycling of pavements, with the exception of the pulverizers, are of the standard road building type (REFERENCE 5). The following types of standard construction equipment are used for the indicated purpose:

1. Motorgraders with scarifiers or bulldozers with ripper teeth for initial breakup of the pavement.
2. Bulldozers, rollers, and compactors for further breakdown of pavement pieces as required.

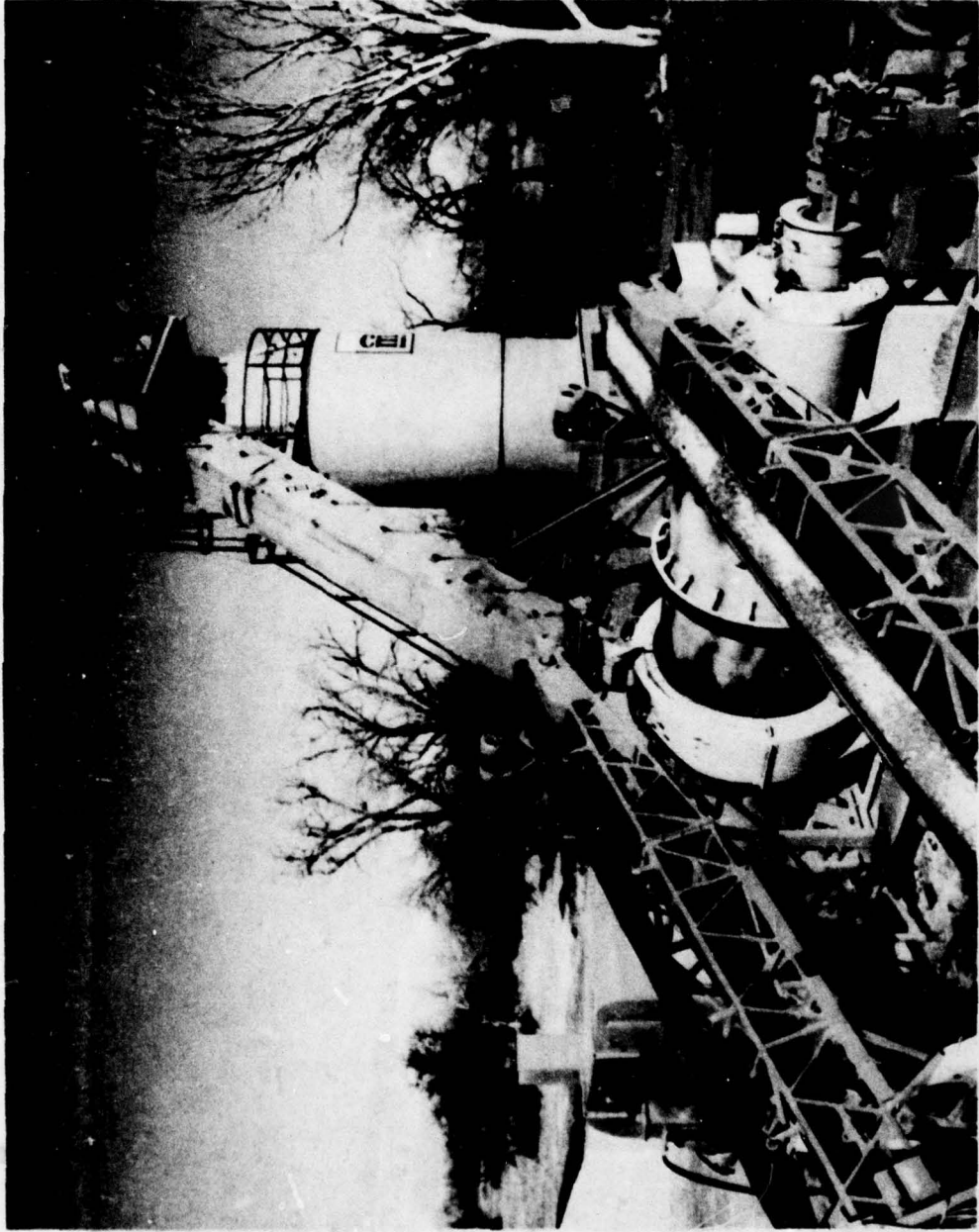


FIGURE 5. CMI DRYER-DRUM USED TO RECYCLE AC MATERIAL.

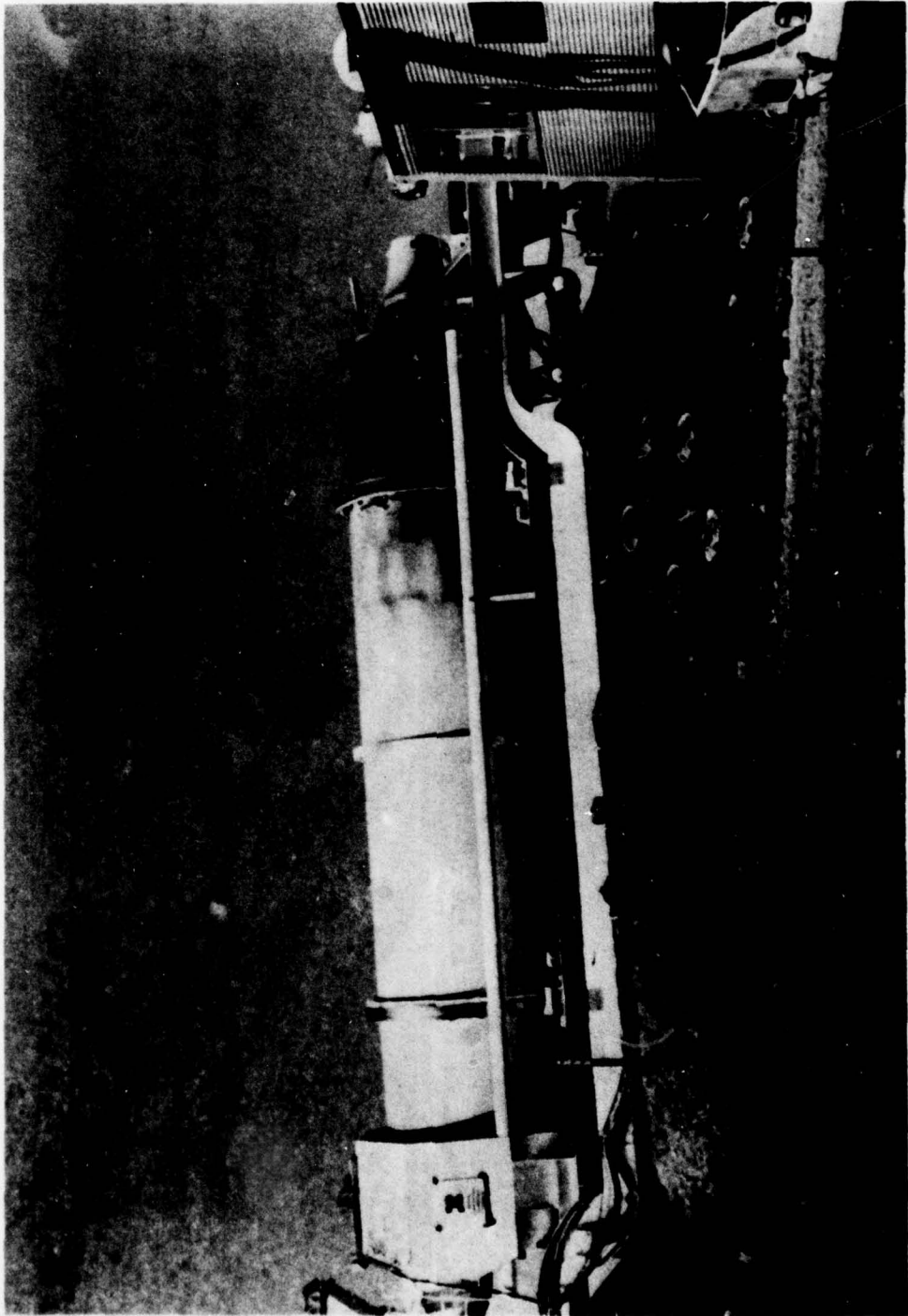


FIGURE 6. BOEING DRYER-DRUM IN OPERATION IN ARIZONA.

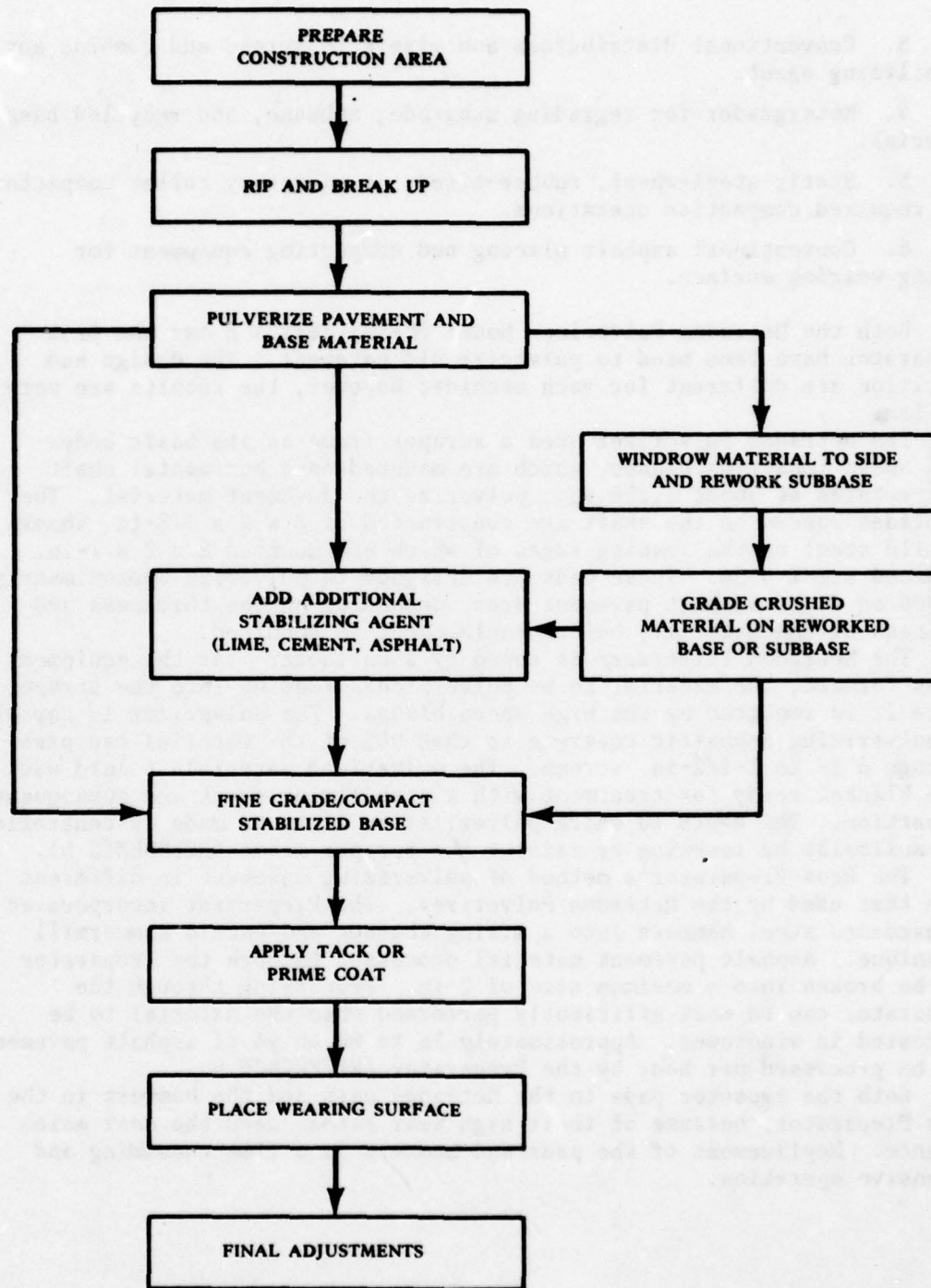


FIGURE 7. OPERATIONAL STEPS FOR COLD-MIX RECYCLING OF PAVEMENTS (FROM REFERENCE 5).

3. Conventional distributors and mixers to spread and combine any stabilizing agent.

4. Motorgrader for regrading subgrade, subbase, and recycled base material.

5. Static steel-wheel, rubber-tired, or vibratory roller compactors for required compaction operations.

6. Conventional asphalt placing and compacting equipment for laying wearing surface.

Both the Metradon Pulverizer Model PM-127 Series B and the Bros Preparator have been used to pulverize old pavement. The design and operation are different for each machine; however, the results are very similar.

The Metradon Pulverizer uses a scraper frame as its basic body. High speed impacting blades, which are mounted on a horizontal shaft that rotates at about 1,250 rpm, pulverize the pavement material. The 64 blades spaced on the shaft are constructed of 8 x 2 x 5/8-in. shanks of mild steel on the leading edges of which are mounted 2 x 2 x 1-in. hardened steel pads. These pads are designed to pulverize approximately 40,000 sq ft of asphalt pavement area, depending on the thickness and hardness of the material, before replacement is required.

The Metradon Pulverizer is towed by a bulldozer. As the equipment moves forward, the material to be pulverized slides up into the scraper where it is impacted by the high speed blades. The pulverizer is capable of pulverizing asphaltic concrete so that 90% of the material can pass through a 1- to 1-1/2-in. screen. The pulverized material is laid back in a blanket ready for treatment with a stabilizing agent and subsequent compaction. The depth to which pulverization is to be made is controlled hydraulically by lowering or raising the scraper frame (REFERENCE 5).

The Bros Preparator's method of pulverizing pavement is different than that used by the Metradon Pulverizer. The Preparator incorporates 22 hardened steel hammers into a mixing chamber and uses a hammermill technique. Asphalt pavement material processed through the Preparator can be broken into a maximum size of 2 in. Processing through the Preparator can be most efficiently performed when the material to be processed is windrowed. Approximately 25 to 60 cu yd of asphalt pavement can be processed per hour by the Preparator (REFERENCE 5).

Both the impactor pads in the Metradon unit and the hammers in the Bros Preparator, because of their high wear rates, need the most maintenance. Replacement of the pads and hammers is a time-consuming and expensive operation.

## RECYCLING TEST SAMPLES

### Description

To provide materials for use in the laboratory testing phase of this investigation, samples of airfield and airport AC pavements were obtained from five sources. The samples selected represented the types of aged pavements that would be likely recycling candidates in the future. Such samples provided a realistic basis for mix designs, choice of softening agents, solving of crushing problems, and blending of aggregates. Approximately 1,000 lb of asphalt concrete were obtained from each of the following: Marine Corps Air Station, El Toro, Calif.; Naval Air Station, Fallon, Nev.; Naval Air Station, Whiting Field, Fla.; McCarran International Airport, Las Vegas, Nev.; and Los Angeles International Airport (LAX), Calif. At El Toro, Fallon, and Whiting Field, approximately 500 lb of the underlying base course were also obtained for testing. The pavement samples were from 9 to 34 yr old and were all constructed as airfield or airport pavements. Each pavement section sampled is described in TABLE 1.

### Properties

After the samples were received at the Civil Engineering Laboratory (CEL), tests were conducted on representative portions of each sample to determine asphalt content and aggregate gradation. The extracted asphalt binder was then tested to determine the physical properties of penetration, ductility, absolute viscosity, and kinematic viscosity. The results of these tests, along with the determined asphalt contents, are presented in TABLE 2.

The remainder of each of the 1,000 lb of asphalt concrete samples was crushed to less than 1-in. particle size in a portable rock-crushing plant. The plant consisted of a Cedarapids 24- by 36-in. jaw crusher and a Cedarapids 18- by 36-in. roll crusher. No problems were encountered with any of the materials during the crushing operations. Concern had been expressed that screens would become clogged, but no evidence of clogging was noted with any of the materials processed.

The resulting crushed asphalt concrete and sand asphalt were then subjected to gradation analyses. To assess the possibility of using this crushed material without further treatment as base or subbase courses, the gradations were compared with Federal Aviation Administration (FAA) and Navy base course specification limits (REFERENCES 9,10\*) in FIGURES 8 through 12.

\*9. Federal Aviation Administration. Advisory Circular No. 150/5370-10: Standards for Specifying Construction of Airports. Washington, D.C., Oct 1974.

10. Naval Facilities Engineering Command. NAVFAC DM-21: Design Manual - Airfield Pavements. Alexandria, Va., Jun 1973.

TABLE 1. DESCRIPTION OF RECYCLING SAMPLES

Geographic Location	Facility	Description
Marine Corps Air Station El Toro, California	Runway 16L-34R	Asphalt concrete overlay on portland cement concrete constructed in 1951. Nominal 4-in. thickness. Slurry-sealed in 1957, 1961, and 1966.
Naval Air Station Fallon, Nevada	Abandoned Runway 13-31	Nominal 2 in. asphalt concrete constructed in 1943-44. No other data available.
McCarran International Airport, Las Vegas, Nevada	Abandoned Taxiway A	Nominal 5-in. thickness: a 2-in. overlay placed in 1968 as part of a heater scarification job over an original 3-in.-thick pavement placed in 1958.
Los Angeles International Airport, Los Angeles, California	Sample came from a stockpile of removed pavement material stored at Los Angeles (LAX)	Nominal 4-in. thickness believed by LAX maintenance personnel to be at least 15 years old.
Naval Air Station, Whiting Field, Florida	North Field, abandoned Runway 9-27	Mixed-in-place sand asphalt made with RC-1 in 1943, nominal 6-in. thickness. Overlaid in 1945 with 1 in. of hot-mix sand asphalt leveling course and 2 in. of asphalt concrete surface course. Seal-coated in 1946, 1953, and 1958.

TABLE 2. PROPERTIES OF RECOVERED BITUMEN

Sample Origin	Asphalt Content (%)	Penetration (dmm at 77°F)	Ductility (cm at 77°F)	Absolute Viscosity (poises at 140°F)	Kinematic Viscosity (centistokes at 275°F)
El Toro	5.3	7	0	454,900	6,300
Fallon	5.1	3	0	a	-
Las Vegas	4.5	20	-	28,000	-
Los Angeles (LAX)	5.1	19	0	24,300	-
Whiting	5.8	2	0	a	-

<sup>a</sup>Viscosity too high for equipment.

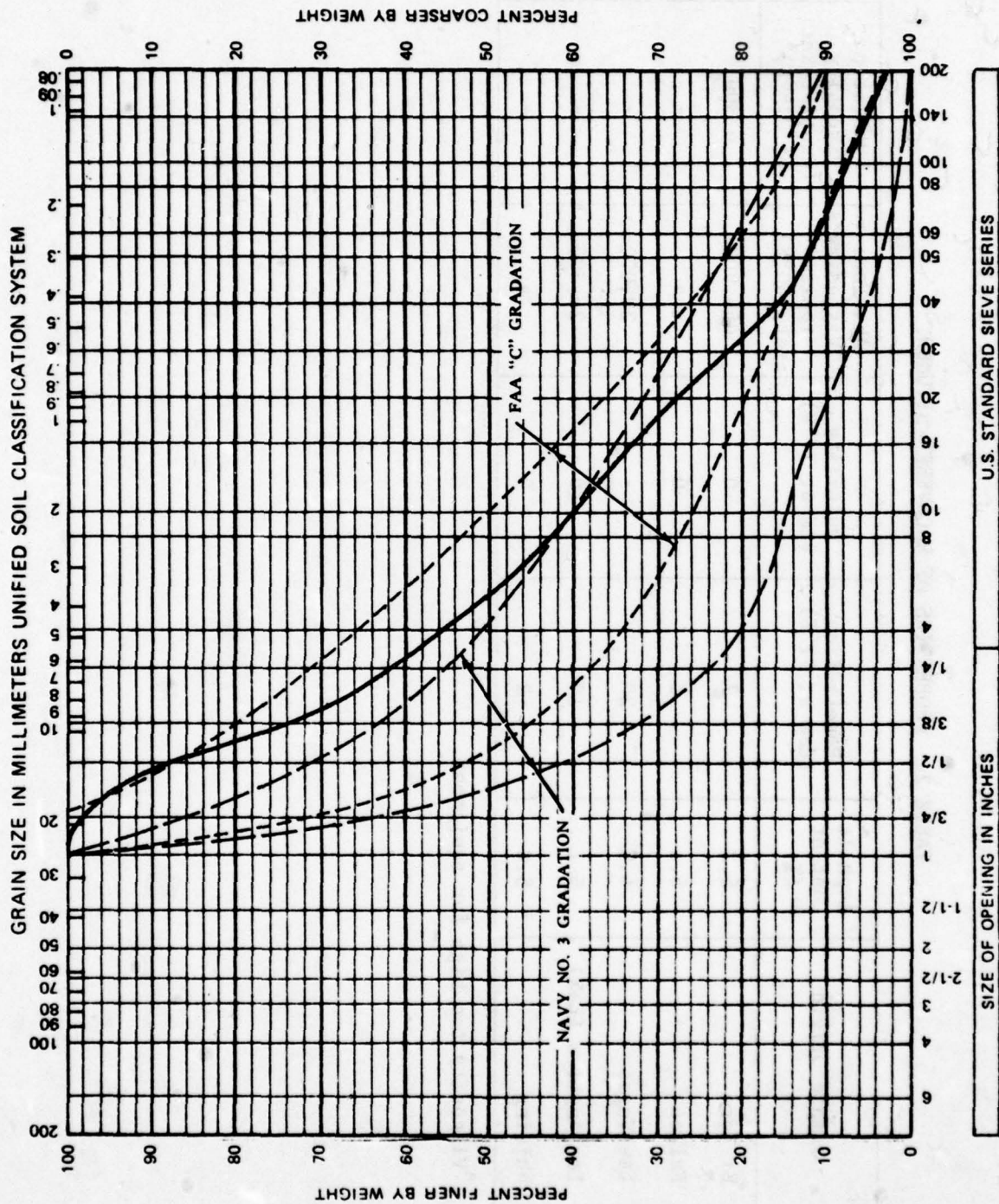


FIGURE 8. COMPARISON OF EL TORO CRUSHED MATERIAL WITH FAA P209 AND NAVY BASE COURSE SPECIFICATIONS.



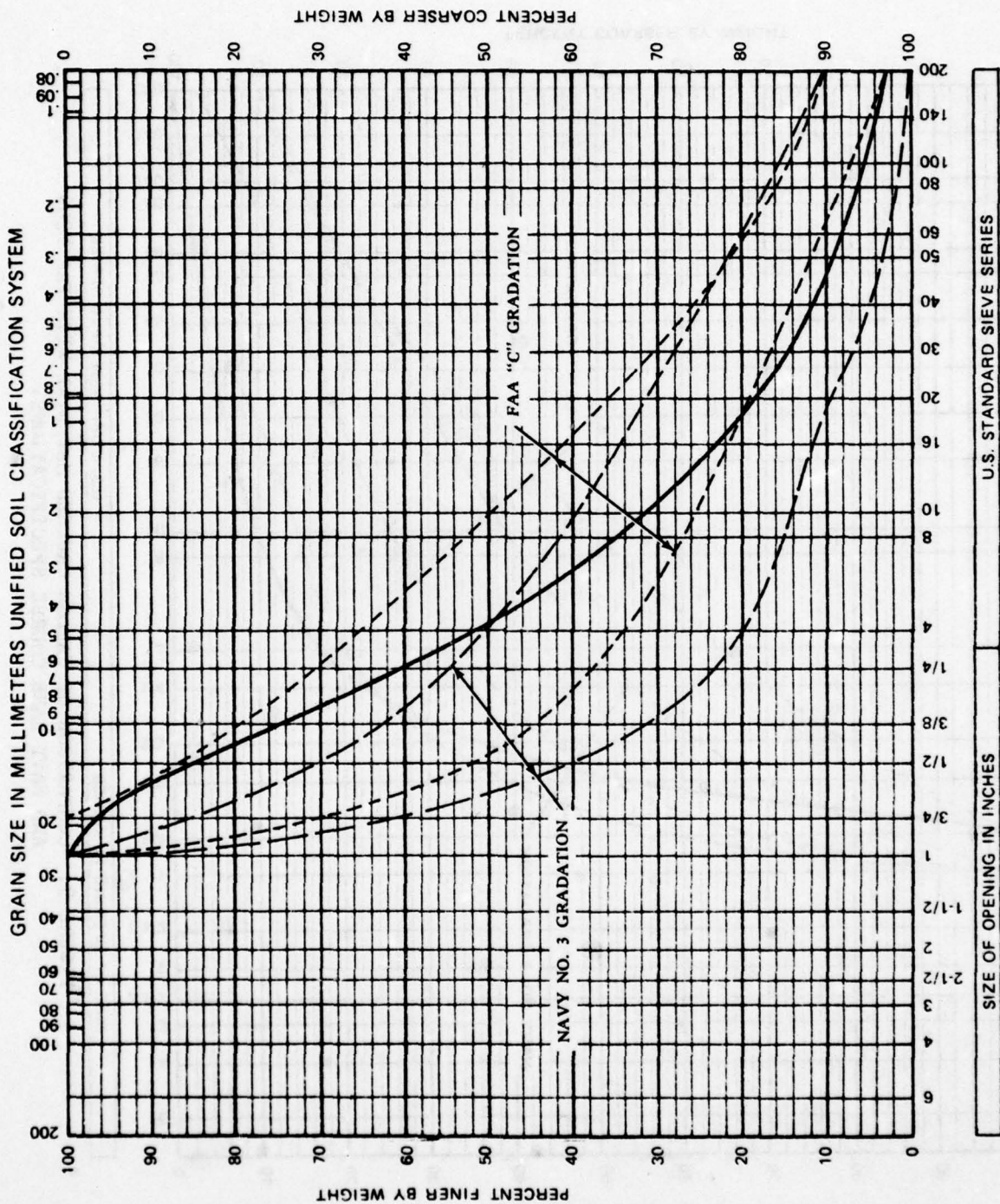


FIGURE 10. COMPARISON OF LAS VEGAS CRUSHED MATERIAL WITH FAA P209 AND NAVY BASE COURSE SPECIFICATIONS.

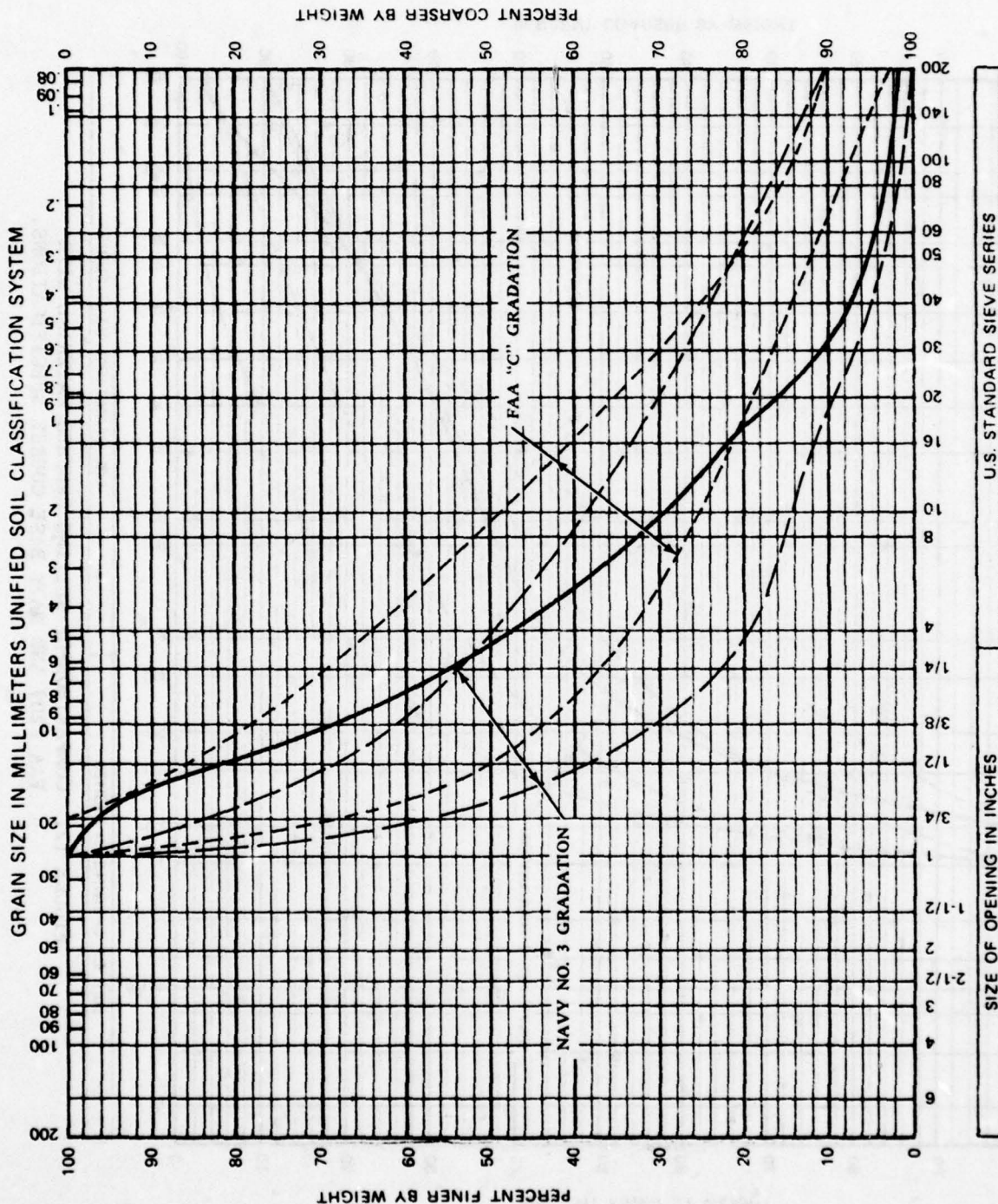


FIGURE 11. COMPARISON OF LOS ANGELES (LAX) CRUSHED MATERIAL WITH FAA P209 AND NAVY BASE COURSE SPECIFICATIONS.

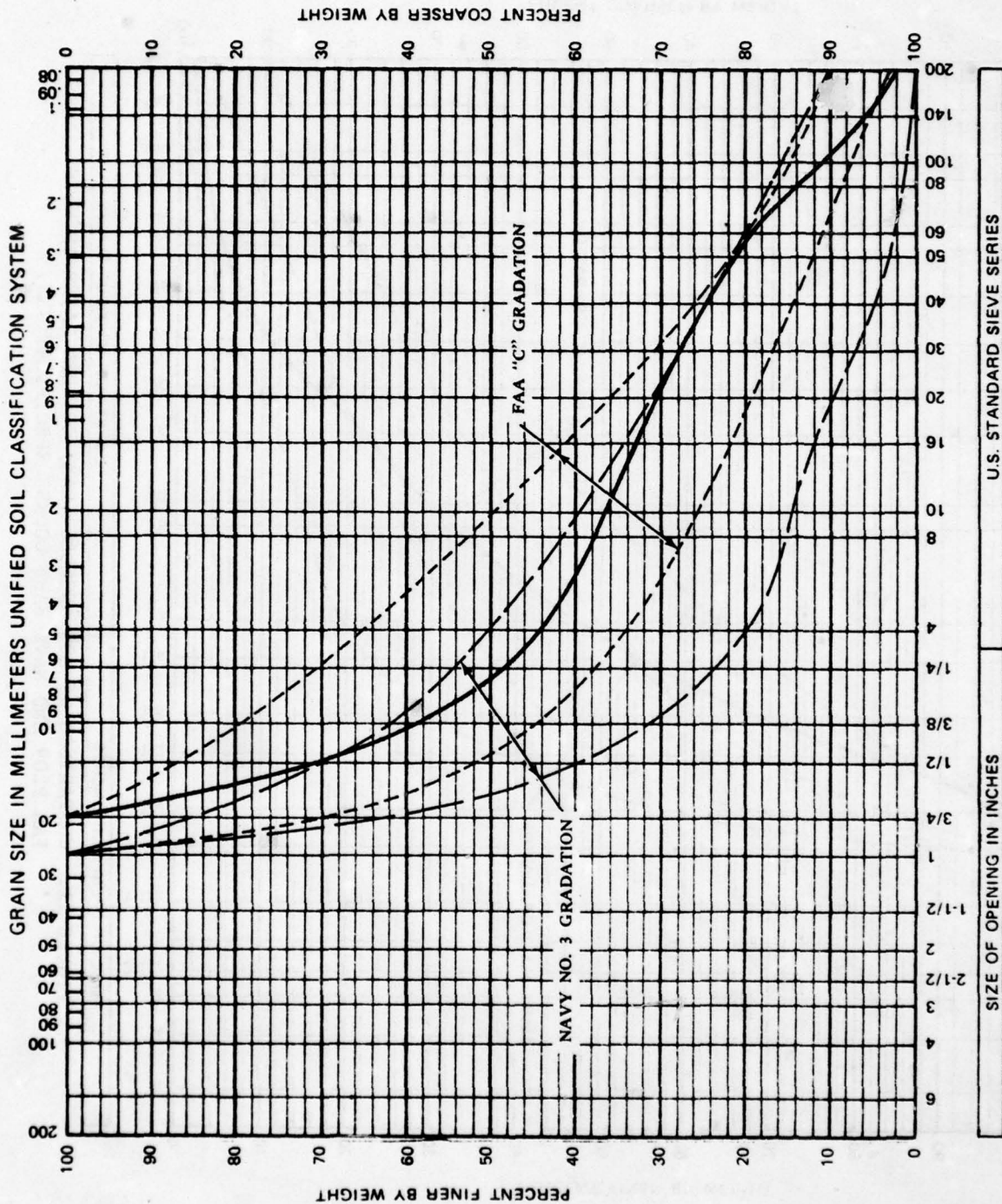
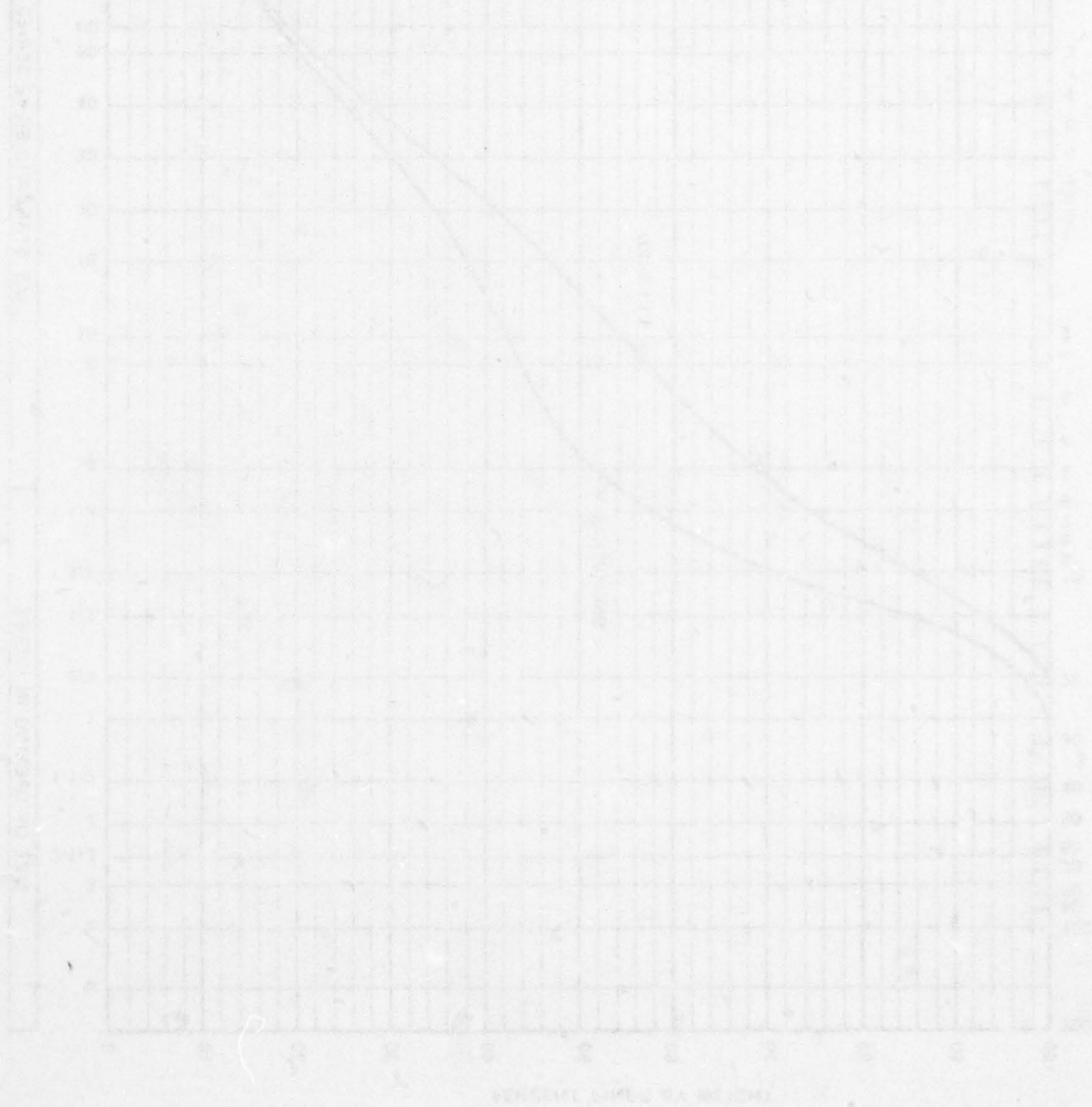
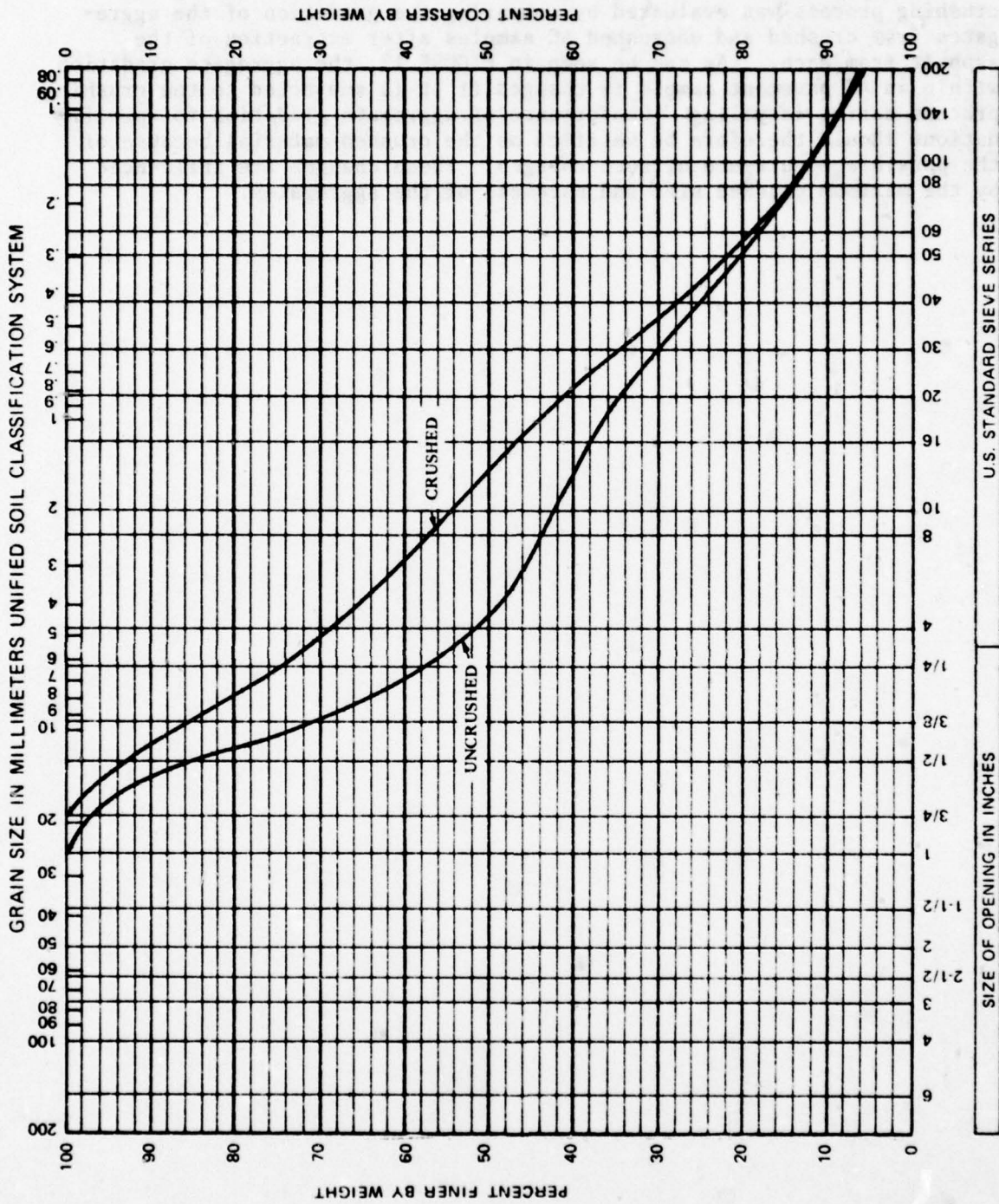


FIGURE 12. COMPARISON OF WHITING CRUSHED MATERIAL WITH FAA P209 AND NAVY BASE COURSE SPECIFICATIONS.

The possibility of the aggregate gradation being changed by the crushing process was evaluated by comparing the gradation of the aggregates from crushed and uncrushed AC samples after extraction of the asphalt from each. As can be seen in FIGURE 13, the aggregate gradation within an AC pavement sample is changed if it is subjected to the crushing process during recycling. Conformance of aggregate gradation to specifications should therefore be verified on the crushed material because of the possible occurrence of such changes. These changes are influenced by the maximum crushed size and hardness of the aggregates.





## SOFTENING AGENTS

The concept of restoring an asphalt binder to a new condition by addition of softening agents is not new. A chemical approach to rejuvenation has been investigated by Rostler (REFERENCES 11 and 12\*), and considerable field experience has been gained by many agencies using the proprietary products developed from Rostler's work (REFERENCES 11,12,13\*). Recent recycling efforts in highway construction have used flux oils, usually similar to extender oil 101, as defined by ASTM D2226-70. In most cases, additional asphalt is added to satisfy mix design requirements. Any softening agent or combination of softening agent and asphalt used must satisfy design parameters of (1) changing the aged asphalt characteristics to obtain a consistency (viscosity or penetration) appropriate to the mix design, (2) restoring asphalt durability, and (3) bringing the total asphalt content of the mix to the optimum quantity as determined by the mix design procedure used.

### Description

The softening agents used in this investigation fall into four general categories: (1) aromatic extender oils, (2) soft grades of asphalt, (3) liquid asphalt, and (4) other materials such as coal tar derivatives, including proprietary materials. The sources of softening agents are given in TABLE 3 and their properties are described in TABLE 4. No attempt was made to use specially compounded materials of unique qualities. All of the softening agents used are available on the open market.

### Test Procedure

The softening agents were evaluated by blending them with recovered asphalt cement from the five airports sampled. The blend was tested for penetration according to ASTM D5, and for absolute viscosity at 140°F (60°C) according to ASTM D2171. All softening agents were tested with the El Toro residual asphalt; however, only Paxole 1007 and softer asphalts were tested with the residual asphalt from the samples from the other four facilities. After testing of the blended materials, the

\*11. F. S. Rostler. "A Chemical Approach to the Problem of Maintenance of Asphaltic Pavements," paper presented at the Third World Wide United States Air Force Pavements Conference, Berkeley, Calif., 27-31 Jul 1959. Bakersfield, Calif., Golden Bear Oil Co.

12. Air Force Weapons Laboratory. Technical Report AFWL-TR-70-83: Rejuvenation of Asphalt Pavements, by F. S. Rostler and R. M. White. Kirtland Air Force Base, N.M., Dec 1970.

13. Air Force Civil Engineering Center. Report AFCEC-TR-76-3: Evaluation of Rejuvenators for Bituminous Pavements, by E. R. Brown and R. R. Johnson. Tyndall Air Force Base, Fla., Feb 1976.

samples were artificially aged by a 5-hr exposure in the thin-film oven at 325°F (163°C). The aging procedure is that described in ASTM D1754. The aged residue was again tested for penetration and viscosity. The results of these tests are given in TABLE 5.

TABLE 3. SOURCES OF SOFTENING AGENTS

Name	Description	Source
Paxole 1007	Sold specifically as a softener	Pax International Spokane, Wash.
AR-1000	Standard asphalt cement grade	Edgington Oil Co. Long Beach, Calif.
AR-2000	Standard asphalt cement grade	Edgington Oil Co. Long Beach, Calif.
SC-3000	Standard slow cure liquid asphalt	Edgington Oil Co. Long Beach, Calif.
Lube Stock	Lubricating oil base stock	Edgington Oil Co. Long Beach, Calif.
Sundex 840T	Low viscosity aromatic extender oil	Sun Oil Company Tulsa, Okla.
Sundex 790T	Medium viscosity aromatic extender oil	Sun Oil Company Tulsa, Okla.
Koppers BPR	Coal-tar based pavement rejuvenator	Emulsified Asphalts Inc. Fontana, Calif.
Dutrex 739	Medium viscosity aromatic extender oil	Shell Oil Co. Los Angeles, Calif.
Califlux GP	Medium viscosity aromatic extender oil	Golden Bear Oil Co. Bakersfield, Calif.
Reclamite	Emulsified pavement rejuvenator	Golden Bear Oil Co. Bakersfield, Calif.

TABLE 4. PROPERTIES OF SOFTENING AGENTS

Name	Physical Data		Chemical Data							$\frac{N}{P}$	$\frac{N + A_1}{P + A_2}$
	Flash Point COC (°F)	Viscosity (centistokes, 140°F)	Molecular Analysis (%) <sup>a</sup>					Paraffins (P)			
			Asphaltenes (A)	Nitrogen Bases (N)	First Acidaffins (A <sub>1</sub> )	Second Acidaffins (A <sub>2</sub> )					
Paxole 1007	425	172	0.7	20.4	16.8	48.3	13.8	1.5	0.60		
AR-1000	510 <sup>b</sup>	58,000	12.8	40.4	13.8	20.6	12.4	3.3	1.64		
AR-2000	510 <sup>b</sup>		14.1	39.9	14.1	19.5	12.4	3.22	1.69		
Lube Stock	418	80	0.4	14.6	16.5	35.3	33.3	0.4	0.45		
SC-3000	365	3,296	15.0	35.8	14.3	20.1	14.8	2.4	1.44		
Dutrex 739	425	187	1.3	25.5	19.8	46.1	7.3	3.5	0.85		
Sundex 840T	345	12	1.5	7.4	12.3	63.7	15.1	0.5	0.25		
Sundex 790T	445	96	0.5	8.8	13.0	55.2	22.5	0.4	0.28		
Califlux GP	415	159	0.0	17.0	20.0	51.0	12.0	1.4	0.59		

<sup>a</sup> Koppers EPR not analyzed.

<sup>b</sup> Pensky-Martin closed test.

TABLE 5. EFFECTS OF SOFTENERS ON RESIDUAL ASPHALTS

Softener	Quantity of Softener <sup>a</sup> (%)	Before Thin Film Oven Test		After Thin Film Oven Test	
		Penetration (dmm)	Absolute Viscosity (poises at 140°F)	Penetration (dmm)	Absolute Viscosity (poises at 140°F)
El Toro					
None	0	7	454,941	4	1.54x10 <sup>6</sup>
Paxole 1007	15	27	22,545	-	-
Paxole 1007	30	118	1,061	60	2,478
AR-1000	50	36	8,761	15	17,634
AR-2000	50	32	12,313	20	15,180
Lube Stock	30	136	926	77	3,767
SUNDEX 840T	30	400+	128	212	574
SUNDEX 790T	30	174	785	92	2,352
Koppers BPR	10	25	12,324	10	418,446
Koppers BPR	20	212	888	11	63,573
SC-3000	50	142	791	36	5,195
DUTREX 739	30	123	988	54	2,898
CALIFLUX GP	30	122	990	59	2,588
Reclamite	30	110	-	-	-
Fallon					
None	0	3	b	-	-
Paxole 1007	30	67	5,308	31	19,419
Paxole 1007	40	146	1,225	-	-
Las Vegas					
None	0	20	27,972	-	-
Paxole 1007	10	38	4,039	-	-
Paxole 1007	20	98	950	-	-

continued

TABLE 5. CONTINUED

Softener	Quantity of Softener <sup>a</sup> (%)	Before Thin Film Oven Test		After Thin Film Oven Test	
		Penetration (dmm)	Absolute Viscosity (poises at 140°F)	Penetration (dmm)	Absolute Viscosity (poises at 140°F)
Las Vegas (continued)					
AR-1000	25	27	8,740	18	20,465
AR-1000	50	47	2,631	37	5,118
AR-2000	30	27	7,916	-	-
AR-2000	50	35	4,188	27	7,360
AR-2000	70	60	1,644	-	-
AR-4000	50	32	6,104	-	-
Los Angeles (LAX)					
None	0	19	24,330	-	-
Paxole 1007	10	32	5,459	-	-
Paxole 1007	20	90	1,174	-	-
Whiting					
None	0	2	b	-	-
Paxole 1007	20	10	673,602	-	-
Paxole 1007	30	35	40,130	-	-
Paxole 1007	40	92	1,087	-	-
AR-1000	40	8	1.01x10 <sup>6</sup>	-	-
AR-1000	60	18	24,800	-	-

<sup>a</sup> Percentage Softener =  $\frac{\text{wt. of softener}}{\text{wt. of softener} + \text{wt. of residual asphalt}} \times 100$

<sup>b</sup> Viscosity was too high to measure with available equipment.

## Analysis of Results

An approximately linear relationship between the log of viscosity or penetration and the amount of softening agent in an asphalt/softener mixture was found to exist by other investigators (REFERENCE 14\*). To verify the applicability of such a relationship for the asphalt/softener mixtures used in this investigation, a limited number of tests were performed with four of the softening agents. It was verified that a linear relationship does exist for mixtures made with these softening agents, which included Paxole 1007, Koppers BPR, AR-1000, and AR-2000. Because the existence of a linear relationship was confirmed by these tests, the remaining softening agents were blended in one concentration, usually 30% for extender oils and 50% for asphalt cements, and a straight-line relationship between the log of viscosity or penetration was assumed. The results of all of these tests are shown graphically in APPENDIX A. These relationships are considered valid for only the range of softener/residual asphalt blends made. When over 50% softener is used, a linear relationship no longer exists (REFERENCE 15\*). Thus, for such higher concentrations of softeners, more detailed testing will be required.

The softening effect of the agents can be measured by the slope of the viscosity versus percentage of softener plot. Based on this rationale, Koppers BPR softens with the lowest percentage of softener, and AR-2000 asphalt, as expected, requires the highest percentage. It can also be seen that a softener will have different effects on asphalts of different origin and viscosity or penetration. This points out the necessity for in-depth laboratory testing of a proposed softener with recovered asphalt from the pavement to be recycled.

The susceptibility of the asphalt-softener blends to harden in hot pugmill or drum mixers was evaluated by use of the Thin Film Oven Test (TFOT). The extender-oil-softened asphalts generally performed as well as new asphalt cements in this artificial aging process. This is also true of the blends with softer grades of asphalt. These results are shown in TABLE 5. The Koppers BPR and SC-3000 liquid asphalt showed a greater gain in viscosity and loss of penetration in the TFOT. This result is believed to reflect the lower boiling point of these materials, compared to extender oils or asphalts. For example, Koppers BPR has an initial boiling point (IBP) of 356°F (180°C) and a flash point of 200°F (93°C); a typical extender oil, Dutrex 739, has an IBP of 740°F (393°C) and a flash point of 425°F (218°C). Ratios of viscosities after the TFOT to before TFOT ranged from a low of 1.23 for an El Toro sample softened with AR-2000 to 71.6 for an El Toro sample softened with Koppers

\*14. Arizona Department of Transportation Office Memo of 3 May 1977 from J. A. Faulkner to W. J. Tolonen, Subj: Asphalt Recycling.

15. D. D. Davidson, W. Canessa, and S. J. Escobar. "Recycling of Substandard or Deteriorated Asphalt Pavements - A Guideline for Design Procedures," preprint of paper presented at the Annual Meeting of the Association of Asphalt Paving Technologists, San Antonio, Tex., 21-23 Feb 1977. Oildale, Calif., Witco Chemical Corp.

BPR. The acceptable maximum increase in viscosity after the TFOT of viscosity-graded asphalt cements is five times the original viscosity (ASTM D3381). Only the blends made with Koppers BPR and SC3000 exceed this limit. The other mixtures, because of falling within the limit, may perform as well as new asphalts during pugmill or drum mixer operations. Similar findings were obtained from the penetration test results.

Another parameter which has been suggested by Rostler and others to be an indicator of durability is the chemical reactivity ratio (CRR) (REFERENCES 16,17\*). CRR of the asphalt fractions, as defined by Rostler, is:

$$\text{CRR} = \frac{N + A_1}{A_2 + P}$$

where N = nitrogen bases, %  
A<sub>1</sub> = first acidifins, %  
A<sub>2</sub> = second acidifins, %  
P = paraffins, %

These asphalt fractions are determined by performing a Rostler-Sternberg analysis, as given in ASTM D2006. The results of component analyses of most of the softeners used in this study are shown in TABLE 4. The Rostler-Sternberg analysis can only be performed on a noncracked petroleum oil having an initial boiling point above 536°F (280°C); therefore Koppers BPR, a coal-tar derivative, could not be analyzed. The SC-3000 may contain some cracked petroleum, so the results for that sample may be in error and should be considered for information only.

In REFERENCE 15 it is suggested that softening agents should have a CRR of 0.4 to 1.0 and nitrogen bases (N) to paraffin bases (P) ratio (N/P) of greater than 1.0. It is assumed that these parameters would apply only to extender oil types of softeners since many asphalt cements such as those used in this investigation do not meet these criteria. Of the softening agents tested, only Paxole 1007, Dutrex 739, and Califlux GP meet these criteria. Not coincidentally, these three materials, along with softer grades of asphalt cement, have been the most frequently used softening agents. These parameters of the softening agent are not the total answer to specifying a softening agent. Consideration should

\*16. Transportation Research Board. Transportation Research Record 595: Asphalts, Aggregates, Mixes, and Stress-Absorbing Membranes. Washington, D.C., 1976.

17. Bureau of Public Roads. Changes in Fundamental Properties of Asphalts During Service in Pavements, by B. A. Vallerga, R. M. White, and K. S. Rostler. Washington, D.C., Materials Research and Development, Inc., Jan 1970. (Contract No. FH-11-6147)

also be given to the effect of the softener on the compositional parameters of the residual asphalt. The significance of this consideration was amplified by tests performed on El Toro residual asphalt combined with Paxole 1007.

A sample of El Toro residual asphalt was softened with 27% Paxole 1007 by weight of the blended mixture to achieve a viscosity similar to AC-10 and penetration of 85 to 100. As shown in TABLE 6, the addition of the Paxole decreased the percentage of asphaltenes and increased the percentage of second acidifins, as expected, since Paxole is composed of 48.3% second acidifins. This property causes a dramatic change in the CRR. REFERENCE 17 has shown that a correlation exists between hardening of asphalts in the field and CRR at a constant void content. The investigation of REFERENCE 17 suggests that optimal CRR values are within the range of 1.00 and 1.40. The softened El Toro asphalt has a CRR of 1.08 and thus is within this optimum range. Even after aging for 5 hr in the TFOT, the compositional parameters of softened El Toro asphalt are changed only slightly, resulting in little effect on the CRR (1.09) which is still within the optimum range. This compares favorably with a new AC-10 or AR-2000 asphalt.

It should be noted that the thin film oven test, as a measure of durability, does not consider the effect of sunlight, possible catalytic reaction of aggregates, and effects of traffic on the properties of the asphalt cement. It is, however, felt to be an effective screening tool for eliminating obviously unsuitable softening agents.

#### Methods for Determination of Quantity Needed

The amount of softening agent required can be determined by either the viscosity or penetration methods, depending on which specification is used locally in specifying asphalt cements. In either method, the grade (viscosity or penetration) of asphalt normally used in the local area for such intended construction projects must be identified. Tests of viscosity or penetration of the recovered residual asphalt and softening agent blends are then made at various percentages of softener contents. The data obtained from these tests are then used to develop plots similar to those in APPENDIX A or equations by established regression analysis techniques. The amount of softening agent required is determined from either the viscosity or penetration plot or equation by using the data on the identified grade of asphalt used locally. An example illustrating the complete procedure for determining the required amount of softening agent is presented in APPENDIX B.

TABLE 6. EFFECT OF 27% PAXOLE 1007 ON COMPOSITION OF RECOVERED EL TORO ASPHALT

Description	Recovered Asphalt			AR-2000	Aged AR-2000 <sup>a</sup>
	Aged	Softened	Softened Then Aged <sup>a</sup>		
<b>Composition (%)</b>					
Fraction A (asphaltenes)	41.5	28.9	30.2	14.1	16.4
Fraction N (nitrogen bases)	29.2	28.0	27.1	39.9	38.7
Fraction A <sub>1</sub> (first acidafins)	7.0	9.0	9.3	14.1	13.2
Fraction A <sub>2</sub> (second acidafins)	12.5	22.8	22.2	19.5	19.3
Fraction P (paraffins)	9.8	11.3	11.2	12.4	12.4
N/P	2.98	2.48	2.42	3.22	3.12
Chemical Reactivity Ratio (CRR)	1.62	1.08	1.09	1.69	1.62

<sup>a</sup> Aged 5 hr in thin film oven at 325°F.

## HOT-MIX DESIGN AND MARSHALL STABILITY TESTS

The objectives for performing the Marshall mix design procedure on the asphalt concrete (AC) samples collected from the various airports were to:

- (a) Determine that aged AC pavement material can be successfully recycled into acceptable mixes that meet specifications for new airport pavements.
- (b) Establish and develop procedures for performing mix designs for the recycling of AC pavement material based on the Marshall method.
- (c) Determine in general the effect of and quantities required of various softening agents intended for use in recycling AC pavements.

The Marshall method of mix design as standardized in ASTM D1559 (Resistance to Plastic Flow of Bituminous Mixtures Using Marshall Apparatus) was used for preparing trial recycled hot-mixes. This is one of the more generally accepted methods for preparing hot-mix designs using virgin aggregates and asphalts for airport pavements. During conduct of the Marshall procedure for each mix design batch with the recycle material, additional steps were required to determine the quantity of softening agent to be used and to adjust aggregate gradations to meet specifications wherever necessary. The procedure for determining the amount of softening agent required in a particular mix is described in APPENDIX B. The procedure used for blending two or more aggregates to modify gradations to meet specifications is described in MS-2 of the Asphalt Institute.

The softening agents used in the Marshall method for mix design included Paxole 1007 softener and standard asphalt cement grades AR-1000, AR-2000, and AR-4000. There were no particular reasons for selecting Paxole 1007 as the softening agent for use in the Marshall tests. In general, any of the other softeners mentioned in an earlier section of this report could have been used satisfactorily in preparing the Marshall test samples. Paxole 1007 was selected simply for convenience in limiting the number of variables in the tests.

The results of the Marshall tests on specimens prepared with the material from the various airports are summarized in TABLE 7. The plots of Marshall stability, flow, unit weight, percentage of air voids, and percentage of voids filled with bitumen from which the summary data in this table were obtained are presented in APPENDIX C. Shown in TABLE 7 for each design are the initial residual bitumen content of the material being recycled; the composition of each specimen; the softening agents used; and the values for stability, flow, percentage of air voids, percentage of voids filled with bitumen, and unit weight at the average optimum bitumen content for each mix design.

For a mix by the Marshall method of mix design to be acceptable as a surface course for heavy airport pavement traffic loadings, it must meet all of the following criteria:

Stability	1,800 lb, minimum
Flow	8 to 16 (units of 0.01 in.)
Air Voids	3% to 5%
Voids Filled with Bitumen	70% to 80%

These criteria are the same for both FAA and Navy applications (REFERENCES 9,10).

If the above criteria are compared to the values obtained at the average optimum bitumen content for each mix design shown in TABLE 7, it can generally be concluded that (with the exception of material from Whiting Field\*) aged airport AC pavement material can be successfully recycled into acceptable mixes for bituminous surface courses. Some of the mixes shown in TABLE 7 are marginal in meeting the criteria for voids filled with bitumen, which should be in the range of 70% to 80%. Six mixes exceed the 80% maximum value by 1% to 2%. If required in an actual job, these mixes could be modified by using adjustment methods such as that described in MS-2 of the Asphalt Institute so that all of the criteria are met for each mix. Specific discussions on the preparation and results of each mix using materials from the various airports are presented below.

#### El Toro

The first mixture attempted was with the El Toro sample. A design asphalt cement grade of 85 to 100 penetration and a viscosity of 2,000 poises at 140°F was selected. Using the viscosity/penetration versus percentage of Paxole 1007 relationship previously developed, 27% of Paxole 1007 by weight of the asphalt/softener blend was selected. This blend was expected to yield a penetration of 87 and a viscosity of 2,000 poises.

The first series of tests was performed on crushed El Toro material with Paxole 1007 and AR-2000 asphalt. No additional aggregate was used. As shown in FIGURE C-1, the stability versus asphalt content curve indicates a higher than optimum asphalt content with just Paxole 1007 added. Addition of AR-2000 made this more obvious as stability and air voids dropped further. A sample was molded using only 13% Paxole, which produced stability, air void, and voids filled within specification; however, it is believed that this mix would be extremely difficult to compact in the field due to resulting high asphalt viscosity of approximately 33,000 poises at 140°F. This mix would also have very poor fatigue life and low durability. This first series of tests demonstrated that an asphalt concrete, even though aged, probably contains something approaching the optimum asphalt content; thus, the addition of a softening agent in sufficient quantity to achieve workability and durability will raise the total asphalt content above a desirable level. The most reasonable approach to correct this problem is to add suitable aggregate to the mix to balance the additional asphalt binder.

\*The material from Whiting Field can be recycled into acceptable mixes for bituminous base courses.

TABLE 7. SUMMARY OF MARSHALL STABILITY TEST AND DENSITY-VOIDS ANALYSIS RESULTS ON HOT-MIX SAMPLES

Sample Identification <sup>a</sup>	Residual Bitumen Content (%)	Crushed Recycle Sample Amount (%)	New Aggregate Amount and Size (%), (in.)	Softening Agent (%), V <sup>b</sup>	Marshall Stability (lb)	Flow (0.01 in.)	Air Voids (%)	Voids Filled With Bitumen (%)	Average Optimum Bitumen Content (%)	Unit Weight (lb/cu ft)
C1 - El Toro	5.3	100	0	27 (Paxole 1007) V (AR-2000)	c	-	-	-	-	-
C2 - El Toro	5.3	75	25 (-3/4-in. AC aggregate)	27 (Paxole 1007) V (AR-2000)	2,460	14	3.0	81	6.2	144
C3 - El Toro	5.3	75	25 (base course)	27 (Paxole 1007) V (AR-2000)	2,100	12	3.6	80	6.8	141
C4 - El Toro	5.3	50	50 (-3/4-in. AC aggregate)	V (AR-1000)	3,000	16	3.2	81	5.7	143
C5 - El Toro	5.3	50	50 (-3/4-in. AC aggregate)	V (AR-2000)	3,160	16	3.7	79	6.2	143
C6 - Fallon	5.1	75	25 (-1/4 crusher fines)	28 (Paxole 1007) V (AR-4000)	2,980	14	2.8	82	7.6	140
C7 - Fallon	5.1	75	25 (-3/4-in. AC aggregate)	28 (Paxole 1007) V (AR-4000)	2,960	14	4.0	78	6.9	142
C8 - Fallon	5.1	75	25 (base course)	28 (Paxole 1007) V (AR-4000)	3,770	14	4.5	80	7.0	142
C9 - Las Vegas	4.5	100	0	20 (Paxole 1007) V (AR-2000)	c	-	-	-	-	-
C10 - Las Vegas	4.5	75	25 (-3/4-in. AC aggregate)	V (AR-1000)	c	-	-	-	-	-
C11 - Las Vegas	4.5	75	25 (-3/4-in. AC aggregate)	V (AR-2000)	3,360	15	3.3	79	5.3	147
C12 - Las Vegas	4.5	75	25 (-3/4-in. AC aggregate)	14 (Paxole 1007) V (AR-4000)	2,660	16	3.1	81	5.1	147
C13 - Las Vegas	4.5	50	50 (base course)	V (AR-1000)	2,130	11	3.4	79	6.4	141

continued

TABLE 7. CONTINUED

Sample Identification <sup>a</sup>	Residual Bitumen Content (%)	Crushed Recycle Sample Amount (%)	New Aggregate Amount and Size (%), (in.)	Softening Agent (%), V) <sup>b</sup>	Marshall Stability (lb)	Flow (0.01 in.)	Air Voids (%)	Voids Filled With Bitumen (%)	Average Optimum Bitumen Content (%)	Unit Weight (lb/cu ft)
C14 - Las Vegas	4.5	50	50 (base course)	20 (Paxole 1007) V (AR-2000)	2,000	10	3.7	78	6.3	140
C15 - Las Vegas	4.5	75	25 (base course)	20 (Paxole 1007) V (AR-2000)	2,480	11	3.6	80	5.5	145
C16 - Los Angeles (LAX)	5.1	100	0	20 (Paxole 1007) V (AR-2000)	<sup>c</sup>	-	-	-	-	-
C17 - Los Angeles (LAX)	5.1	75	25 (-3/4-in. AC aggregate)	20 (Paxole 1007) V (AR-2000)	2,040	14	3.2	82	6.6	144
C18 - Los Angeles (LAX)	5.1	50	50 (-3/4-in. AC aggregate)	20 (Paxole 1007) V (AR-2000)	2,520	13	3.0	82	6.1	144
C19 - Whiting	5.8	75	25 (subgrade soil)	32 (Paxole 1007) V (AR-2000)	-	-	-	-	-	<sup>c</sup>
C20 - Whiting	5.8	75	25 (subgrade soil)	32 (Paxole 1007) V (AR-2000)	-	-	-	-	-	<sup>c</sup>

<sup>a</sup>The sample numbers designated in TABLE 7 are also the figure numbers for the plots for each sample shown in APPENDIX C.

<sup>b</sup>% = 100 (weight of softener)/(weight of softener + residual asphalt)

V = Varying percentages by weight of total bitumen weight.

<sup>c</sup>Plots of Marshall Stability or unit weight do not have the characteristic maximum peak.

The second series of El Toro samples tested used 75% crushed El Toro material and 25% aggregate, meeting the 3/4-in. aggregate gradation requirements for asphalt surfacing. The same percentage of Paxole 1007 as in the first test series was used - 27% by weight of residual asphalt/softener blend. Additional AR-2000 was added to vary the total bitumen content. The results of this series of tests are shown in FIGURE C-2. For this sample, a total bitumen content of 6.2% would be selected, composed of 63 parts residual asphalt, 23 parts Paxole 1007, and 14 parts AR-2000.

The next series of El Toro samples was prepared using 75% El Toro crushed material and 25% base course aggregate. Paxole 1007 and AR-2000 were utilized as in the previous series. The intent of this series was to investigate the possibility of including part of the underlying base course material that might adhere to the pavement when it is ripped and excavated. This mixture can meet the criteria for surface course hot mix; however, the stability is lower, approximately 2,100 lb versus 2,500 lb, than when asphalt concrete aggregate is used. This decrease is attributed to a lower percentage of crushed material, the lower intergranular friction of the base course material, and a higher asphalt content. The results of this series are shown graphically in FIGURE C-3.

The next two series of tests were used to evaluate the Maplewood or heat transfer approach to recycling. This technique uses superheated virgin aggregate added to cold, crushed, recycled material with additional bitumen, as required. No softening agent is used other than the additional asphalt. For this series, a blend of 50% asphalt concrete aggregate and 50% crushed El Toro material was used. Bitumens used were AR-1000 and AR-2000. It was not possible in the laboratory to duplicate the superheating of the virgin aggregate to the 450° to 500°F level employed in the Maplewood process. Therefore, the laboratory samples were combined and heated to 250°F before adding the additional bitumen.

Both series were similar in performance. The AR-1000 series had a slightly lower optimum total bitumen content of 5.7% while the AR-2000 series had a corresponding optimum of 6.2%. For the AR-1000 sample at 5.7% total bitumen, the resulting binder, assuming a complete blending of the residual asphalt and the new material, would have a penetration of 40 and viscosity at 140°F of 6,600 poises. The AR-2000 sample at 6.2% total bitumen would have a penetration of 40 and a viscosity of 7,200 poises. These mixes may be difficult to compact in the field due to the high binder viscosity; however, asphalts with viscosities in this range are used routinely in the Southwestern states (REFERENCE 18\*). No samples were made with higher percentages of virgin aggregate, as it was felt that they would be uneconomical. Results from these tests are shown in FIGURES C-4 and C-5. These tests have shown that the Maplewood process can be used to recycle airport AC pavements.

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\*18. Federal Aviation Administration. Report No. FAA-RD-77-42: Field Compaction of Bituminous Mixes for Airport Pavements, by A. L. McLaughlin. Washington, D.C., Apr 1977.

## Fallon

The extracted crushed gradation of the Fallon sample is shown in FIGURE 14. The gradation meets both FAA and Navy specifications, except for 1.9% larger than 3/4-in. and borderline percentages of no. 4 and no. 8 fractions. Although the gradation was generally within limits, it was felt that additional aggregate would be required to allow addition of sufficient softener to reduce the residual asphalt viscosity to a workable consistency.

The design asphalt grade selected for this series of tests was AR-4000. The AR-4000 used in the tests had a penetration of 53 and a viscosity of 2,343 poises before aging in the TFOT. To match these values of penetration and viscosity in the softening of the residual asphalt to an equivalent AR-4000 grade, 28% of Paxole 1007 was required to achieve a penetration value of 53. However, for this amount of Paxole, the viscosity of the blend was reduced to only 7,200 poises. It was therefore decided to try and match only penetrations for this series to simulate the low penetration, high viscosity asphalts often used for airport pavements in the southwestern part of the United States.

The first series of tests consisted of 75% crushed Fallon material and 25% minus no. 4 crusher fines. The minus no. 4 crusher fines were added to raise the percentage of no. 4 and no. 8. Paxole 1007 was added, as previously discussed, and AR-4000 was used to supply additional bitumen. The results of this series of tests are shown graphically in FIGURE C-6. Except for the value for voids filled being marginal, all of the other criteria for surface course are met for a total bitumen content of 7.6%. This is a rather high optimum bitumen content. It is theorized that some of the residual asphalt is not being softened and is, therefore, acting essentially as part of the aggregate. The increased proportion of fines in the mix also requires more binder.

The next series of tests used 25% asphalt concrete aggregate instead of crusher fines. The results of this series, shown in FIGURE C-7, are very similar to the previous test series, including the higher than normal asphalt content. Part of this can be attributed to the lower compaction temperatures used for recycled mixes than specified in MIL STD 620A. This allows more voids in mineral aggregate, which must be filled with asphalt to meet air voids and voids filled criteria. Again, a suitable mix was achieved for surface course construction.

The next series of Fallon samples was composed of 75% Fallon crushed material and 25% Fallon base course material, which was part of the pavement structure at Fallon. The peak of the stability curve in FIGURE C-8 shows a value of 3,800 lb. This is an exceptionally high stability value and is not considered typical. The results of this series do, however, show the possibility of using a combination of base course and crushed asphalt concrete to make an acceptable bituminous base.

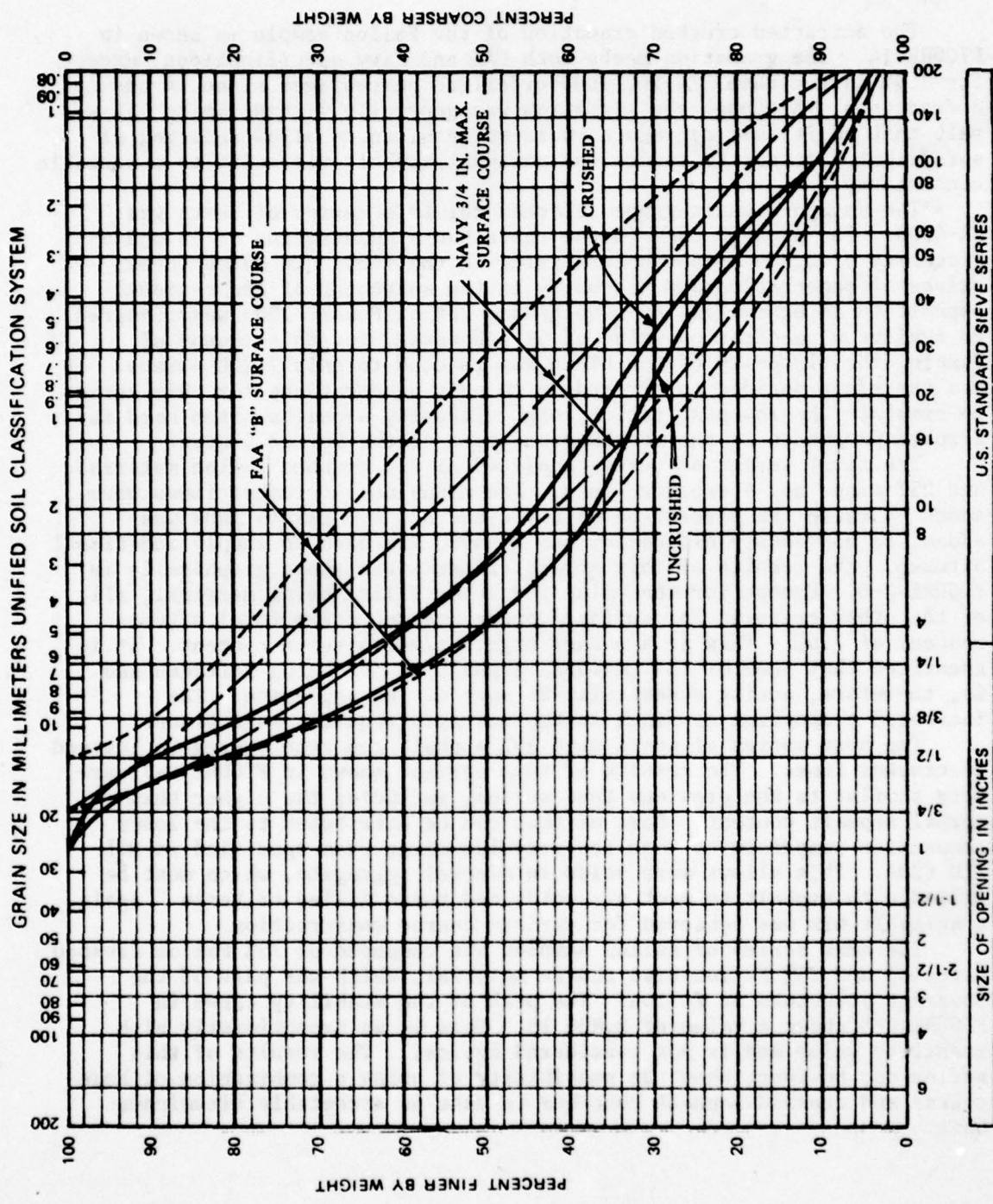


FIGURE 14. ANALYSIS OF FALLON EXTRACTED CRUSHED GRADATION.

## Las Vegas

The crushed extracted gradation of the Las Vegas sample was generally within the FAA specification, but slightly too fine for the Navy criteria, as can be seen in FIGURE 15. Paxole 1007 was again selected as the softening agent. The amount of softener in the residual asphalt blend was selected to approximate the consistency of the AR-2000 asphalt, which was the grade used to supply additional binder. At 20% softener content, expected penetration and viscosity of the residual asphalt of 87 and 875 poises compare favorably with the AR-2000 parameters of 87 and 1,099 poises.

The first series of tests used Paxole 1007, AR-2000, but no additional aggregate. The low residual asphalt content of the Las Vegas sample of 4.5% suggested that optimum binder content might be attainable with just the addition of softener and, perhaps, some additional asphalt. This was not, however, the case, as can be seen in FIGURE C-9. The sample with no softener had, as expected, very high stability, but also high air voids and low voids filled. The addition of Paxole 1007, in the selected quantity of 20%, dropped the stability to 2,500 lb, but also lowered the air voids and raised the voids filled outside of acceptable criteria. The remaining samples of this series, with additional AR-2000, yielded the same type of stability versus bitumen content curve as the El Toro samples made without added aggregate.

The next series of tests with the Las Vegas material was conducted with 75% crushed Las Vegas material, 25% asphalt concrete aggregate, and varying percentages of AR-1000 to act as both a softening agent and additional binder. Again, no peak of curve is evident in the stability versus bitumen content curve shown in FIGURE C-10. The decreasing stability is believed to be a function of the decreasing viscosity of the bitumen as AR-1000 is added. It is possible to meet all mix design criteria at a total bitumen content of 5.1% composed of 65% residual asphalt and 35% AR-1000. This combination would yield a penetration of 32 and a viscosity of 5,500 poises at 140°F. This would probably be an acceptable mix in the hot Southwest where AR-8000 asphalts are routinely used for airfield pavements.

The next series was essentially the same as the previous example, except that AR-2000 asphalt was used. At the average optimum asphalt content of 5.3%, the mix meets all criteria for hot-mix, as can be seen in FIGURE C-11. Combined binder properties at 5.3% composed of 62% residual and 38% AR-2000 would be a penetration of 34 and a viscosity of 6,000 poises. This mix, although it meets criteria, would be difficult to compact in the field and would probably lack durability and fatigue resistance.

The next Las Vegas test series used 75% Las Vegas crushed material, 25% asphalt concrete aggregate, Paxole 1007, and AR-4000 asphalt. The properties of the AR-4000 used were 53 penetration and 2,343-poise viscosity. These properties were closely matched by adding 14% Paxole in the softener/residual asphalt blend. As shown in FIGURE C-12, except for voids filled with bitumen, a satisfactory mix can be made at an

average optimum bitumen content of 5.1%. At this bitumen content, the total binder would be composed of 65% residual asphalt, 11% Paxole 1007, and 24% AR-4000.

The next three series of Las Vegas samples were made with Las Vegas base course material as the added aggregate. This approach was utilized to again evaluate the possibility of combining underlying base course materials with crushed asphalt concrete to yield a suitable hot-mix bituminous base course. The first of the base course series used 50% crushed Las Vegas material and 50% aggregate base course, with varying percentages of AR-1000 asphalt added to supply additional binder and some softening of the residual asphalt. At an average optimum bitumen content of 6.4%, this mix satisfies both Navy and FAA criteria for bituminous base course as can be seen in FIGURE C-13. At this bitumen content, the residual asphalt/AR-1000 blend is composed of 34% residual and 66% AR-1000, which would be expected to yield a resultant viscosity of 1,300 poises at 140°F and a penetration of 45. This is an acceptable consistency and would be a workable mix for field placement.

The next series of tests was performed with the same 50:50 crushed Las Vegas material and base course blend as the previous sample, but Paxole 1007 and AR-2000 were used to supply the softening effect and additional bitumen. At an average optimum bitumen content of 6.3%, the criteria for hot-mix bituminous surface course is met as can be seen in FIGURE C-14.

The last series of Las Vegas samples used 75% crushed Las Vegas material and 25% aggregate base course with the same softener and supplementary asphalt as the previous series. As can be seen in FIGURE C-15, the results are quite similar to the previous test series, but with slightly higher stabilities and slightly lower optimum bitumen content. This is believed to be due to the higher percentage of crushed material in this mix.

#### Los Angeles (LAX)

The residual asphalt from the Los Angeles (LAX) samples had a penetration of 19 and a viscosity of 24,330 poises at 140°F. The gradation of the extracted, crushed aggregate was well within the limits for surface course by both the FAA and Navy criteria, as can be seen in FIGURE 16. Because of the acceptable aggregate gradation, an attempt was made to make a mix using no additional aggregate. The residual asphalt was softened to a penetration of 78 and a viscosity of 1,200 poises at 140°F by adding 20% Paxole 1007 in the residual/softener blend. One test in the series was conducted without softener at the residual asphalt content of 5.1%. The results of this series, shown in FIGURE C-16, are similar to previous samples where no additional aggregate was added; however, in this case, it is possible to meet surface course criteria for stability, flow, voids, and voids filled at a total bitumen content of 6.0%. The stability curve contains no typical peak due to the influence of binder viscosity on Marshall stability.

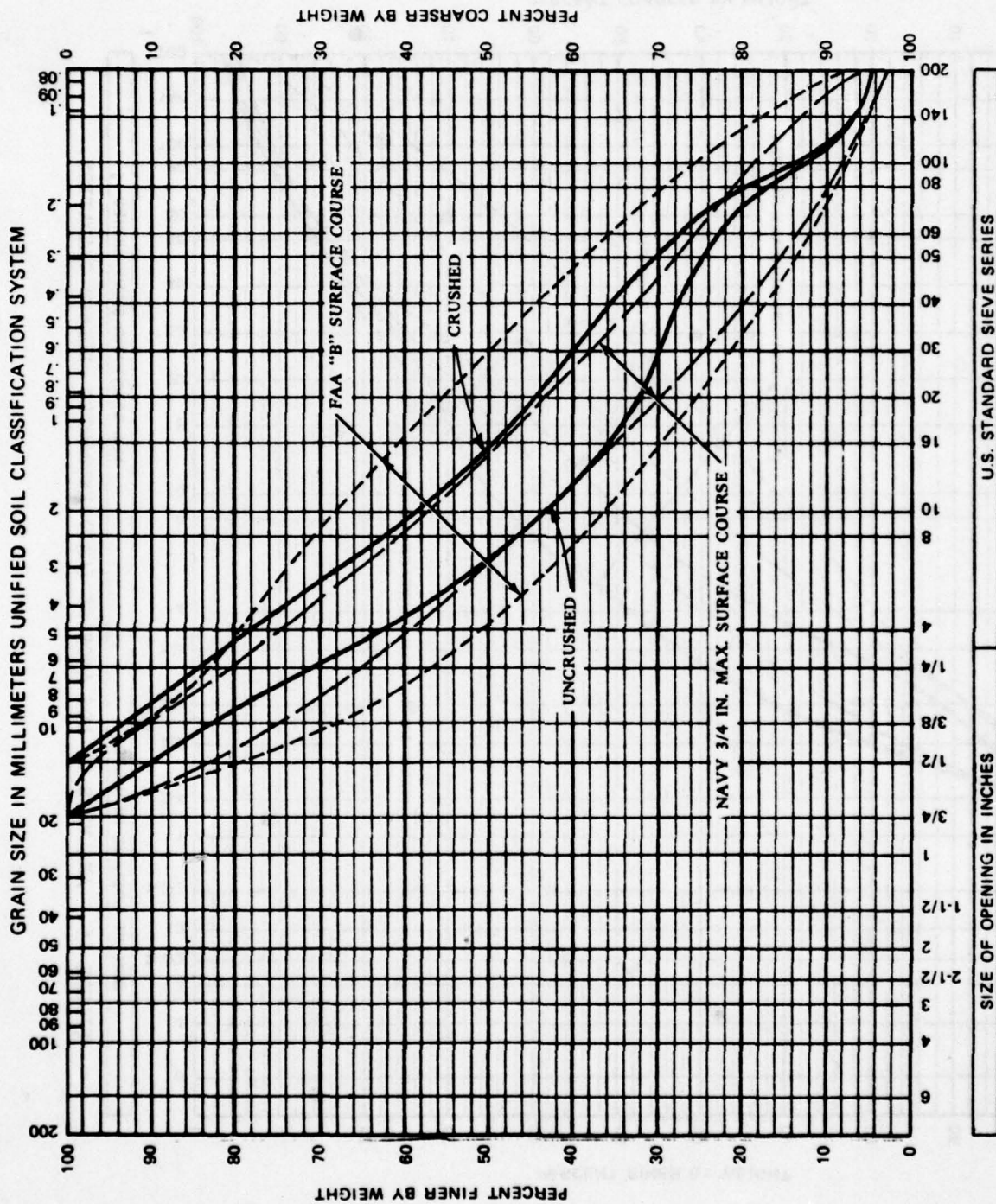


FIGURE 15. ANALYSIS OF LAS VEGAS EXTRACTED CRUSHED GRADATION.

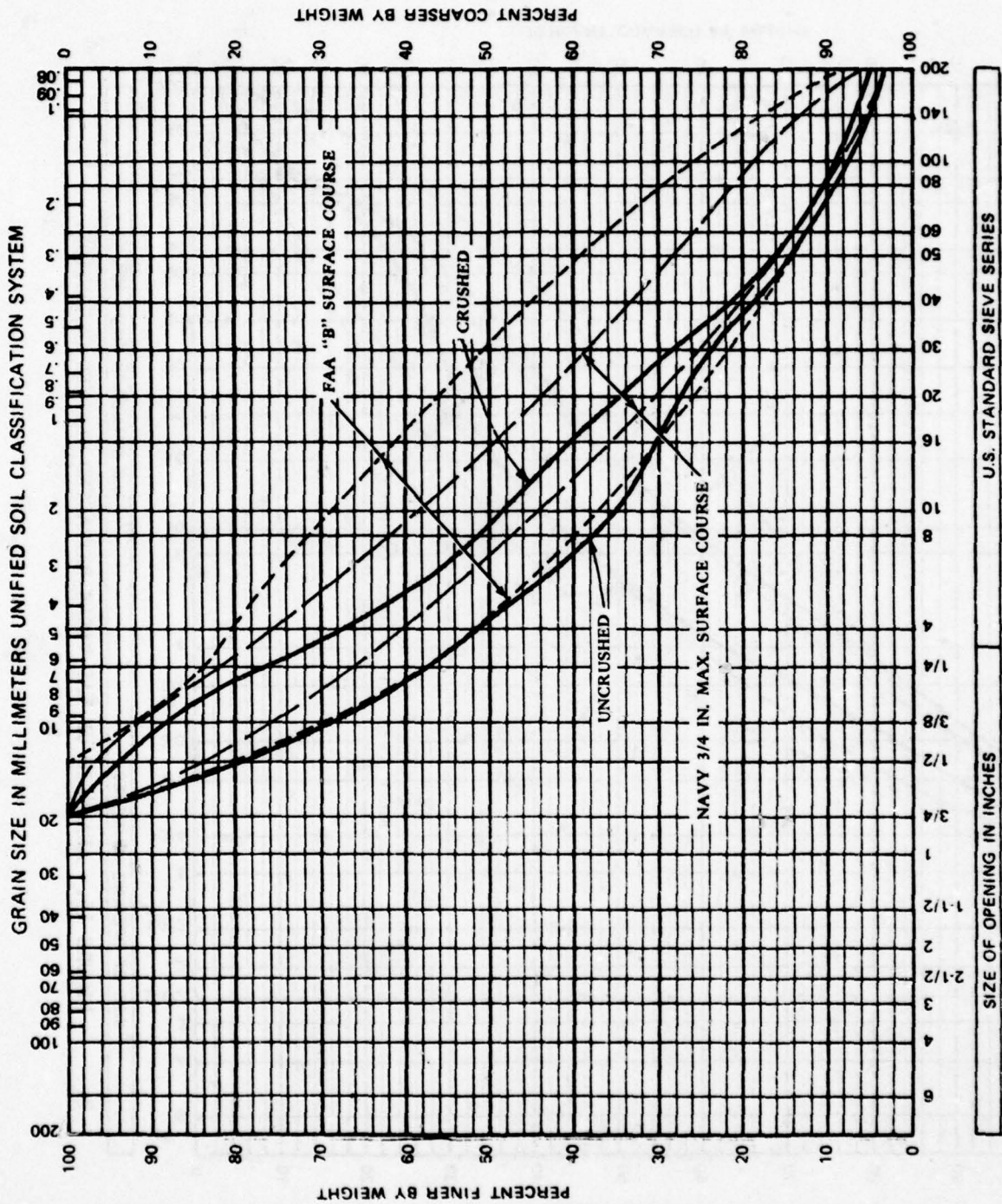


FIGURE 16. ANALYSIS OF LOS ANGELES (LAX) EXTRACTED CRUSHED GRADATION.

The next two series of tests were conducted with 75:25 and 50:50 ratios of crushed Los Angeles (LAX) material to asphalt concrete aggregate, respectively. The same combination of Paxole 1007 and AR-2000 was used as in the previous tests. Average optimum bitumen contents for each combination above were 6.6% and 6.1%, respectively. The results of these two series of tests are shown in FIGURES C-17 and C-18.

#### Whiting

The Whiting samples consisted primarily of a mixed-in-place sand asphalt. The extracted, crushed gradation of this material is shown in FIGURE 17. The gradation does not meet FAA criteria for bituminous sand base. The residual asphalt in this material was extremely brittle, with a penetration of 2 and a viscosity at 140°F which was too high to measure with the available equipment. The addition of sufficient Paxole 1007 to make a 32:68 blend of Paxole to residual asphalt resulted in decreasing the viscosity to 4,000 poises at 140°F and raising the penetration to 80. Two series of tests were made with a 75% crushed Whiting material and 25% Whiting subgrade sand with 32% Paxole 1007 and varying percentages of AR-2000 asphalt. Specimens for one series were compacted with 75 blows per side; the results of which are shown in FIGURE C-19. Specimens for the second series, the test results for which are shown in FIGURE C-20, were compacted with 50 blows per side. As can be seen in these figures, satisfactory bituminous surface course mixes are not attainable with the material from Whiting Field. These mixes, however, are acceptable for bituminous base courses.

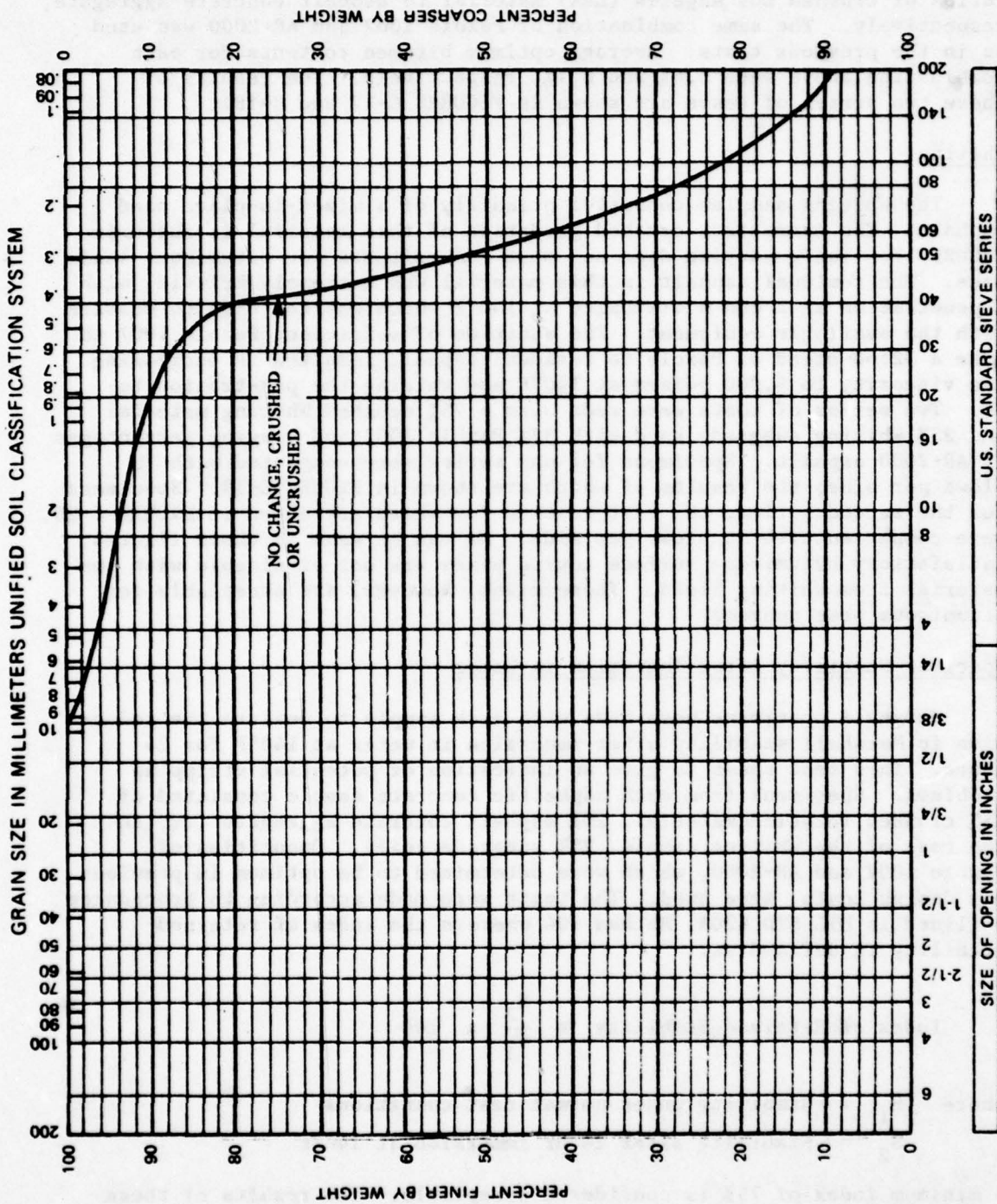
#### Specimen Stability After Immersion in Water

Marshall specimens were made with each sample to measure the reduction in Marshall stability after immersion in water at 140°F for 24 hours. This test seems to give an indication of potential stripping problems. Specimens from each asphaltic concrete sample consisted of 75% crushed recycled material, 25% asphalt concrete aggregate (or, in the case of the Whiting sample, 25% subgrade soil). Quantities of Paxole 1007 and AR-2000, which were determined to be optimum in previous mix design tests, were used. The tests were made according to procedures outlined in MIL STD 620A, Method 104 wherein the index of retained stability is defined as:

$$\text{Index of Retained Stability} = \frac{S_2}{S_1} \times 100$$

where  $S_1$  = Stability under normal test conditions  
 $S_2$  = Stability after 24 hr immersion at 140°F

A minimum index of 75% is considered acceptable. The results of these tests are shown in TABLE 8.



U.S. STANDARD SIEVE SERIES

SIZE OF OPENING IN INCHES

FIGURE 17. ANALYSIS OF WHITING EXTRACTED CRUSHED GRADATION.

TABLE 8. RESULTS OF MARSHALL STABILITY TESTS  
AFTER 24 HOUR IMMERSION

Sample	Original Stability <sup>a</sup> (lb)	Stability After Immersion for 24 Hr at 140°F (lb)	Index of Retained Stability (%)
El Toro, Paxole 1007 and AR-2000	3,096	2,353	76.0
Fallon, Paxole 1007 and AR-2000	2,813	1,844	66.0
Fallon, Paxole 1007, AR-2000, and 1% hydrated lime	2,836	2,077	73.2
Fallon, Paxole 1007, AR-2000, and 1% Redicote 80-S	2,810	1,895	67.4
Las Vegas, Paxole 1007, AR-2000	2,562	2,560	100.0
Los Angeles, (LAX) Paxole 1007, AR-2000	2,325	2,338	100.0
Whiting, Paxole 1007, AR-2000	2,355	1,992	84.6

<sup>a</sup>Tests performed according to MIL-STD-620A, Method 104.

Only the Fallon sample failed to retain more than 75% of its stability. To attempt to improve stability retention, samples of Fallon material were molded with the addition of hydrated lime in one and a commercial antistrip additive in the other. For the lime-treated sample, a slurry containing 1% hydrated lime by weight of aggregate was mixed with the aggregate before heating. Paxole 1007 and AR-2000 were then added and the sample compacted. This mixture improved the stability retention to 73.2%; however, this is still short of the minimum acceptable index of 75%.

For the antistrip additive, 1% of Redicote 80-S by weight of the total asphalt softener combination was added to the heated AR-2000 and Paxole 1007. This was then mixed with heated aggregate and then followed by normal compaction procedures. Based on test results on samples made by this method, no significant effect on the index of retained stability was noted.

The lime and antistripping additives have been successfully used in new pavements to reduce stripping tendencies. It is theorized that their relative ineffectiveness in this recycling effort is due to an inability to coat and chemically alter the surface of the old crushed pavement aggregate. Additional research is needed to find effective means of treating hydrophilic aggregates in recycling operations.

The performance of the stability-flow tests and density-voids analyses on samples prepared from each of the five airports has shown that:

1. Aged airport AC pavement material can be successfully recycled into acceptable hot mixes for bituminous surface courses. This can be seen by comparing the criteria for acceptable mixes and the values obtained from the tests and analyses and summarized in TABLE 7.

2. The addition of any softening agent to a sample made up of 100% AC recycle material will result in bitumen contents that are higher than optimum on the stability curve. This is because, even though aged, the asphalt concrete contains bitumen in amounts at or near optimum. For example, see samples C1, C9, and C16 in TABLE 7.\* Thus, to achieve an optimum bitumen content on the stability curve, it is necessary that additional new aggregate and binder be introduced, resulting in the mix containing less than 100% recycled material.

3. Base course material at each of the respective airports from which AC pavement material was obtained can be included as new aggregate to be used with the recycle material to produce acceptable mixes (e.g., samples C3, C8, C13, C14, and C15). Depending on the method of removal of the aged pavement, some of the base material may adhere to the pavement and thus will be included in the recycling process. These tests have shown that such base material in general can be included in the recycle mix to produce acceptable results.

4. The heat transfer or Maplewood process can be used to recycle aged AC airport pavements by using 50% recycled material and 50% new aggregate with additional asphalt and no softening agent. Samples C4 and C5 were prepared by this method of superheating the new aggregate and mixing with the material being recycled.

5. Samples made with recycled material are capable of passing the standard test of immersion in water to determine asphalt stripping tendencies by the Marshall stability test method. In the sample (Fallon) where stripping would be a potential problem, anti-stripping agents commonly used in virgin mixes were introduced and found to be relatively ineffective.

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\*The sample numbers designated in TABLE 7 are also the figure numbers for the plots for each sample shown in APPENDIX C.

## COLD-MIX RECYCLING OF ASPHALTIC CONCRETE

Cold-mix recycling as defined previously can involve treatment in-place or removal of the asphaltic concrete to a central plant for processing. The processing may or may not include the addition of aggregates, asphalt, portland cement, lime, or other chemicals, including softeners. Generally, cold recycled materials would be used for base course or subbase course and would require a new asphalt concrete wearing surface. In this study, cold recycled asphalt concrete was evaluated in the following modes: (1) as-crushed and with aggregate added, (2) portland cement added, and (3) asphalt emulsions and softener added.

### Crushed Untreated Material and Aggregate Added

The samples of asphalt concrete as-crushed were considered for use as base and subbase material. None of the as-crushed samples met both FAA and Navy gradation requirements. The El Toro material barely met the FAA "C" gradation for crushed aggregate base as specified in P-209 (REFERENCE 9). Of course, the Whiting sand asphalt sample would not be expected to meet the base course gradation, but would be suitable for subbase use.

The samples were also compared to the specification used in Southern California for processed miscellaneous base course (REFERENCE 2). All samples except Fallon met the gradation requirements for processed miscellaneous base course. All the samples met the sand equivalent specifications. The El Toro sample was the only one tested in the Los Angeles abrasion apparatus, and it met the percentage wear criteria.

In spite of the nonconformance of the gradations of these materials to either FAA or Navy specifications, these materials were evaluated for base course use by the performance of moisture-density and California Bearing Ratio (CBR) tests. The first moisture-density relationships were made using as-crushed material. Problems were encountered in compacting the samples in the molds with the conventional drop hammer equipment. The material was shoved around by the hammer in the molds because of a lack of fine binder material and, possibly, the subrounded shape of the crushed asphalt concrete. Moisture-density curves with these materials were completed, however, using the methods described in ASTM D1557, Method D. The maximum densities and optimum moisture contents from these tests are given in TABLE 9.

Additional samples for moisture-density and CBR tests were made with crushed material from the various airfields and airports combined with respective base course material or subgrade soil or minus no. 4 crusher fines. The intent of testing these samples was to simulate what would occur if the asphalt concrete were crushed on-grade and some of the underlying base course or subgrade was mixed in with the crushed asphalt concrete. No attempt was made to control the ultimate gradation of the blended materials. The gradations of the blended and unblended materials as shown in TABLE 10 were compared with FAA and Navy specifications for base and subbase course. Only one sample met the FAA base course gradation, and only one sample met the Navy base course gradation.

TABLE 9. RESULTS OF BASE COURSE CBR TESTS

Sample Description	Maximum Density (lb/cu ft)	Optimum Moisture Content (%)	Method of CBR Sample Compaction	CBR at 95% of Maximum Density
El Toro	126.3	6.5	drop hammer	48
El Toro	126.3	6.5	static load	58
El Toro + 25% Base Course	124.3	7.7	static load	106
Fallon + 25% Base Course	125.4	7.1	static load	114
Las Vegas + 25% Base Course	126.2	6.8	static load	104
Los Angeles (LAX)	120.8	7.3	static load	75
Los Angeles (LAX) + 25% Base Course	126.1	8.0	static load	147
Los Angeles (LAX) + 25% Base Course	126.1	8.0	drop hammer	57
Los Angeles (LAX) + 25% Minus No. 4	127.8	5.5	static load	60
Whiting + 25% Subgrade	117.9	6.4	static load	54

All but one of the samples met the FAA gradations for subbase, while only three satisfied Navy requirements. Because several of the samples were close to the gradation requirements, it was decided to proceed with CBR testing without further gradation adjustment, the rationale again being to simulate field operations where good control of gradation may be lacking.

Attempts to mold CBR samples with the drop hammer, as described in ASTM D1883, resulted in shoving of the material in the mold, which led to lower than anticipated CBR values (see TABLE 9). These lower values were assumed to be primarily due to poor particle interlocking as the sample is shoved during compaction. To overcome this shoving problem, a set of samples was compacted by applying a static load. The technique used was to weigh the proper amount of material to yield 95% of maximum

density when compacted to a volume of 1/13.333 cu ft. The crushed material was then placed in the mold, which was vertically oriented over a flat horizontal pedestal of slightly smaller diameter than the inside diameter of the mold and which was installed in a testing machine. The static load was then applied vertically from above through a circular plate of the same diameter as the pedestal to compress and compact the sample simultaneously from both ends until a sample height of 4.58 inches was reached. The samples were then tested in the normal manner for CBRs, soaked for 4 days, and then penetrated with a 3-sq in. piston in the normal CBR test mode.

The results of the tests on samples formed by static load compaction were generally less erratic and usually higher than those obtained on samples compacted with the drop hammer. The most dramatic example was that from Los Angeles (LAX) plus 25% base course sample, where the static-load-compacted sample had a CBR of 147 versus the drop hammer-compacted sample with a CBR of 57. All the remaining CBR testing used static-load molding of the samples.

The relatively low CBR values, ranging from 48 to 75, of the straight crushed asphalt concrete samples are believed to be caused by the sub-rounded shape of the crushed particles. In the crushing operation, the coarse aggregate is generally not fractured and the fine aggregate remains bonded to the coarser particles by the asphalt cement, thereby yielding an effectively rounded aggregate particle. The addition of virgin crushed aggregate base course effected a substantial improvement in all of the blends tested. This improvement is primarily attributed to increased granular interlock of the crushed aggregate. The overall results of these tests show that straight crushed asphalt concrete will probably not be acceptable as crushed base course for airfield pavements unless modified by blending to improve gradation and intergranular friction. When blended properly, an adequate material for base course with a design CBR of 80 can be produced. A design CBR value of 80 is recommended even though test results show measured CBRs in excess of 100. This is to allow for possible softening of the asphalt binder when pavement temperatures exceed 100°F. All of the materials tested could be used as subbase without modification beyond crushing. A maximum design CBR of 50 is recommended for subbase use of these materials.

#### Portland-Cement-Treated Material

The samples were evaluated using current Navy and FAA criteria for cement-treated base course. For this section of the investigation, only the samples from El Toro, Los Angeles (LAX), and Fallon were used. The samples were preliminarily screened by gradation; only the El Toro sample met the Navy gradation. None of the as-crushed samples met the FAA gradation, as can be seen in TABLE 11. Additional samples were made by blending base course or minus no. 4 crushed rock with the crushed asphalt concrete as are shown in TABLE 11. Only the samples with the minus no. 4 crushed rock met both the Navy and FAA gradations.

TABLE 10. CRUSHED BASE COURSE GRADATIONS, UNBLENDED AND BLENDED

Specimen or Sample	Percent Passing										Meets Base Course Gradation		Meets Subbase Course Gradation	
	3 in.	1 in.	3/4 in.	1/2 in.	No. 4	No. 10	No. 40	No. 100	No. 200	FAA	Navy	FAA	Navy	
	Base Course Specifications										FAA	Navy	FAA	Navy
FAA "C" gradation	-	100	70-100	-	35-65	-	15-25	-	3-10					
Navy No. 3 gradation	-	100	-	40-70	25-50	15-40	5-25	-	0-10					
	Subbase Course Specifications													
FAA	100	-	-	-	-	20-100	5-60	-	0-15					
Navy	-	-	-	-	45-100	36-60	-	3-20	-					
	Recycled Samples Used in This Investigation													
El Toro	100	100	98	87	55	40	15	7	3	Yes	No	Yes	Yes	
El Toro + 25% Base Course	100	100	100	73	41	27	8	2	1	No	No	Yes	No	
Fallon	100	100	100	55	18	10	4	2	0.4	No	No	No	No	
Fallon + 25% Base Course	100	100	100	63	30	20	11	5	2	No	Yes	Yes	No	

continued

TABLE 10. CONTINUED

Specimen or Sample	Percent Passing										Meets Base Course Gradation		Meets Subbase Course Gradation	
	3 in.	1 in.	3/4 in.	1/2 in.	No. 4	No. 10	No. 40	No. 100	No. 200	FAA	Navy	FAA	Navy	
	Recycled Samples Used in This Investigation													
Los Angeles (LAX)	100	100	97	86	49	31	8	3	2	No	No	Yes	No	
Los Angeles (LAX) + 25% Base Course	100	100	97	87	53	37	13	9	3	No	No	Yes	Yes	
Los Angeles (LAX) + 25% Minus No. 4	100	100	100	80	42	25	9	4	2	No	No	Yes	Yes	
Las Vegas	100	100	97	84	51	32	13	6	3	No	No	Yes	No	
Las Vegas + 25% Base Course	100	100	100	80	46	29	10	2	1	No	No	Yes	No	
Whiting	100	100	100	71	44	37	25	11	2	No	No	Yes	No	
Whiting + 25% Subgrade	100	100	100	78	58	53	37	18	2	No	No	Yes	Yes	

TABLE 11. AGGREGATE GRADATIONS FOR CEMENT-TREATED BASE COURSES

Source of Specimen	Percent Passing						Meets Gradation Requirements	
	1 in.	3/4 in.	No. 4	No. 30	No. 40	No. 200	Navy	FAA
Navy	100	90-100	40-70	12-40	-	3-15		
FAA	100	70-100	35-65	-	15-30	5-15		
El Toro	100	98	55	22	15	3	Yes	No
El Toro and base, 75/25	100	100	41	17	11	3	Yes	No
El Toro and Minus No. 4 rock, 75/25	100	100	47	18	15	5	Yes	Yes
Fallon	100	100	18	5	4	0.4	No	No
Fallon and Fallon base, 75/25	100	100	35	14	12	3	No	No
Fallon and Minus No. 4 rock, 75/25	100	100	52	20	17	5	Yes	Yes
Los Angeles (LAX)	100	97	49	12	8	2	No	No
Los Angeles (LAX) and Minus No. 4 rock, 75/25	100	100	46	14	12	5	Yes	No
Los Angeles (LAX) and Minus No. 4 rock, 50/50	100	100	62	27	23	8	Yes	Yes

Specimens for compressive strength tests were molded using the procedures outlined in ASTM Test Method D-1632, except that 4-in.-diam by 8-in.-high (instead of 2.8-in.-diam by 5.6-in.-high) specimens were used. The specimens were molded at optimum moisture contents and maximum densities obtained, using ASTM Test Method D-558. The samples, after molding, were cured in a room with 100% relative humidity. At selected time intervals, samples were tested in compression according to ASTM D-1633. The results of these tests are shown in TABLE 12.

TABLE 12. COMPRESSIVE STRENGTH OF CEMENT-TREATED BASE COURSE SAMPLES

Sample Description	Portland Cement (%)	Sample Size (in.)	Compressive Strength (psi)		
			7 days	14 days	28 days
Crushed El Toro	4.0	4x8	268	-	-
Crushed El Toro	5.0	4x8	184	-	-
75% Crushed El Toro and 25% Crushed Rock Base	5.0	4x8	191	-	-
75% Crushed El Toro and 25% Minus No. 4 Crushed Rock	5.0	4x8	326	333	328
Crushed El Toro	5.0	4x4 <sup>a</sup>	487	-	566
75% Crushed El Toro and 25% Minus No. 4 Crushed Rock	5.0	4x4 <sup>a</sup>	627	668	772
Crushed Fallon	5.0	4x8	184	-	-
75% Crushed Fallon and 25% Fallon Base	5.0	4x8	247	-	-
75% Crushed Fallon and 25% Minus No. 4 Crushed Rock	5.0	4x8	303	334	395
Crushed Los Angeles (LAX)	5.0	4x8	119	-	-
75% Crushed Los Angeles (LAX) and 25% Minus No. 4 Crushed Rock	5.0	4x8	326	-	-
50% Crushed Los Angeles (LAX) and 50% Minus No. 4 Crushed Rock	5.0	4x8	438	493	789

<sup>a</sup> Samples (4x4 size) tested by the California Department of Transportation method.

The first sample tested was unblended El Toro crushed material with 4% cement. A 7-day compressive strength of 268 psi was not close enough to the desired strength of 750 psi at 7 days to consider further testing of this mixture. The remaining samples were fabricated with a cement content of 5%, the maximum allowed in the Navy specifications for cement-treated base course. As can be seen in TABLE 12, none of the mixtures tested attained a 7-day strength of 750 psi when molded in 4- by 8-in. specimens. One of these samples did reach a strength of 789 psi at 28 days, but this was considered an anomaly. California Department of Transportation (DOT) investigators have reported strengths in excess of 964 psi at 7 days for a recycled mix containing 5% cement (REFERENCE 19\*). It was theorized that the differences between the California and ASTM test methods may account for the higher strengths obtained by California DOT. Two sets of samples were molded using the California procedures and are identified in TABLE 12 as the 4x4-in. samples. Although these samples did yield compressive strengths approximately double the 4x8-in. samples of the same material, they were still below 750 psi at 7 days.

Because of the low compressive strengths obtained, it was decided to terminate testing of cement-treated samples at this point in the investigation.

#### Asphalt-Emulsion-Treated Material

The samples blended with asphalt emulsions were mixed to simulate on-grade recycling. The softening agent used for these samples was Reclamite, a commercially available product described as a cationic emulsion of maltenes and resins. The material has an effective oil content of 60%. A sample of the residual Reclamite oil was blended with El Toro residual asphalt to determine its softening effect. The plots of this blend are shown in FIGURE 18. Using this relationship, the quantity of Reclamite to be added to obtain the desired softened viscosity and penetration was calculated in the same manner as employed for hot-mix samples. The predetermined amount of Reclamite was mixed with an equal amount of water to aid in dispersing the oil throughout the sample. After mixing with the crushed asphalt concrete, the sample was dried in a 140°F oven until the water was evaporated. This temperature was selected to approximate the conditions of samples drying in the sun on-grade. Next, additional asphalt binder in the form of either an SS-1h or CSS-1h emulsion was added. Again the sample was dried at 140°F until the water was evaporated. The mixtures were then compacted in the conventional Marshall test procedure at a compaction temperature of 100°F to simulate on-grade processing. The compacted samples were then tested for bulk specific gravity and Marshall stability.

\*19. California Department of Transportation, Division of Construction and Research ltr of 26 Jan 1977 from G. A. Hill to A. R. Appleton, Subj: Test Results on Lakeville Road Recycling Project Materials.

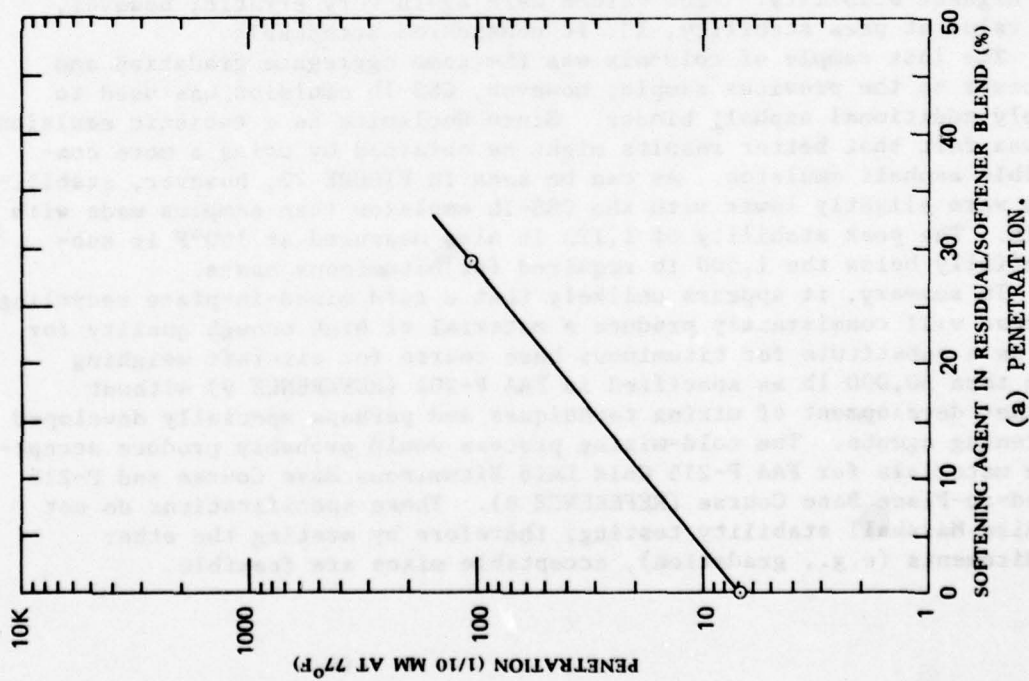
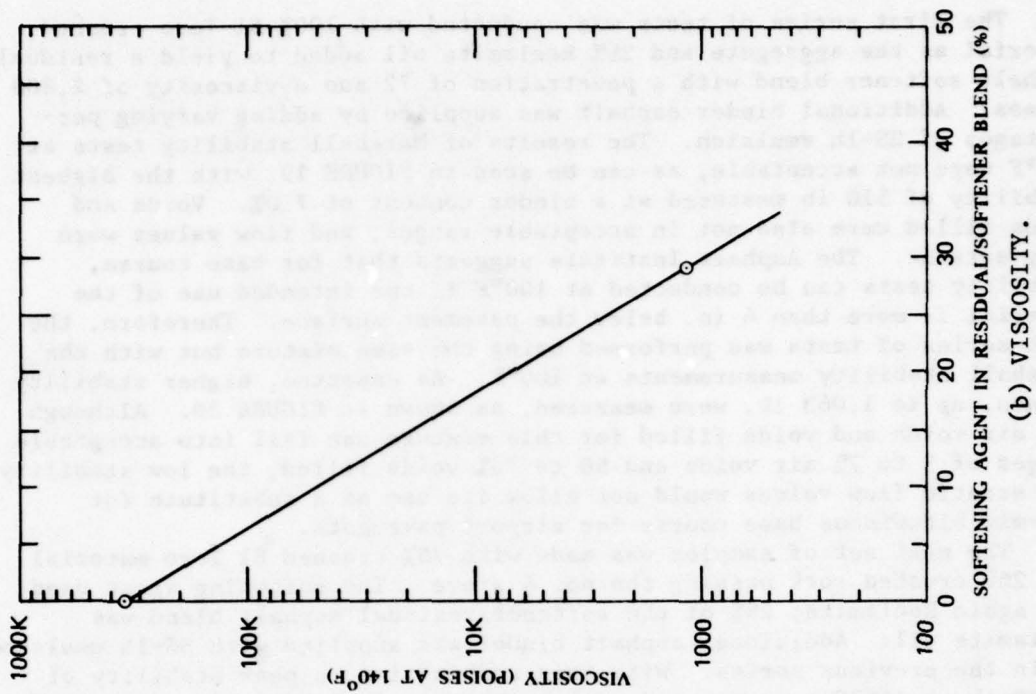


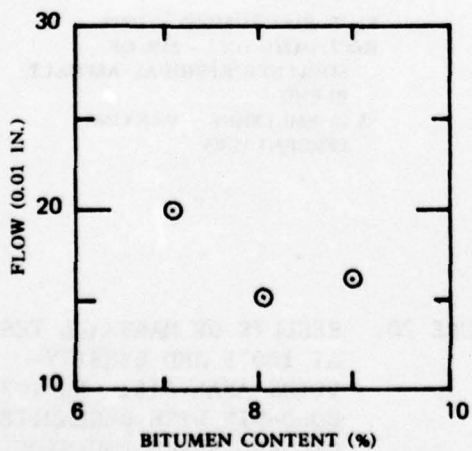
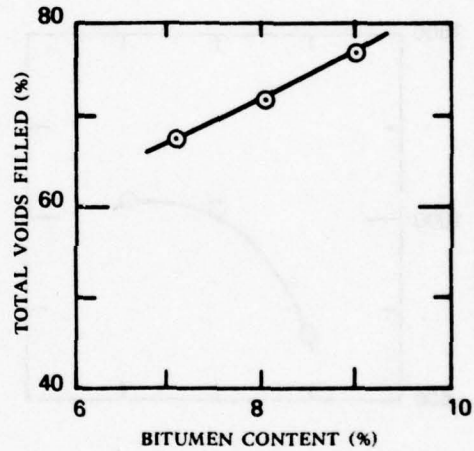
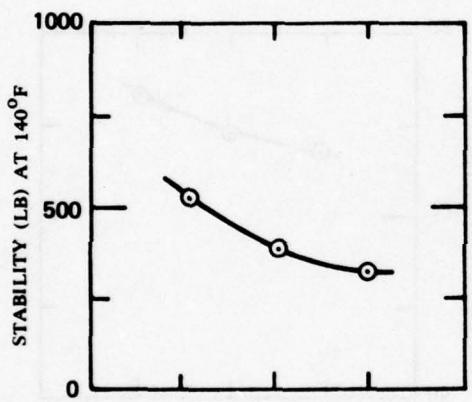
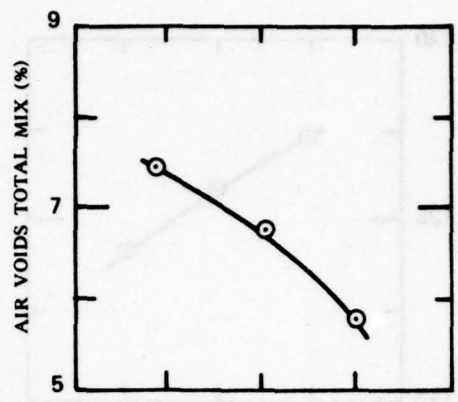
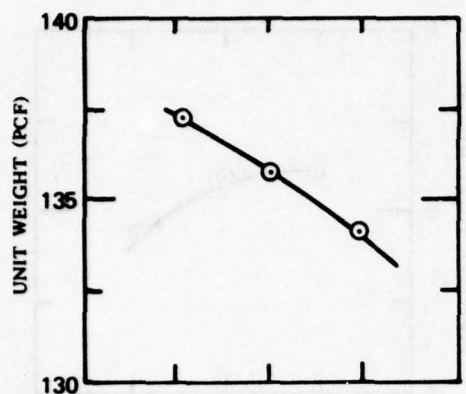
FIGURE 18. SOFTENING EFFECT OF RECLAMITE OIL ON EL TORO RESIDUAL ASPHALT CEMENT.

The first series of tests was conducted with 100% El Toro crushed material as the aggregate and 25% Reclamite oil added to yield a residual asphalt softener blend with a penetration of 72 and a viscosity of 2,800 poises. Additional binder asphalt was supplied by adding varying percentages of SS-lh emulsion. The results of Marshall stability tests at 140°F were not acceptable, as can be seen in FIGURE 19, with the highest stability of 510 lb measured at a binder content of 7.0%. Voids and voids filled were also not in acceptable ranges, and flow values were very erratic. The Asphalt Institute suggests that for base course, stability tests can be conducted at 100°F if the intended use of the material is more than 4 in. below the pavement surface. Therefore, the next series of tests was performed using the same mixture but with the Marshall stability measurements at 100°F. As expected, higher stability values, up to 1,063 lb, were measured, as shown in FIGURE 20. Although the air voids and voids filled for this mixture can fall into acceptable ranges of 5 to 7% air voids and 50 to 70% voids filled, the low stability and erratic flow values would not allow its use as a substitute for hot-mix bituminous base course for airport pavements.

The next set of samples was made with 75% crushed El Toro material and 25% crushed rock passing the no. 4 sieve. The softening agent used was again Reclamite; 25% of the softener/residual asphalt blend was Reclamite oil. Additional asphalt binder was supplied with SS-lh emulsion, as in the previous series. With this combination, a peak stability of 1,500 lb at 100°F was measured, as can be seen in FIGURE 21. Air voids and voids filled criteria were nearly met at the bitumen content with the highest stability. Flow values were again very erratic; however, the value at peak stability, 13, is considered acceptable.

The last sample of cold-mix was the same aggregate gradation and softener as the previous sample; however, CSS-lh emulsion was used to supply additional asphalt binder. Since Reclamite is a cationic emulsion, it was felt that better results might be obtained by using a more compatible asphalt emulsion. As can be seen in FIGURE 22, however, stabilities were slightly lower with the CSS-lh emulsion than samples made with SS-lh. The peak stability of 1,123 lb also measured at 100°F is substantially below the 1,500 lb required for bituminous bases.

In summary, it appears unlikely that a cold mixed-in-place recycling process will consistently produce a material of high enough quality for use as a substitute for bituminous base course for aircraft weighing more than 30,000 lb as specified in FAA P-201 (REFERENCE 9) without further development of mixing techniques and perhaps specially developed softening agents. The cold-mixing process would probably produce acceptable materials for FAA P-215 Cold Laid Bituminous Base Course and P-216 Mixed-in-Place Base Course (REFERENCE 9). These specifications do not require Marshall stability testing; therefore by meeting the other requirements (e.g., gradation), acceptable mixes are feasible.



**MIX DESCRIPTION**

EL TORO CRUSHED - 100%  
 RECLAMITE OIL - 25% OF  
 SOFTENER/RESIDUAL BLEND  
 SS-1h EMULSION - VARYING  
 PERCENTAGES

FIGURE 19. RESULTS OF MARSHALL TEST AT 140°F AND DENSITY-VOIDS ANALYSIS: EL TORO COLD-MIX WITH RECLAMITE OIL AND SS-1h EMULSION.

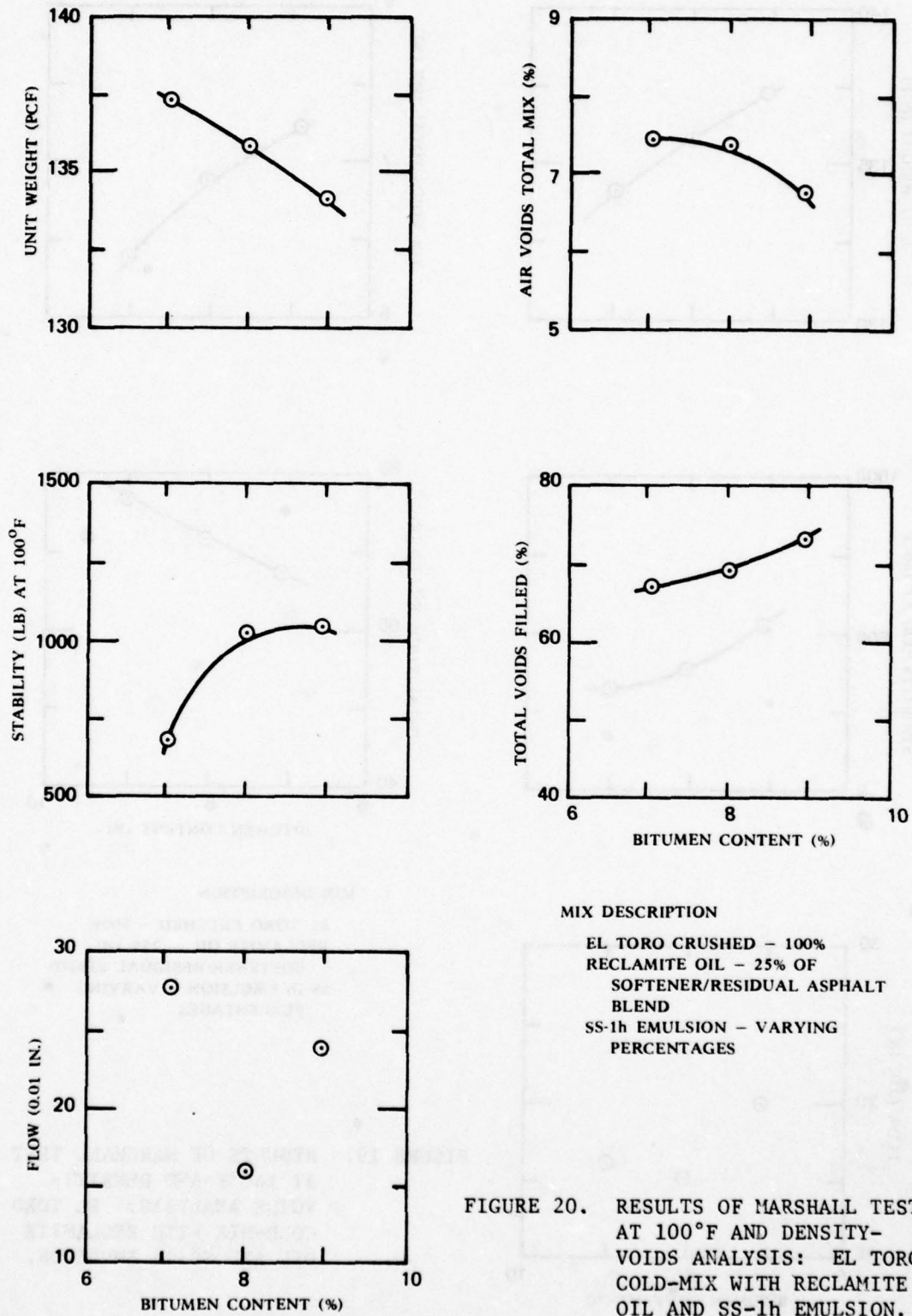
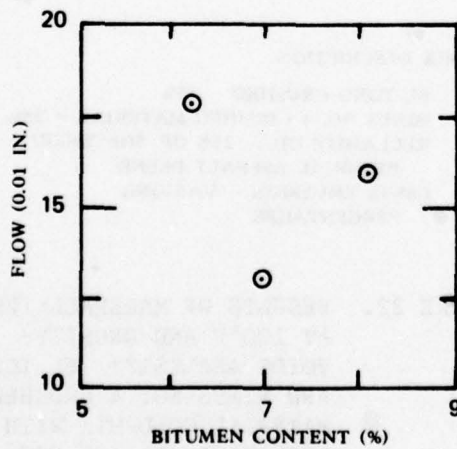
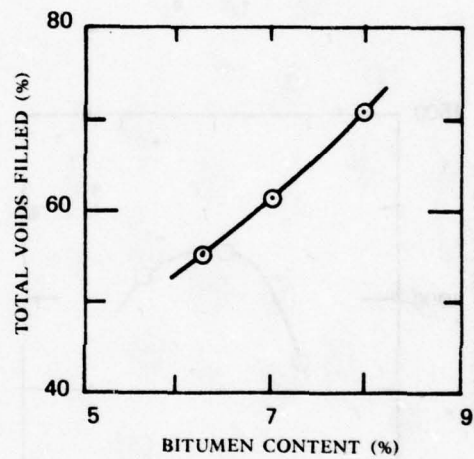
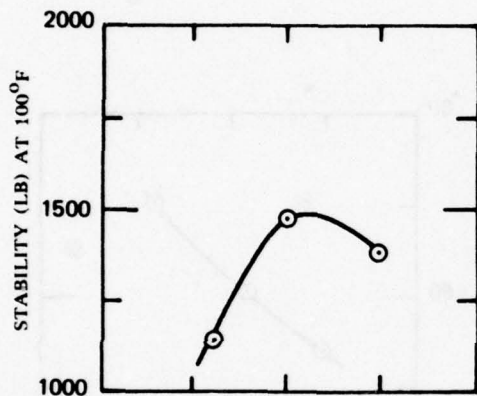
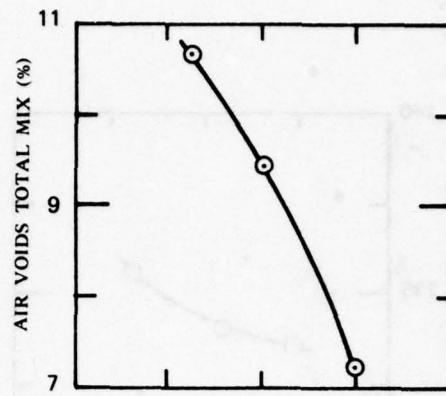
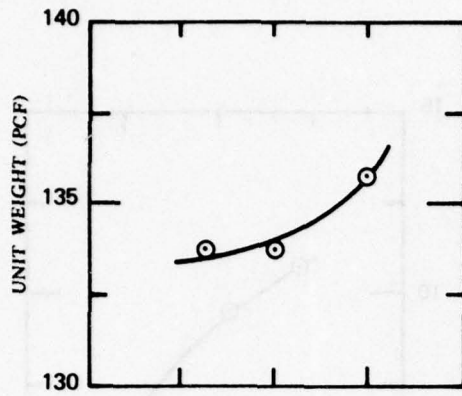


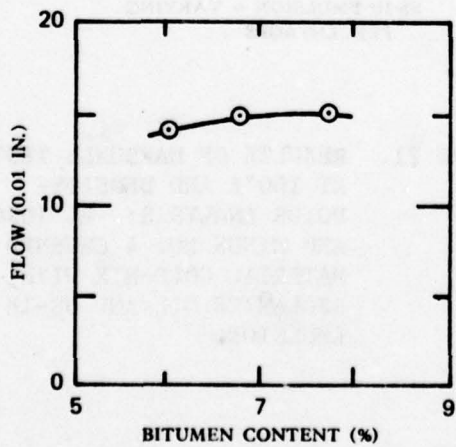
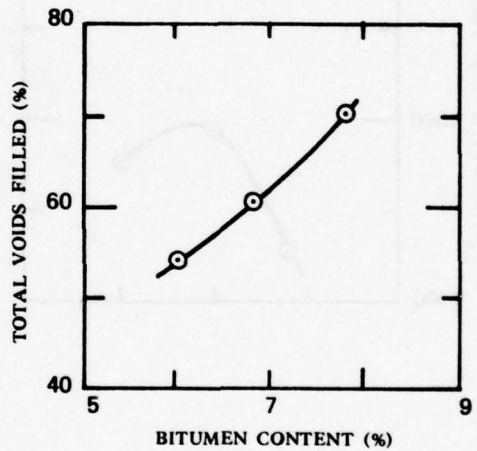
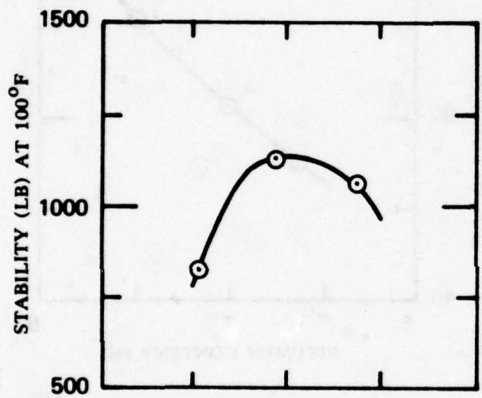
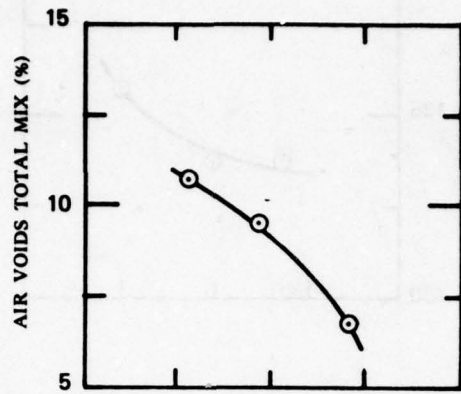
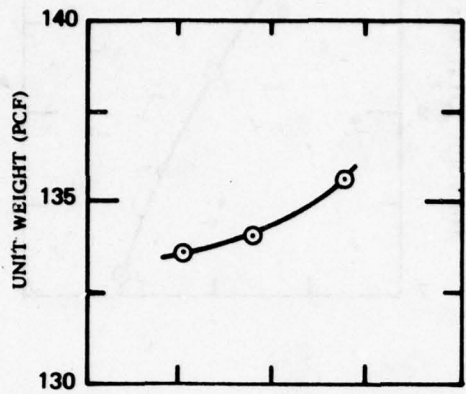
FIGURE 20. RESULTS OF MARSHALL TEST AT 100°F AND DENSITY-VOIDS ANALYSIS: EL TORO COLD-MIX WITH RECLAMITE OIL AND SS-1h EMULSION.



**MIX DESCRIPTION**

EL TORO CRUSHED - 75%  
 MINUS NO. 4 CRUSHED MATERIAL - 25%  
 RECLAMITE OIL - 25% OF  
 SOFTENER/RESIDUAL BLEND  
 SS-1h EMULSION - VARYING  
 PERCENTAGES

FIGURE 21. RESULTS OF MARSHALL TEST AT 100°F AND DENSITY-VOIDS ANALYSIS: EL TORO AND MINUS NO. 4 CRUSHED MATERIAL COLD-MIX WITH RECLAMITE OIL AND SS-1h EMULSION.



**MIX DESCRIPTION**

EL TORO CRUSHED - 75%  
 MINUS NO. 4 CRUSHED MATERIAL - 25%  
 RECLAMITE OIL - 25% OF SOFTENER/  
 RESIDUAL ASPHALT BLEND  
 CSS-1h EMULSION - VARYING  
 PERCENTAGES

FIGURE 22. RESULTS OF MARSHALL TEST AT 100°F AND DENSITY-VOIDS ANALYSIS: EL TORO AND MINUS NO. 4 CRUSHED MATERIAL COLD-MIX WITH RECLAMITE OIL AND CSS-1h EMULSION.

## ASPHALT CONCRETE RECYCLING CRITERIA

### Maintenance Option Selection

Recycling of asphalt concrete provides the pavement engineer with another option in the overall framework of pavement maintenance alternatives. The selection of any maintenance strategy, including recycling, is based on factors such as the following:

1. Types of pavement distress occurring
2. Probable causes of distress
3. Anticipated pavement loading
4. Horizontal and vertical geometries
5. Availability of materials
6. Operational considerations
7. Economics

A decision-making process using these factors is shown in FIGURE 23 (after REFERENCE 20\*).

Once the decision to recycle has been made, the most appropriate recycling technique must be determined. All of the same factors which are considered in selecting a maintenance alternative are also used in determining which recycling option is to be used. In addition, consideration must be given to availability of equipment, suitability of candidate recycle material, alternate sources of materials, and ultimate use of the recycled material in the pavement structure. To assist in this decision-making process the flow chart in FIGURE 24 is offered. Based on this preliminary decision, detailed laboratory analyses, economic feasibility, and material properties can be determined for the selected alternative.

### Quality Assessment of Candidate Material

After a recycling option has been selected, the quality of the candidate recycle materials must be evaluated through detailed laboratory investigations. Experience gained during this investigation showed that no new test procedures are required to evaluate candidate materials for recycling. The applicable test procedures and standards are summarized in TABLE 13. Some of the data pertaining to material properties of candidate recycle pavement may be available from construction records; however, check tests should be performed to verify such data.

\*20. J. A. Epps et al. "A Review of Pavement Materials Recycling Techniques and Associated Laboratory Tests and Evaluation," Proceedings of the Association of Asphalt Paving Technologists, New Orleans, La., 1976, pp 304-337.

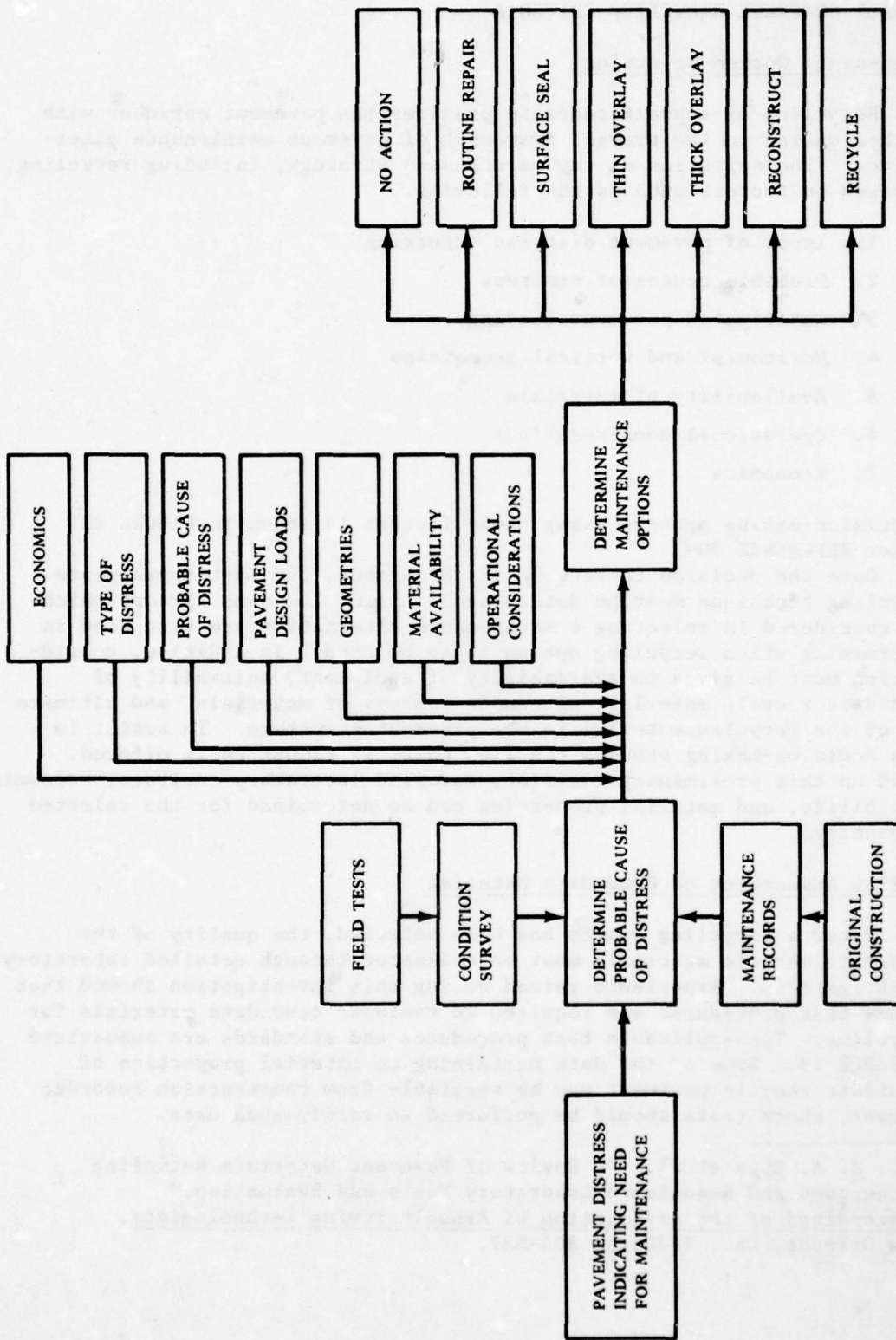


FIGURE 23. ASPHALT CONCRETE MAINTENANCE OPTIONS (AFTER REFERENCE 20).

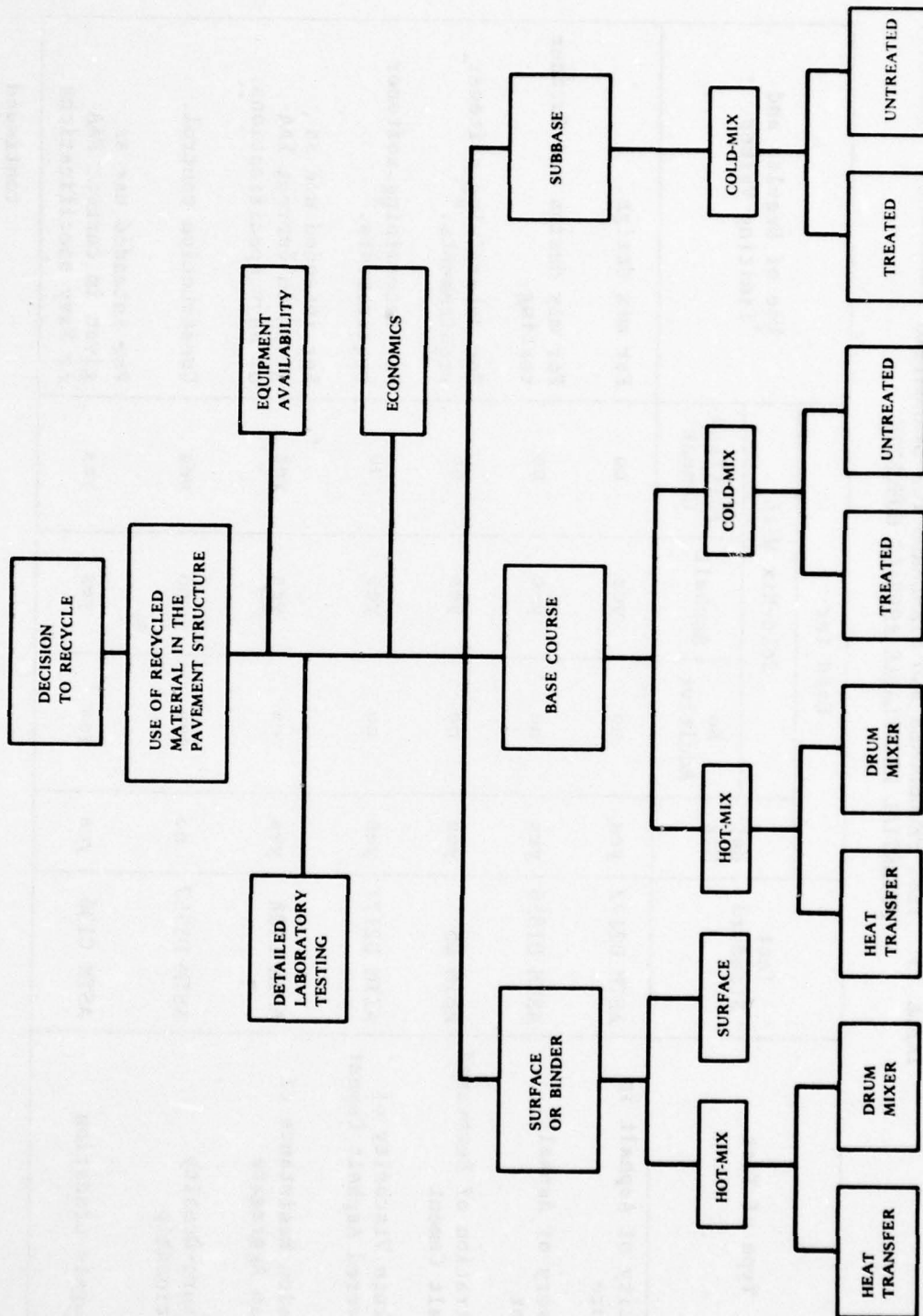


FIGURE 24. FLOW CHART: SELECTING ASPHALT CONCRETE RECYCLING ALTERNATIVE.

TABLE 13. TEST PROCEDURES AND STANDARDS FOR EVALUATING  
POTENTIAL RECYCLABLE ASPHALT CONCRETE

Type of Test	Test Standard	Used for --				Use of Results and Limiting Values
		Hot-Mix	Cold-Mix With			
			No Additive	Asphalt	Portland Cement	
Quantity of Asphalt in Mixture	ASTM D2172	yes	no	yes	no	For mix design.
Recovery of Asphalt Cement	ASTM D1856	yes	no	yes	no	For mix design and further testing.
Penetration of Recovered Asphalt Cement	ASTM D5	yes	no	yes	no	For determining softener requirements.
Absolute Viscosity of Recovered Asphalt Cement	ASTM D2171	yes	no	yes	no	For determining softener requirements.
Abrasion Resistance of Coarse Aggregate	ASTM C128	yes	yes	yes	yes	For intended use as given in current FAA or Navy specifications.
Moisture-Density Relationship	ASTM D1557	no	yes	no	yes	Construction control.
Aggregate Gradation	ASTM C136	yes	yes	yes	yes	For intended use as given in current FAA or Navy specifications.

continued

TABLE 13. CONTINUED

Type of Test	Test Standard	Used for --				Use of Results and Limiting Values
		Hot-Mix	Cold-Mix With			
			No Additive	Asphalt	Portland Cement	
Liquid Limit	ASTM D423	no	yes	yes	yes	For intended use as given in current FAA or Navy specifications.
Plastic Limit	ASTM D424	no	yes	yes	yes	For intended use as given in current FAA or Navy specifications.
Sand Equivalent	ASTM D2419	no	yes	yes	yes	For intended use as given in current FAA or Navy specifications.

<sup>a</sup> A lower limit of penetration and an upper limit of viscosity for recyclable asphalt have not been precisely defined. Testing of residual asphalt and softener blends is relied on to determine adequacy of binder material.

### Softening Agent Criteria.

Softening agents used on projects observed during this study were primarily aromatic extender oils as described in the softening agent section of this report. Other materials used have been soft grades of asphalt, typically AR-1000 or AC-5, and proprietary products such as Reclamite. Hot-mix recycling projects using drum mixers have typically used an extender oil and additional new asphalt to provide an optimum asphalt content when virgin aggregate is added. Heat transfer process (Maplewood) projects have used only asphalt cements; it is feasible, however, to also use an extender oil in the heat transfer process if sufficient softening is not obtained with only asphalt cements. Criteria for softening agents, presented in TABLE 14, are based on the mixtures tested during this investigation and observation of recycling projects. These criteria should be considered preliminary because recycling is a dynamic field and new developments in softening agents specifically designed for hot- and cold-mix recycling are anticipated.

It must be emphasized again that laboratory tests must be performed on any selected softening agent with the residual asphalt cement contained in the particular material to be recycled.

### Evaluation of Recycled Mixes

Just as is required for new pavement mixes, recycled mixes, whether hot or cold, must be evaluated for suitability. Based on the mixtures tested during this investigation, conventional test procedures as outlined in applicable FAA and Navy specifications can be used to evaluate such mixes. An exception to this is the procedure for determining the amount of softening agent required, as described in APPENDIX B. This procedure must be followed for each mixture when a softening agent is used to avoid having the effects of a very high viscosity asphalt binder alter the mixture properties. For example, it is easily possible to obtain high Marshall stability values by not softening the residual asphalt sufficiently. The Las Vegas test series shown in FIGURE C-9 demonstrates this possibility. The sample mix at 4.5% asphalt content contains no softener and has a stability of 4,500 lb while the sample with sufficient softener to obtain an equivalent AR-2000 binder has a stability of 2,500 lb. A higher asphalt content of 5.5%, rather than 4.5%, also lowered the stability; however, the dominant cause is due to a lower binder viscosity. This points out the need for caution in evaluating Marshall stabilities of recycled mixes.

A tabulation of test procedures and suggested limiting values for evaluating recycled mixes is presented in TABLE 15.

TABLE 14. PRELIMINARY SOFTENING AGENT CRITERIA

Type of Test	Test Standard	Limiting Values	Use of Results
Softener Only <sup>a</sup>			
Kinematic Viscosity	ASTM D2170	80-500 centistokes at 140°F	Measure of ease of dispersion in mix.
Flash Point	ASTM D92	390°F (min.)	Handling safety.
Composition Analysis <sup>b</sup>	ASTM D2006	N/P > 1.0, N+A <sub>1</sub> /P+A <sub>2</sub> = 0.4 to 1.0	Compatibility and durability.
Softener/Residual Asphalt Blend			
Absolute Viscosity, poises at 140°F	ASTM D2171	As specified	Blend viscosity or penetration; match asphalt grade used for new construction.
Penetration, 77°F	ASTM D5	As specified	Use method in use in local area.
Thin Film Oven Test	ASTM D1754	--	Aging of blend to assess durability.
Residue After Thin Film Oven Test			
Retained Penetration, Percent of Blend Original, 77°F	ASTM D5	Minimum 40	Measure of durability.

continued

TABLE 14. CONTINUED

Type of Test	Test Standard	Limiting Values	Use of Results
Residue After Thin Film Oven Test (continued)			
Increase in Viscosity, Percent of Blend Original, Poises at 140°F	ASTM D2171	Maximum 500%	Measure of durability.
Ductility, 77°F, 5 cm/min. Blends with original penetration >140 or viscosity <750 P	ASTM D113	Minimum 100 cm	Measure of durability and adhesion.
Blends with original penetration <140 or viscosity >750 P		Minimum 75 cm	

<sup>a</sup>Applies only to active oil portion if softener is emulsified.

<sup>b</sup>For paving grade asphalts, this test not required if candidate material has a good record of performance.

TABLE 15. TEST PROCEDURES AND STANDARDS FOR EVALUATING RECYCLED MIXES

Type of Test	Test Standard	Used for --				Use of Results and Limiting Values
		Hot-Mix	Cold-Mix			
			No Additive	Asphalt	Portland Cement	
Marshall Stability	ASTM D1559 or MIL-STD 620A, Method 100	yes	no	yes	no	Determination of stability 1,800 lb minimum, other properties from specifications for intended use.
Theoretical Maximum Specific Gravity	ASTM D2041	yes	no	yes	no	Determination of air voids and voids filled.
Bulk Specific Gravity	ASTM D1188	yes	no	yes	no	Determination of optimum asphalt content and for voids analysis.
Immersion Compression Test	MIL-STD 620A, Method 104	yes	no	yes	no	Stripping potential, index of retained stability must be >75.
Penetration	ASTM D5	yes	no	yes	no	Consistency of asphalt/softener blend, matching of penetration of added virgin asphalt or grade normally used.
Absolute Viscosity	ASTM D2171	yes	no	yes	no	Consistency of blend, matching of viscosity of asphalt grade normally used.

continued

TABLE 15. CONTINUED

Type of Test	Test Standard	Used for --				Use of Results and Limiting Values
		Hot-Mix	Cold-Mix			
			No Additive	Asphalt	Portland Cement	
California Bearing Ratio	ASTM D1883 or MIL-STD 621A, Method 100	no	yes	no	no	Evaluation of subbase and base course blends, minimum CBR = 80, subbase course minimum CBR = 40.
Compressive Strength	ASTM D1633	no	no	no	yes	Cement-treated base, minimum 750 psi at 7 days.
Wet-Dry Tests	ASTM D558	no	no	no	yes	Weight loss after 12 cycles <14%.
Freeze-Thaw Tests	ASTM D559	no	no	no	yes	Weight loss after 12 cycles <14%.
Sieve Analysis	ASTM C136	yes	yes	yes	yes	Conformance to specifications for intended use.
Liquid Limit	ASTM D423	no	yes	no	yes	Conformance to specifications for intended use.
Plastic Limit	ASTM D424	no	yes	no	yes	Conformance to specifications for intended use.
Sand Equivalent	ASTM D2419	no	yes	no	yes	Conformance to specifications for intended use.

## DESIGN GUIDELINES

To assist pavement and material engineers in recycling asphalt concrete materials, a series of design guidelines for hot and cold recycling has been established based on experience gained with mixes during this investigation. The design guidelines are presented as a step-by-step process with accompanying flow charts. Application of these procedures and good engineering judgment will enable the designer to obtain a satisfactory mix. The first step as described in earlier sections of this report is to select the recycling option, hot or cold, best suited for the intended use of the material. After that decision has been made, one of the following procedures can be used to prepare the mix design.

### Hot-Mix

The step numbers hereafter referred to in this section correspond with the block numbers in the flow chart shown in FIGURE 25.

- Step 1. Decision to Recycle (covered in the section on ASPHALT CONCRETE RECYCLING CRITERIA).
- Step 2. Hot-Mix Recycling - Mix design procedures are applicable to both heat transfer and drum mixer operations.
- Step 3. Sample Candidate Materials - A minimum of 200 lb of asphalt concrete representative of the material to be recycled is necessary. If the full depth of the pavement is to be recycled, the sample must contain representative portions of all layers of the asphalt concrete pavement structure.
- Step 4. Extract and Recover Asphalt and Aggregate - Extract the asphalt binder using the procedures in ASTM D2172. Recover the asphalt cement from the extraction solution by following ASTM D1856. Retain all of the mineral aggregate for gradation and quality checks.

### I. Residual Asphalt Evaluation

- Step 5. Determine the absolute viscosity or penetration of the residual asphalt using ASTM D2171 or ASTM D5, respectively. (Viscosity is the preferred method of test as it measures a fundamental property of asphalt, requires less material for testing, and is more sensitive to changes in consistency.)
- Step 6. Select the type of softening agent and verify suitability. (Generally, if the viscosity of the residual asphalt is greater than 20,000 poises at 140°F or penetration is less than 20 at 77°F, an extender oil type softener will be necessary to achieve a viscosity approaching a new asphalt. If the viscosity of the residual is less than 20,000 poises at 140°F or penetration is greater than 20 at 77°F, additional makeup asphalt

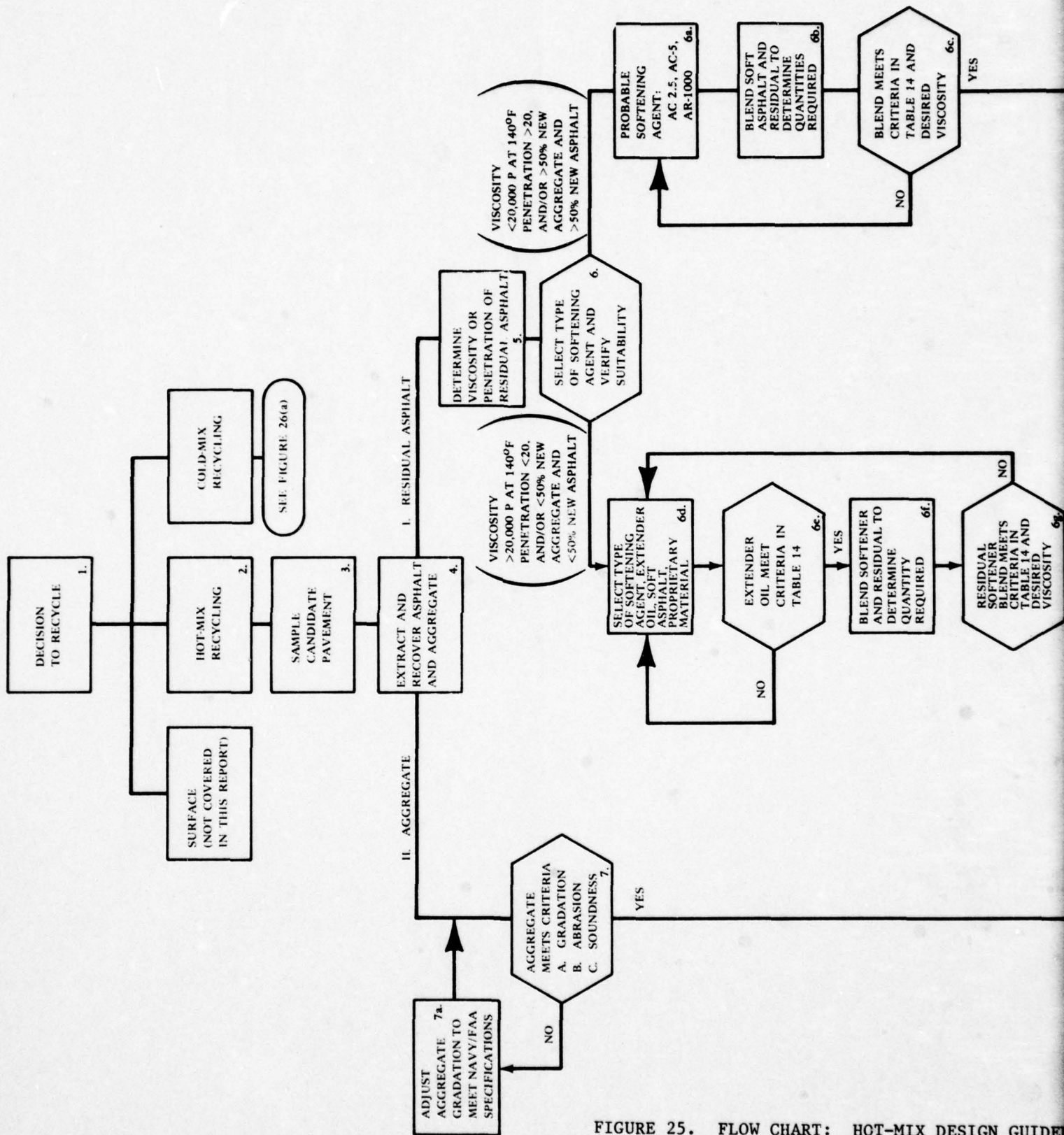


FIGURE 25. FLOW CHART: HOT-MIX DESIGN GUIDE

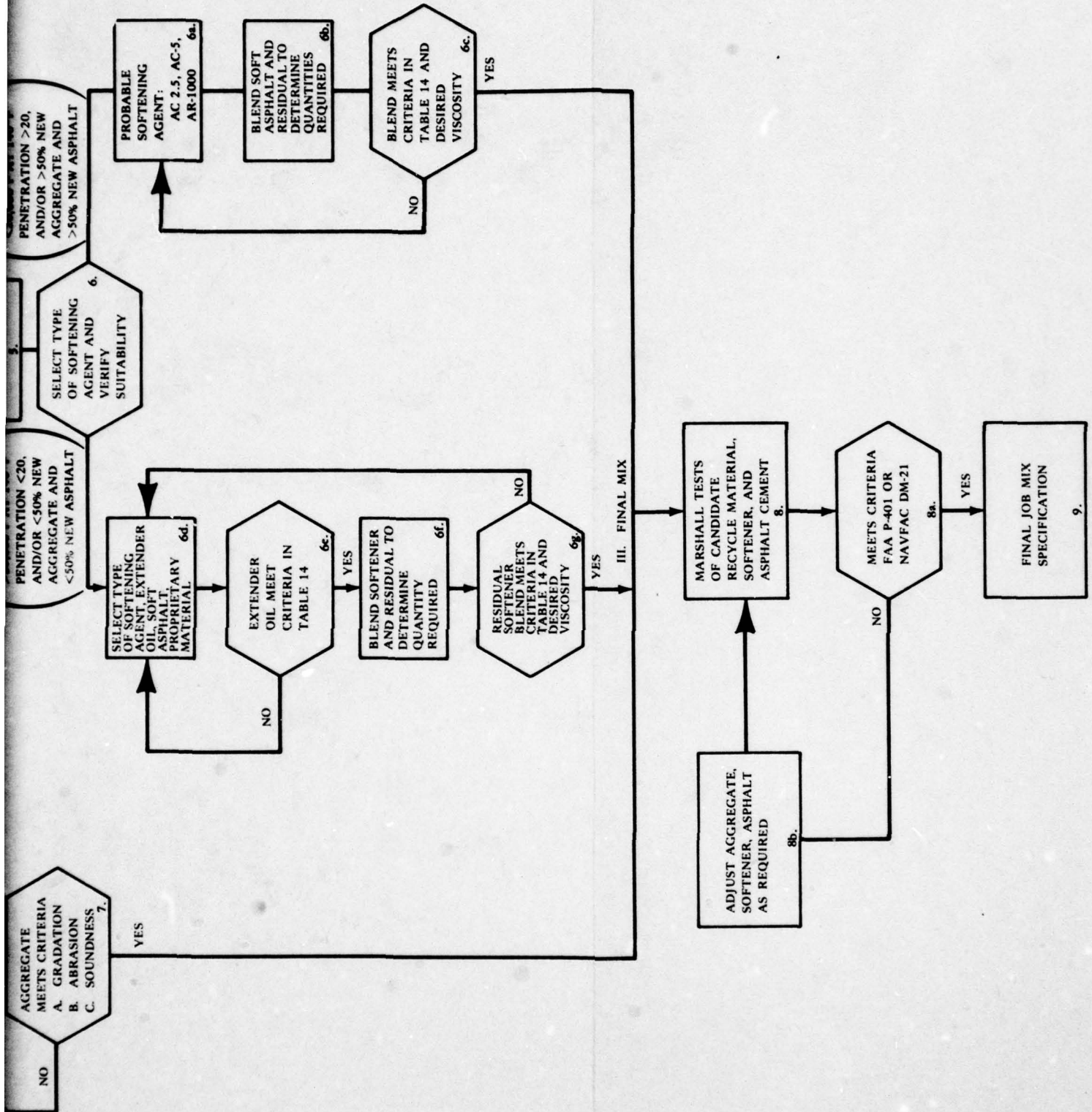


FIGURE 25. FLOW CHART: HOT-MIX DESIGN GUIDELINES.

to take care of new aggregate added could act as the sole softening agent. This would also apply to the heat transfer process where 50% or more new aggregate and thus 50% or more new asphalt is used. For example, assume the Las Vegas sample is to be recycled using the heat transfer process and 50% new aggregate is to be used. This would mean that the final mix will require approximately equal parts of new and residual asphalt cement ( $\approx$ 50:50 new:residual asphalt blend). Checking this blend using AR-1000 in FIGURE A-12(b) shows a viscosity of 2,600 poises and a penetration of 47, which are acceptable values. On the other hand, if a drum mixer approach is selected for the same Las Vegas material and a preliminary design of 10% new aggregate is selected, the alternate approach using an extender oil plus required makeup asphalt would be selected.)

#### A. Asphalt Cement as Softening Agent

- Step 6a. Probable softening agents - AC-2.5, AC-5, AR-1000, 200-300 penetration. Verify that the asphalt cements used meet applicable ASTM D946 or D3381.
- Step 6b. Blend selected asphalt and residual to determine quantities required. Use the procedures in APPENDIX B to determine required quantity of soft asphalt required.
- Step 6c. Check to verify that the blend meets criteria in TABLE 14 and produces the design viscosity.

#### B. Extender Oil and Asphalt Cement Combination as Softening Agent

- Step 6d. Select softening agent - extender oil, proprietary material, or combination of extender oil and asphalt cement.
- Step 6e. Verify that the softening agent selected meets the criteria in TABLE 14. These tests (viscosity, flash point, and chemical composition) are used to screen out unsuitable agents.
- Step 6f. Blend selected softening agent and residual asphalt to determine quantity required to reach the design viscosity. Use the procedures in APPENDIX B.
- Step 6g. Verify that the softener/residual asphalt blend meets the criteria in TABLE 14 and produces the design viscosity.

### II. Aggregate Evaluation

- Step 7. Evaluate the aggregate from the candidate pavement for gradation, abrasion resistance, soundness, and other properties required by FAA P-401 or NAVFAC DM-21 for asphalt concrete aggregate (REFERENCES 9 or 10).

to take care of new aggregate added could act as the sole softening agent. This would also apply to the heat transfer process where 50% or more new aggregate and thus 50% or more new asphalt is used. For example, assume the Las Vegas sample is to be recycled using the heat transfer process and 50% new aggregate is to be used. This would mean that the final mix will require approximately equal parts of new and residual asphalt cement ( $\approx$ 50:50 new:residual asphalt blend). Checking this blend using AR-1000 in FIGURE A-12(b) shows a viscosity of 2,600 poises and a penetration of 47, which are acceptable values. On the other hand, if a drum mixer approach is selected for the same Las Vegas material and a preliminary design of 10% new aggregate is selected, the alternate approach using an extender oil plus required makeup asphalt would be selected.)

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- Step 7a. Make adjustments (if required) to gradation to meet current Navy and FAA specifications. (If other criteria are not met, evaluate the possibility of alternative use of recycled material; e.g., base versus surfacing where requirements are not as stringent. Note that actual job gradation will depend on the crushing method used in the field, and adjustments during construction may be necessary.)

### III. Final Mix Design

- Step 8. Perform Marshall mix design procedure with the previously selected softening agent, aggregate, asphalt, and recycle material. (The mix design procedure requires preparation of test specimens over a range of different asphalt contents to define a test curve showing an "optimum" asphalt content. Examples of mix designs are given in this report in the section on Marshall mix design. Detailed procedures for mix design can be found in Asphalt Institute Manual Series No. 2, "Mix Design Methods for Asphalt Concrete and Other Hot-Mix Types." The softening agent must be included in all mixes in quantity determined in Steps 6b or 6f.)
- Step 8a. Determine whether the mix meets FAA P-401 or NAVFAC DM-21 criteria (REFERENCES 9 or 10). (Particular attention must be given to stability, voids, and voids filled to assure satisfactory mix performance.)
- Step 8b. Adjust mix proportions, if required to meet criteria, by adjusting aggregate gradations and softener and asphalt contents.
- Step 9. Prepare job mix specifications. (After finalizing the mix design, prepare job specifications which include amount and type of softening agent, amount and gradation of new aggregate, amount and grade of new asphalt cement, if required, and overall mix proportions.)

### Cold-Mix

Selection of a cold-mix option is made by analyzing the intended end use versus material and equipment availability. For example, assume sufficient volume of asphalt concrete is available to provide a recycled base course 8 in. thick on a runway reconstruction project. Further assume that design calculations, however, show a need for 12 in. of base course because of predicted aircraft loading. By utilizing asphalt stabilization substitution of 1 in. of stabilized material for 1.5 in. of plain untreated material according to Navy criteria, the design requirements can be satisfied. This type of analysis is a very simplified example of the decision-making process involved in determining the most appropriate recycling option. Other factors, of course, such as availability of equipment, adequate materials, and qualified contractor personnel must also be considered. A series of design guidelines for each type of cold recycling is given in succeeding sections.

## I. Crushed Untreated Material and Aggregate Added

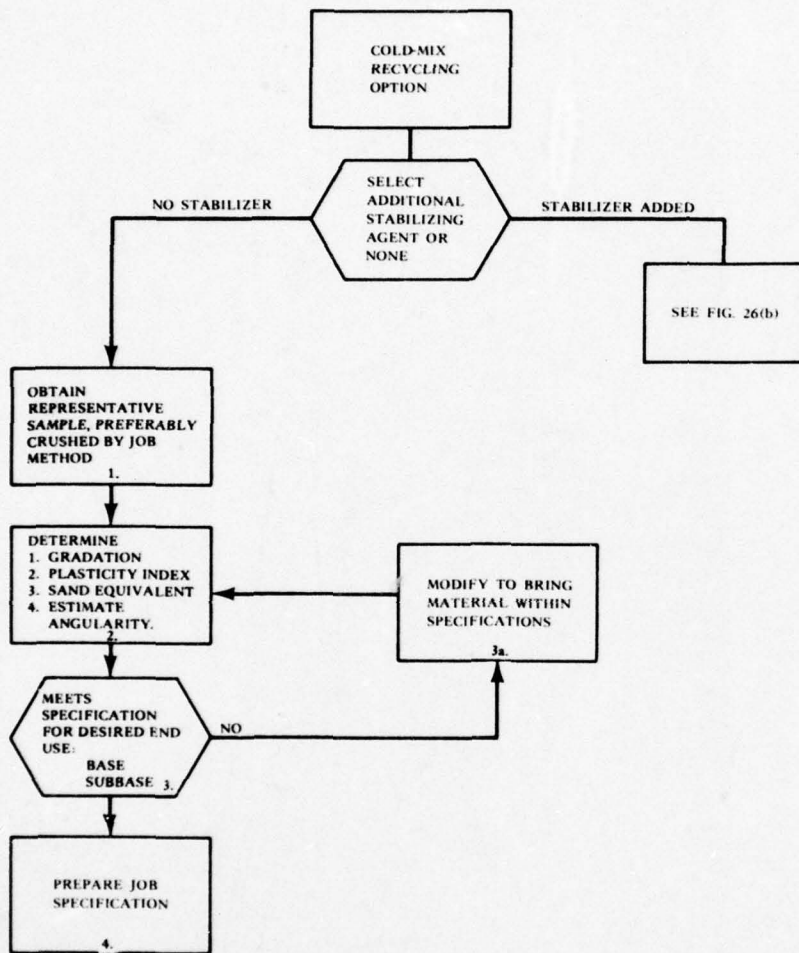
The step numbers in the description refer to the flow chart in FIGURE 26(a).

- Step 1. Obtain a representative sample of the material to be recycled. This sample should be crushed by the job method to yield a sample which will have the same characteristics as the job run material, particularly gradation and angularity.
- Step 2. Perform standard gradation analysis, plasticity index, sand equivalent, and other physical tests as required by end use specifications. Check the material retained on the No. 4 sieve for angularity. (The jaw and roll crusher used in this investigation yielded rounded particles. Other means of aggregate preparation such as the CMI Rotomill and the Metradon Pulverizer may yield crushed material with more angularity.)
- Step 3. Compare the results of the tests with applicable specifications.
- Step 3a. If specifications are not met or angularity is inadequate, add crushed aggregate base conforming to FAA P-209 or applicable NAVFAC guide specifications and retest.
- Step 4. When criteria have been met, prepare job specifications to include crushing method, aggregate blending if required, and job gradation.

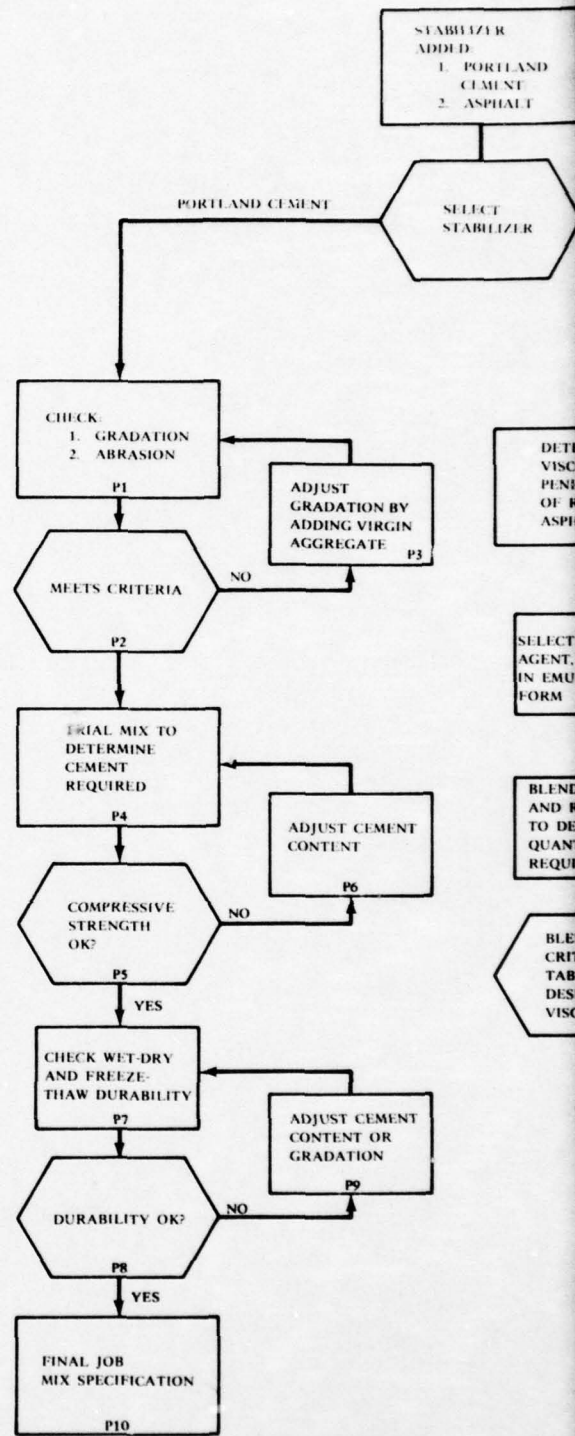
## II. Asphalt Emulsion Treated

A flow chart showing the sequence of steps in designing a cold-mix recycled pavement with asphalt emulsion is given in FIGURE 26(b). The design procedure is the same for both in-place and central plant recycling.

- Step A1. Extract and recover asphalt and aggregate. (This is necessary to provide materials for softening agent and gradation tests. The test methods are given in TABLE 14.)
- Steps A2-A4. Test the recovered aggregate for compliance with FAA P-215 or P-216 specifications. (If necessary blend virgin aggregate which meets the specifications to correct gradation, abrasion loss, or other deficiencies.)
- Step A5. Determine the viscosity or penetration of the residual asphalt. (This provides baseline data for determining the quantity of softener required as described in APPENDIX B.)
- Step A6. Select a softening agent. (Use of a softening agent is recommended to allow effective use of the asphalt cement already in the sample. Softening agents in emulsified form are the most suitable for cold recycling applications.)

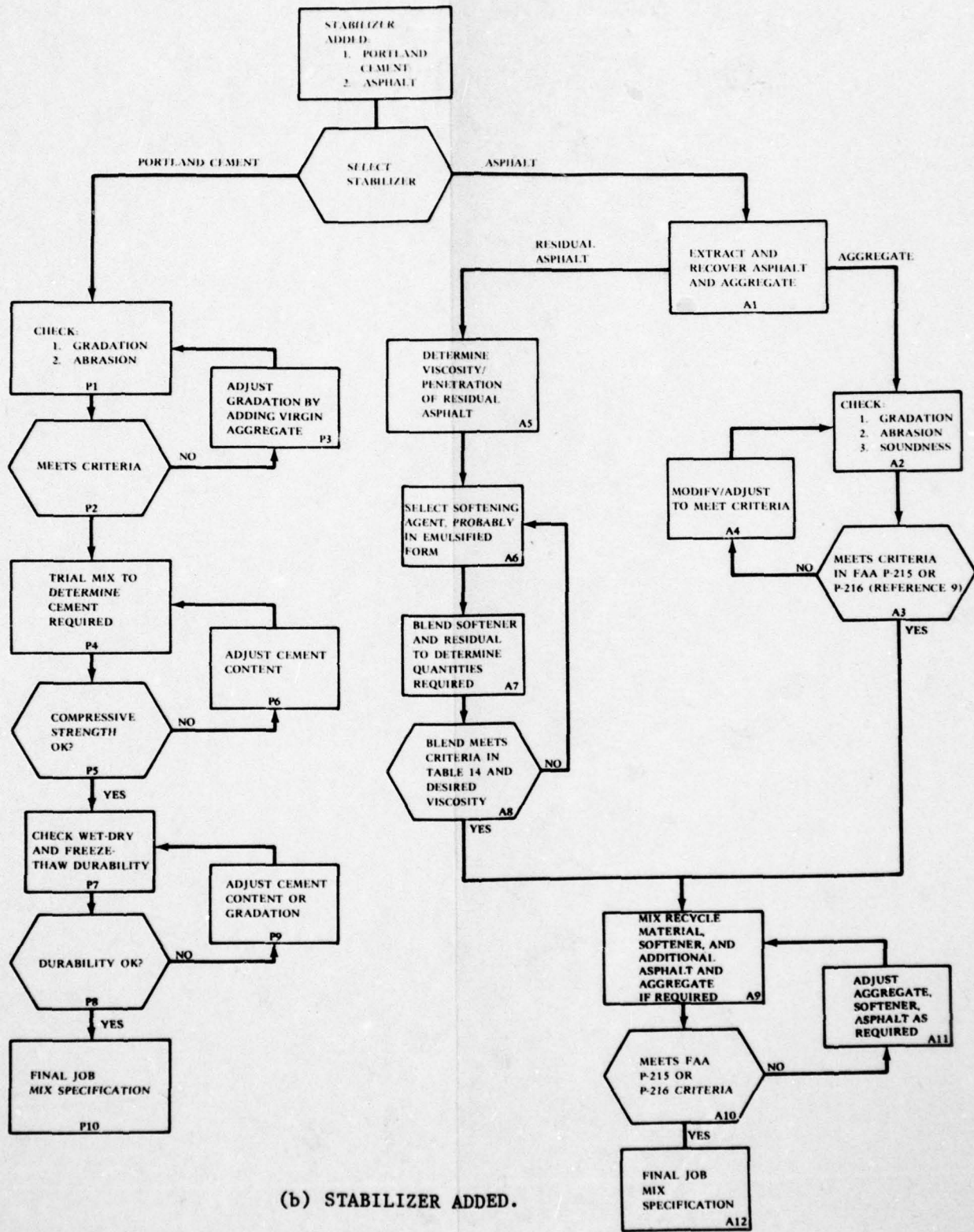


(a) NO STABILIZER ADDED.



(b) STABILIZER ADDED.

FIGURE 26. FLOW CHART: COLD-MIX DESIGN GUIDELINES.



(b) STABILIZER ADDED.

FIG. 26. FLOW CHART: COLD-MIX DESIGN GUIDELINES.

- Step A7. Blend the selected softeners and the residual asphalt to determine quantity of softener required. (If the softener is emulsified it should be distilled to remove the water portion and then the residue used in the procedure described in APPENDIX B.)
- Step A8. Check the properties of the blend against the criteria in TABLE 14.
- Steps A9-A11. Blend the recycle material, softening agent, additional asphalt emulsion, and additional aggregate as required. Verify that the design criteria as specified in P-215 or P-216 are met. If not, make adjustments in the mix as required. (Marshall stability testing of these cold mixes is not required.)
- Step A12. Prepare the final job mix specification including the percentages of recycled material, softening agent, asphalt emulsion, and virgin aggregate.

### III. Portland Cement Treated

Although none of the laboratory mixes in this investigation had a compressive strength of 750 psi at 7 days as is normally required for cement treated base course, guidelines are given to provide a framework for further investigation of these mixes. The possibility of meeting strength requirements exists or lower strengths might be acceptable by using thicker design sections. The flowchart for this series of guidelines is shown in FIGURE 26(b).

- Steps P1-P3. Using the specifications in FAA P-304 (REFERENCE 9) or NAVFAC DM-21 (REFERENCE 10), check the crushed recycle material for gradation, abrasion resistance, plasticity index, and sand equivalent as required. (If the specifications are not met the gradation and other properties may be met by blending virgin aggregate with recycle material. If criteria cannot be met, consideration should be given to another form of recycling.)
- Steps P4-P6. Mix samples of recycled material, cement, water, and additional aggregate, if determined to be required in steps P1-P3, and prepare compressive strength samples. (If samples cannot be made with a cement content of 3% to 6% and compressive strength of at least 750 psi at 7 days is not achieved, consider other means of recycling.)
- Steps P7-P9. Providing that strength requirements can be met, durability of the mixtures should be evaluated by subjecting the samples to 12 cycles of the wet-dry and freeze-thaw tests in accordance with AASHTO T-135 and T-136. The maximum weight loss of the specimens for either test shall be 14%.

**Step P10. If all of the criteria are met, prepare a final job mix specification giving gradation, cement content, water content, and density.**

## CONCLUSIONS

Based on the results of this investigation involving laboratory experiments on aged asphaltic concrete samples obtained from three Naval airfields and two civilian airports, the following general conclusions are warranted:

1. Aged asphalt concrete can be hot-mix recycled into mixtures with properties conforming to Navy and FAA specifications for new asphaltic concrete mixes. In the recycling process, the binders can be modified by adding proper amounts of softening agents or asphalt cement or both and proper amounts of virgin aggregates to obtain an acceptable stability-flow-density-voids relationship for the recycled mixes.
2. Aged asphalt concrete can be cold-mix recycled into mixtures with properties that meet Navy and FAA specifications for certain applications as base courses by addition of crushed rock or chemical stabilizer.
3. Design procedures and guidelines for recycling asphalt concrete pavements have been established in this investigation.

The following specific conclusions are also offered.

### Softening Agents

1. A reasonably good linear relationship exists between softener/residual asphalt blends and the log of viscosity or penetration for softener concentrations of up to 50%.
2. The extender oil softeners, when blended with residual asphalt, yield materials which appear to have most of the physical properties of new asphalt cements.
3. Each softening agent must be tested with the particular residual asphalt to be recycled.

### Hot-Mix Recycling

1. Once the amount of softener required to attain a design viscosity is determined, conventional mix design procedures can be followed.
2. The gradation of recycled pavement aggregate is altered by crushing and therefore may require job adjustments if laboratory testing is done on uncrushed material.
3. For most asphalt concrete pavement recycling material, addition of a softening agent will raise asphalt contents over optimum, thereby requiring addition of new aggregate.
4. With most mixes, a softening agent in addition to soft grades of asphalt will be required. In some heat transfer mixes where more than 50% new asphalt is used, additional softeners will not be required.

5. Mixes that exhibit a tendency for stripping may not be acceptable for recycling because of difficulties in introducing antistripping admixtures.

### Cold-Mix Recycling

#### No Chemicals Added (Unstabilized).

1. The samples prepared with recycle-only material had low CBR values. Addition of approximately 25% crushed rock base material raised the CBR to an acceptable 80 value or better.
2. In-place methods of crushing that were observed appear to yield more angular material and to compact more readily than material crushed in the laboratory.
3. If gradation, angularity, plasticity index, or sand equivalent requirements in base course specifications can be met, a design CBR of 80 is reasonable for recycled base course.

#### Portland Cement Treated.

1. Compressive strengths of all mixtures tested were less than the required 750 psi at 7 days as is specified in FAA P-304 and NAVFAC DM-21 (REFERENCES 9 and 10).

#### Asphalt Emulsion Treated.

1. Low stability values and erratic test results preclude recommending cold-mix recycled material to replace P-201 bituminous base course specified material at this time.
2. Criteria for P-215, cold-laid bituminous base course and P-216 mixed in-place base course can be met by cold recycling.

## RECOMMENDATIONS

It is recommended that a pilot demonstration project be conducted to recycle, by a hot-mix recycling procedure, an aged airport pavement into a new surface course. The project should include utilization of the design procedures developed herein, close monitoring of the recycling material and construction procedure, and a program for long term assessment of the performance of the recycled pavement.

It is also recommended that the following specific areas be investigated further; these are not listed in order of priority:

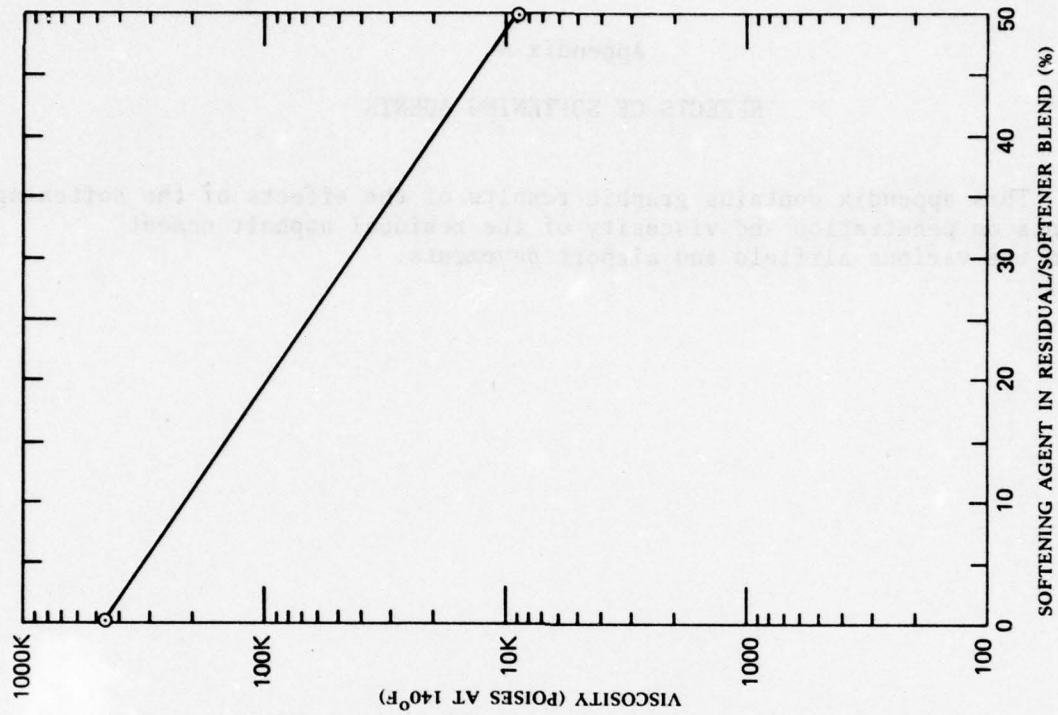
1. Materials and techniques to reduce stripping in both hot and cold recycled mixes.
2. Long-term durability of recycled pavements by laboratory accelerated-aging tests.
3. Materials and techniques for enhancing and refining cold-mix recycling of asphalt concrete materials.
4. Structural performance of recycled pavement sections compared to pavements constructed with virgin materials.
5. Materials and methods to obtain higher strengths with portland cement treated, recycled, asphalt materials.
6. Long-term effects of softening agents on residual asphalt cements and recycled mixes.
7. State-of-the-art of recycling portland cement concrete airport pavements.

**ACKNOWLEDGMENT**

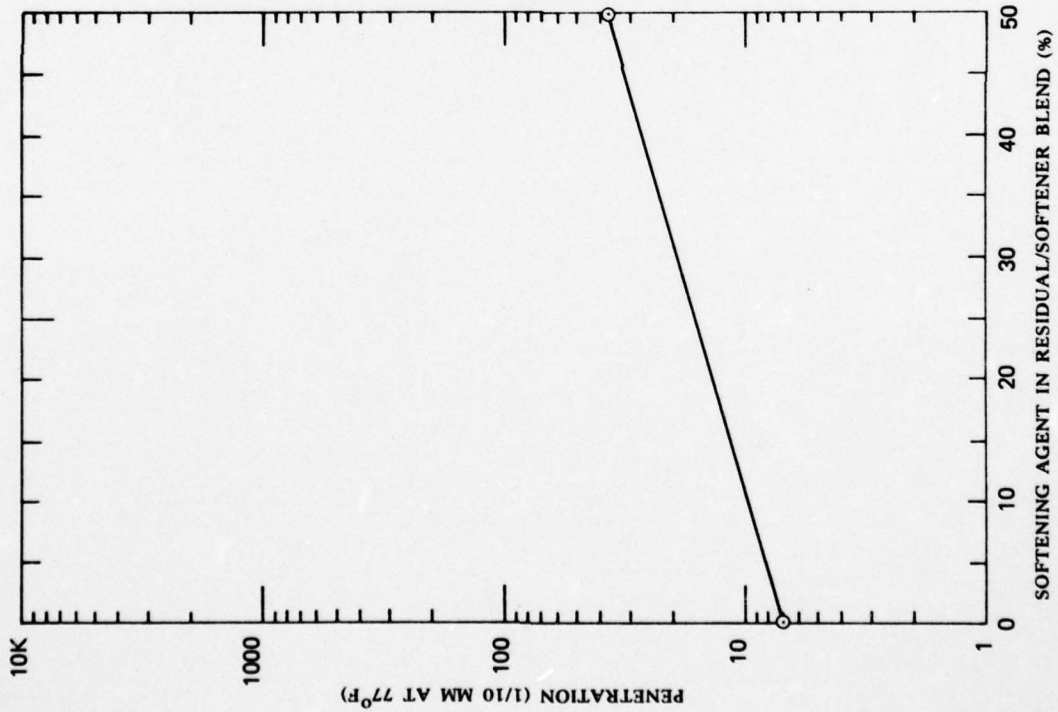
Mr. S. Tuccillo of CEL planned and initiated this investigation. He also supervised and guided the major portion of the associated laboratory investigations and subsequent data analyses. When he left CEL to accept employment with another agency, this investigation was reassigned to the authors.

Appendix A  
EFFECTS OF SOFTENING AGENTS

This appendix contains graphic results of the effects of the softening agents on penetration and viscosity of the residual asphalt cement from the various airfield and airport pavements.

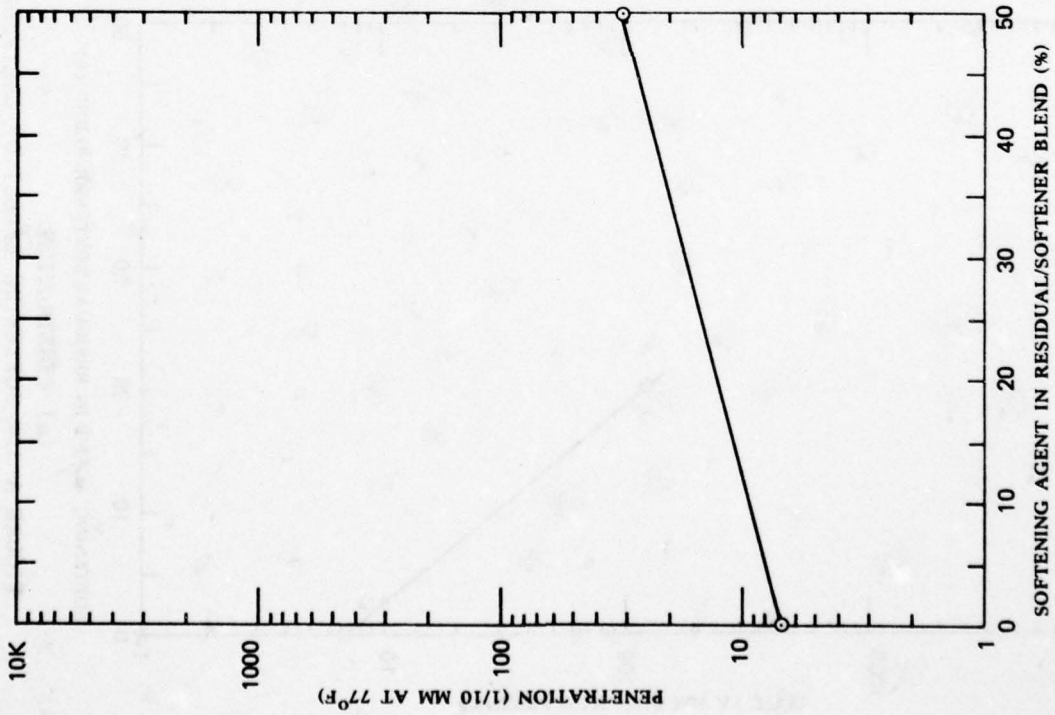


(a) PENETRATION.

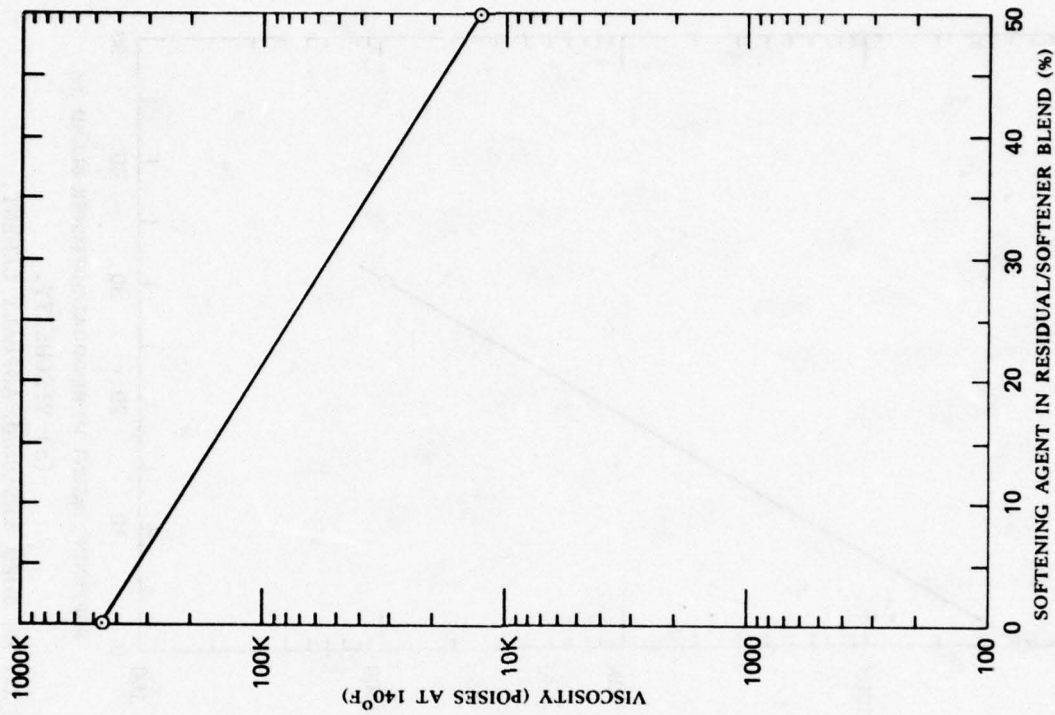


(b) VISCOSITY.

FIGURE A-1. SOFTENING EFFECT OF AR-1000 ON EL TORO RESIDUAL ASPHALT CEMENT.

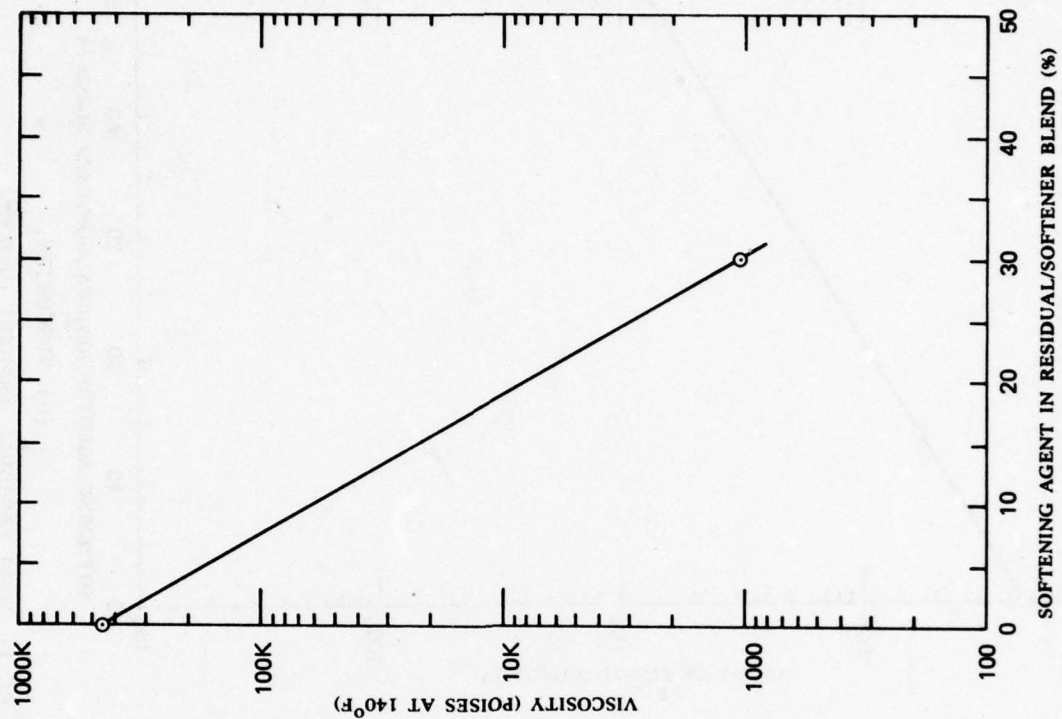


(a) PENETRATION.

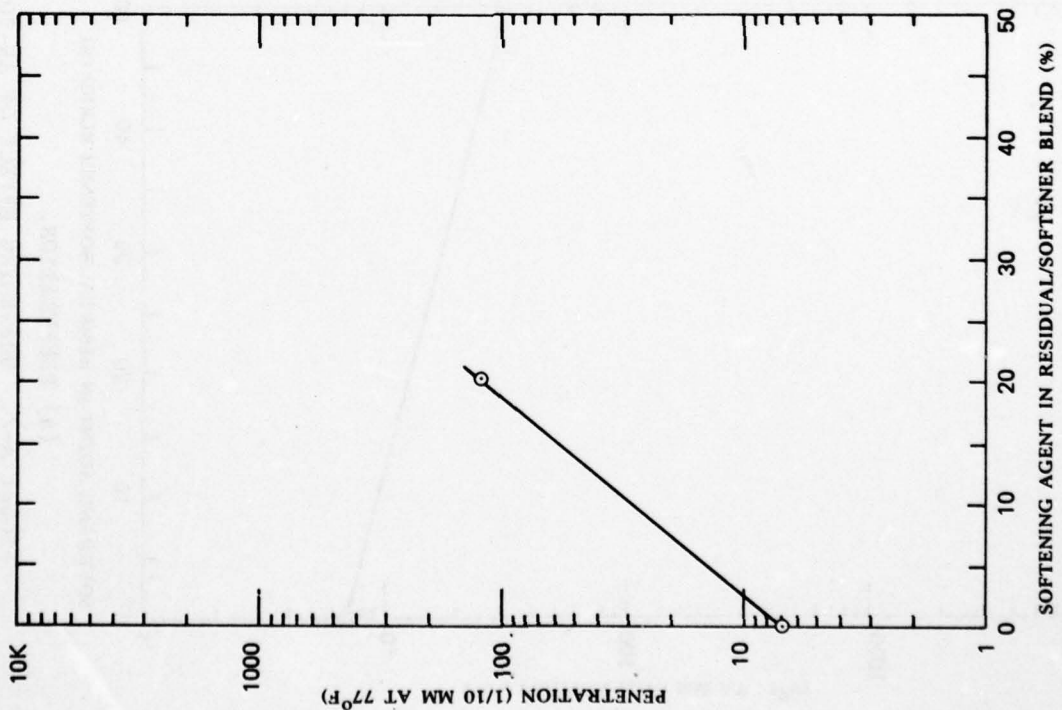


(b) VISCOSITY.

FIGURE A-2. SOFTENING EFFECT OF AR-2000 ON EL TORO RESIDUAL ASPHALT CEMENT.

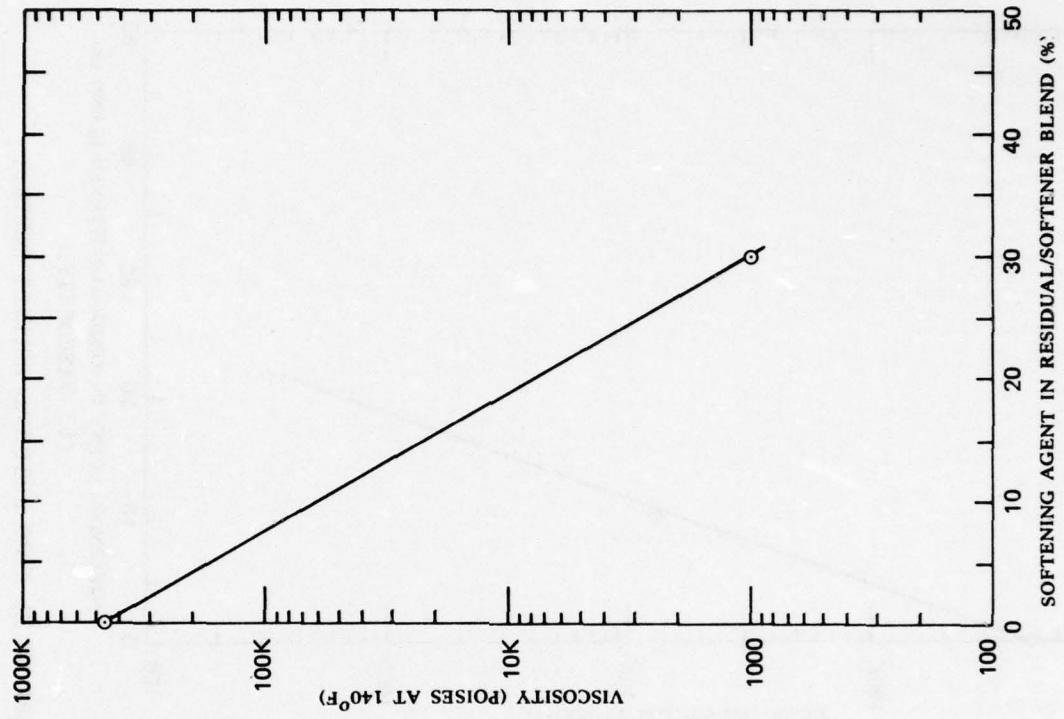


(a) PENETRATION.

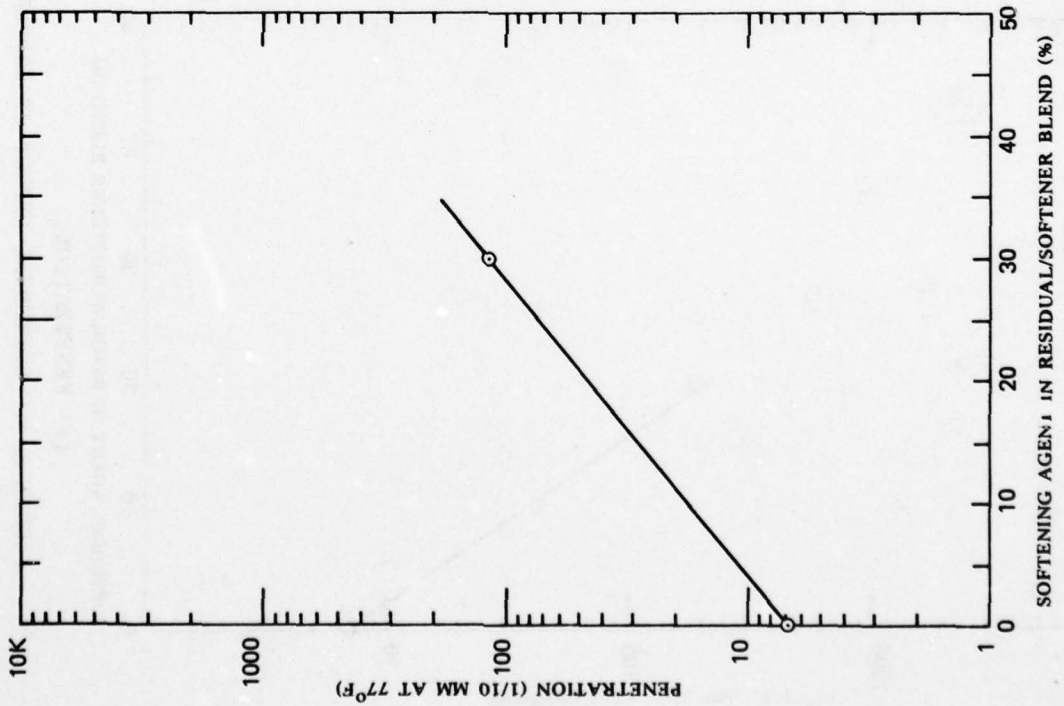


(b) VISCOSITY.

FIGURE A-3. SOFTENING EFFECT OF CALIFLUX GP ON EL TORO RESIDUAL ASPHALT CEMENT.



(a) PENETRATION.



(b) VISCOSITY.

FIGURE A-4. SOFTENING EFFECT OF DUTREX 739 ON EL TORO RESIDUAL ASPHALT CEMENT.

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RECYCLING OF ASPHALT CONCRETE AIRFIELD PAVEMENT. A LABORATORY S--ETC(U)  
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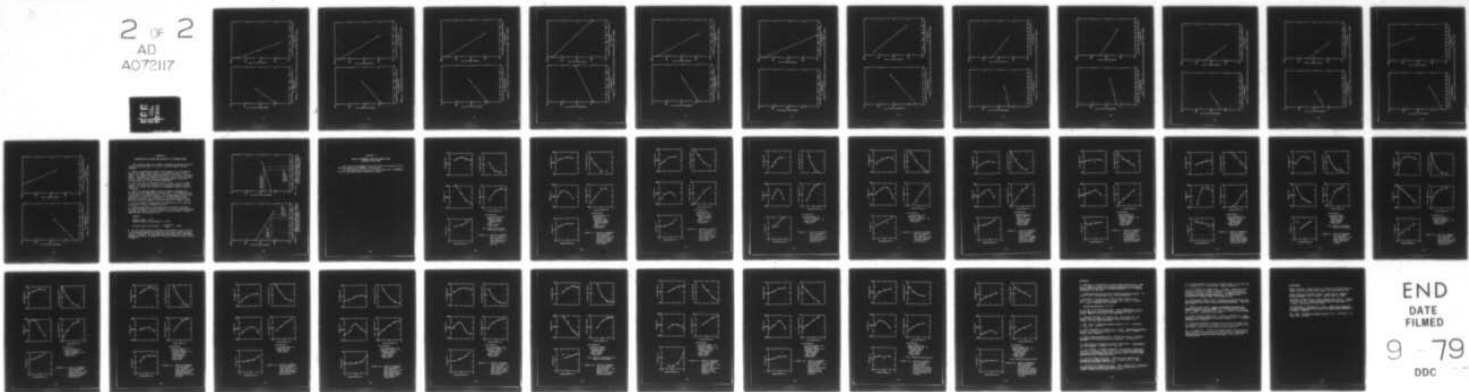
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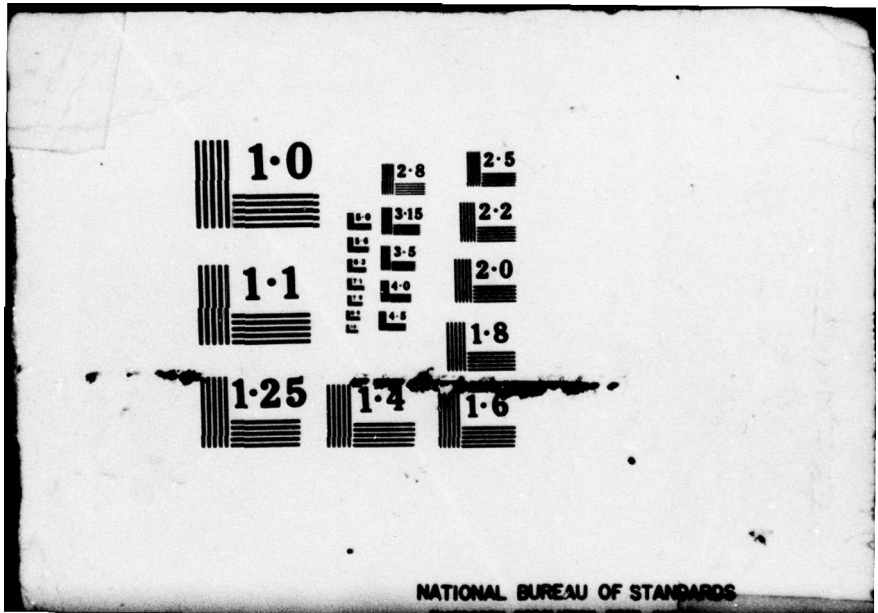
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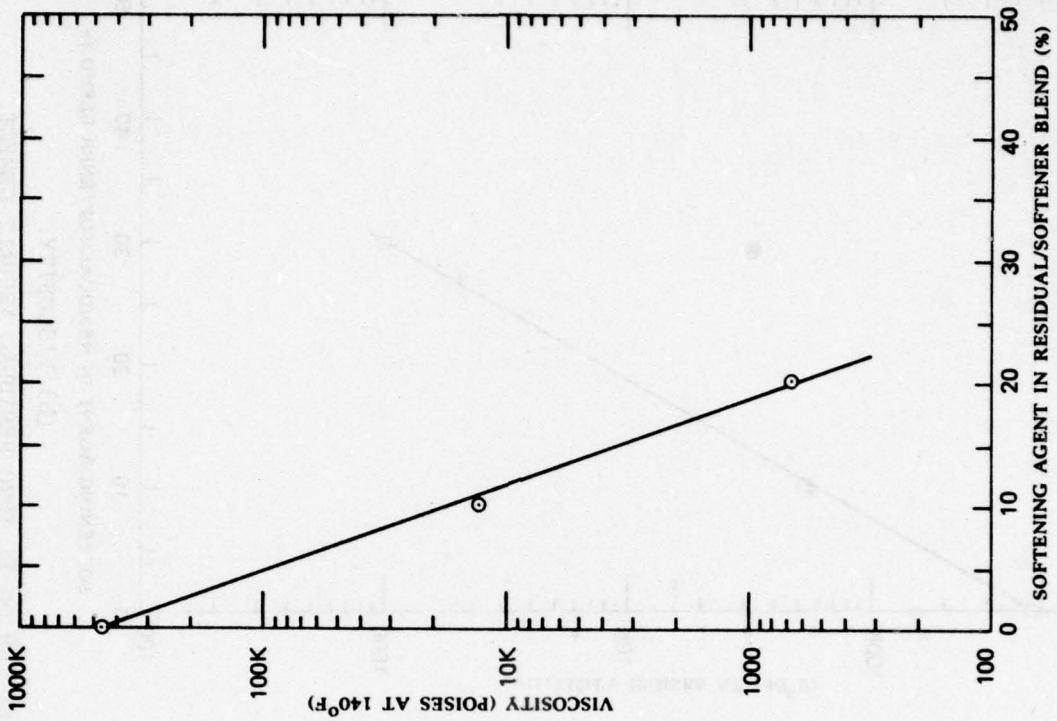
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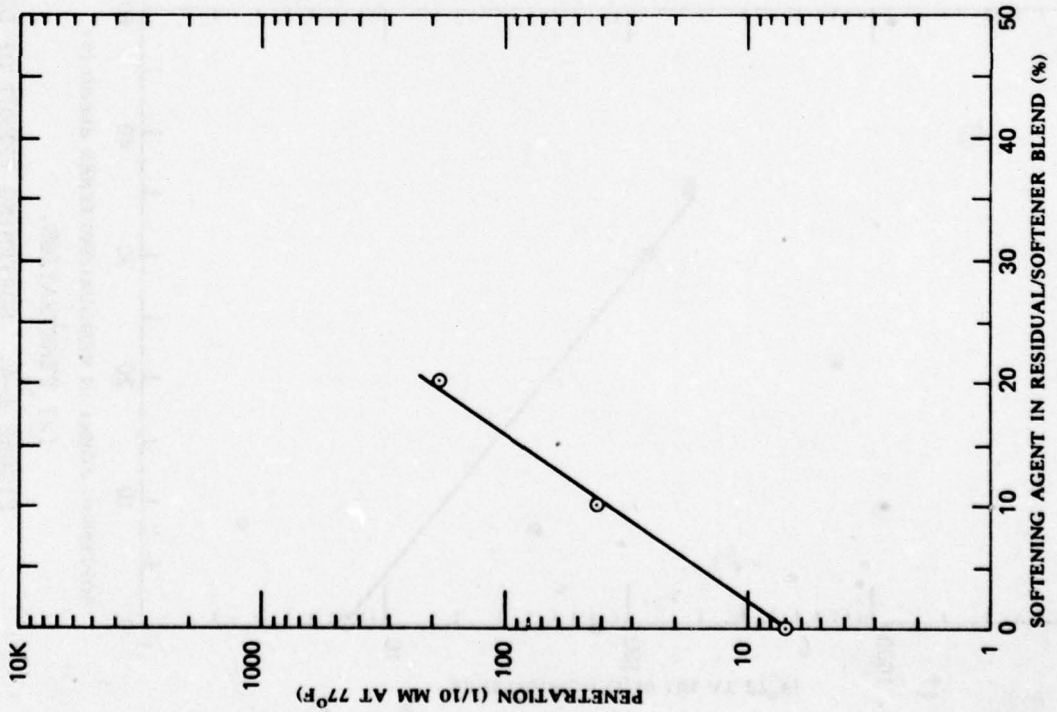
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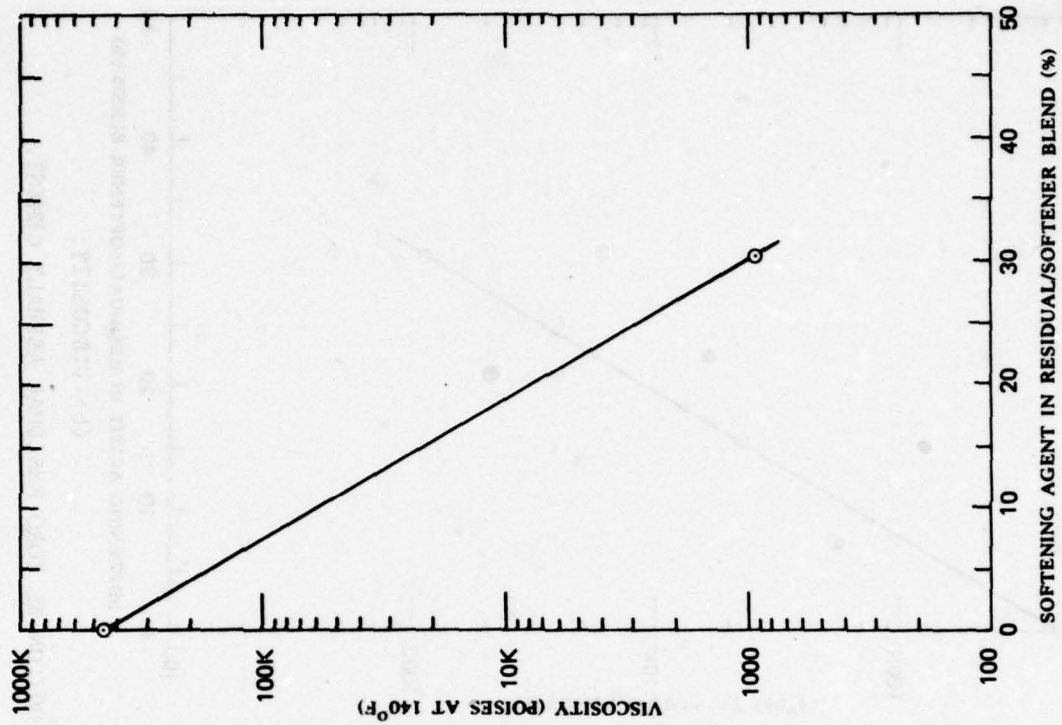


(a) PENETRATION.

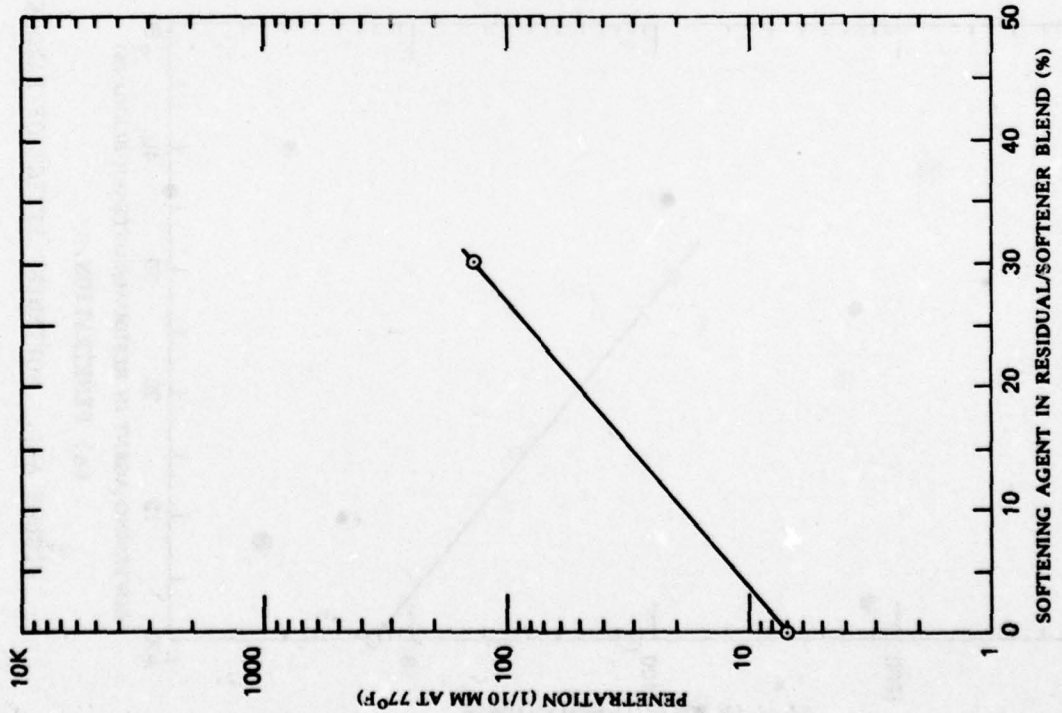


(b) VISCOSITY.

FIGURE A-5. SOFTENING EFFECT OF KOPPERS BPR ON EL TORO RESIDUAL ASPHALT CEMENT.

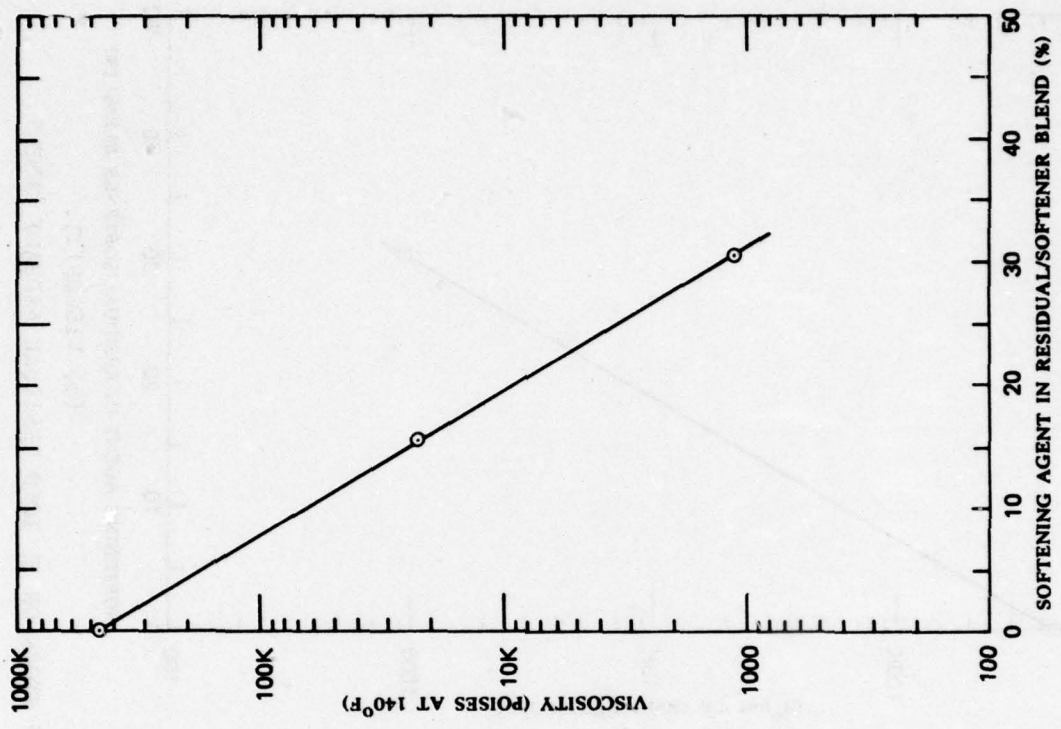


(a) PENETRATION.

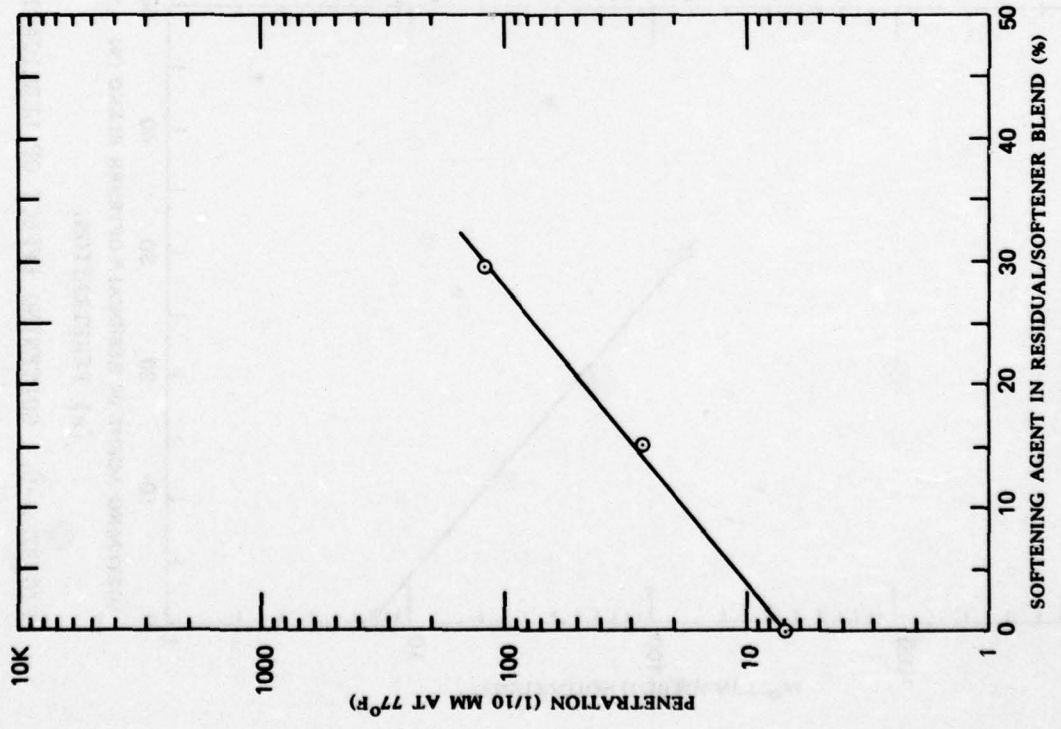


(b) VISCOSITY.

FIGURE A-6. SOFTENING EFFECT OF LUBRICATION STOCK ON EL TORO RESIDUAL ASPHALT CEMENT.

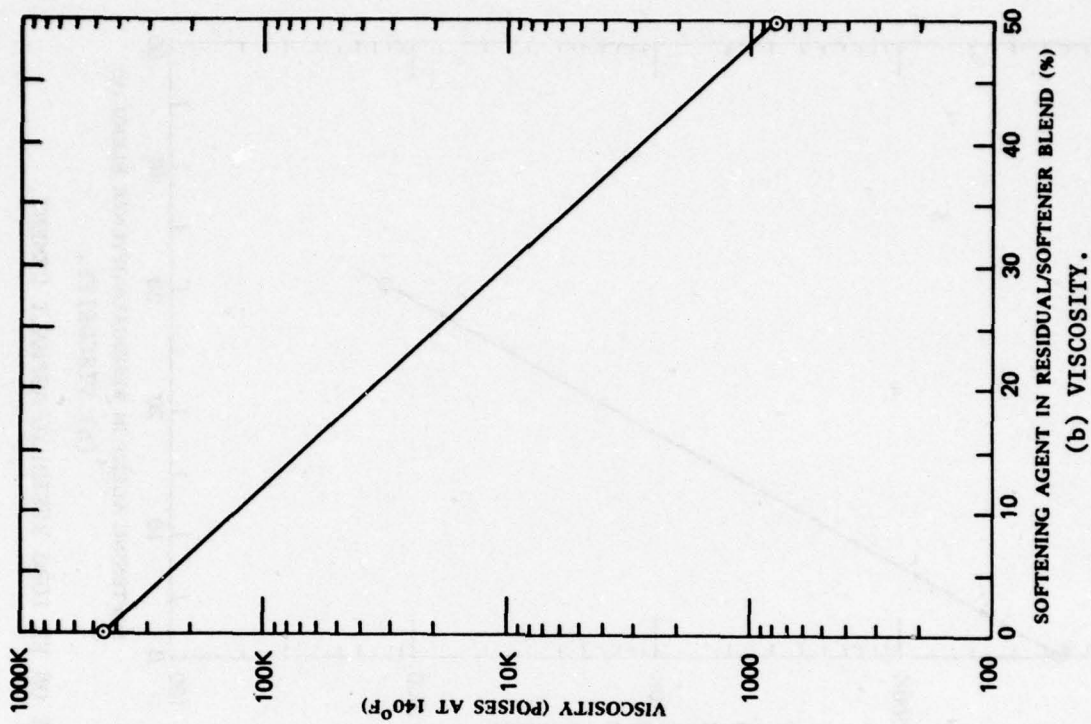


(a) PENETRATION.

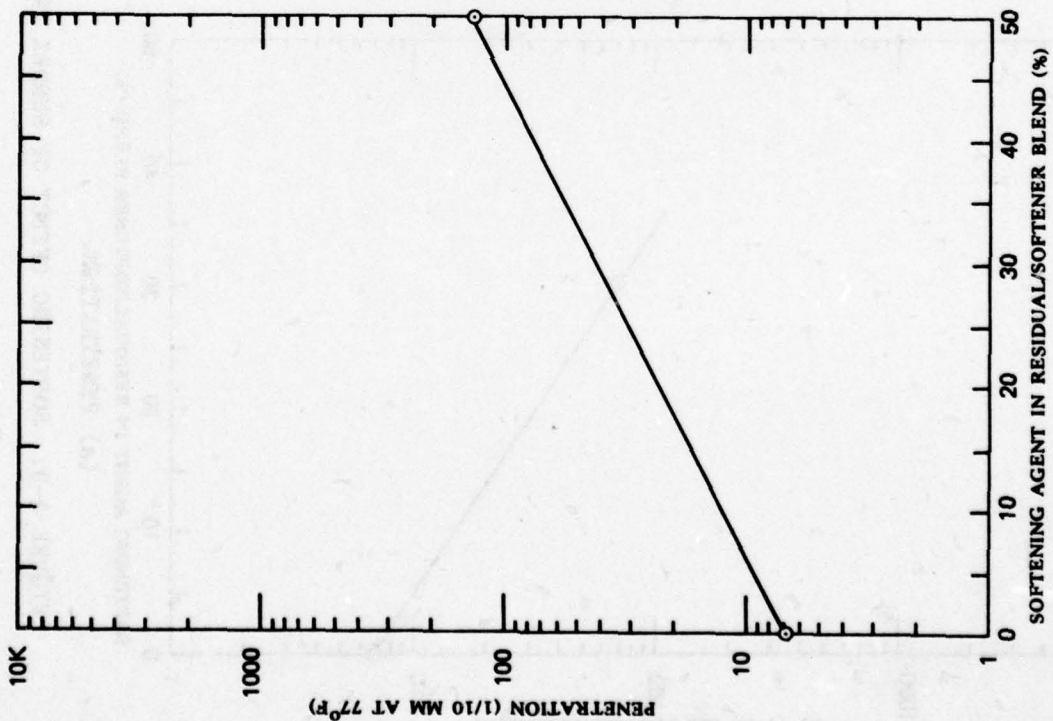


(b) VISCOSITY.

FIGURE A-7. SOFTENING EFFECT OF PAXOLE 1007 ON EL TORO RESIDUAL ASPHALT CEMENT.



(a) PENETRATION.



(b) VISCOSITY.

FIGURE A-8. SOFTENING EFFECT OF SC-3000 ON EL TORO RESIDUAL ASPHALT CEMENT.

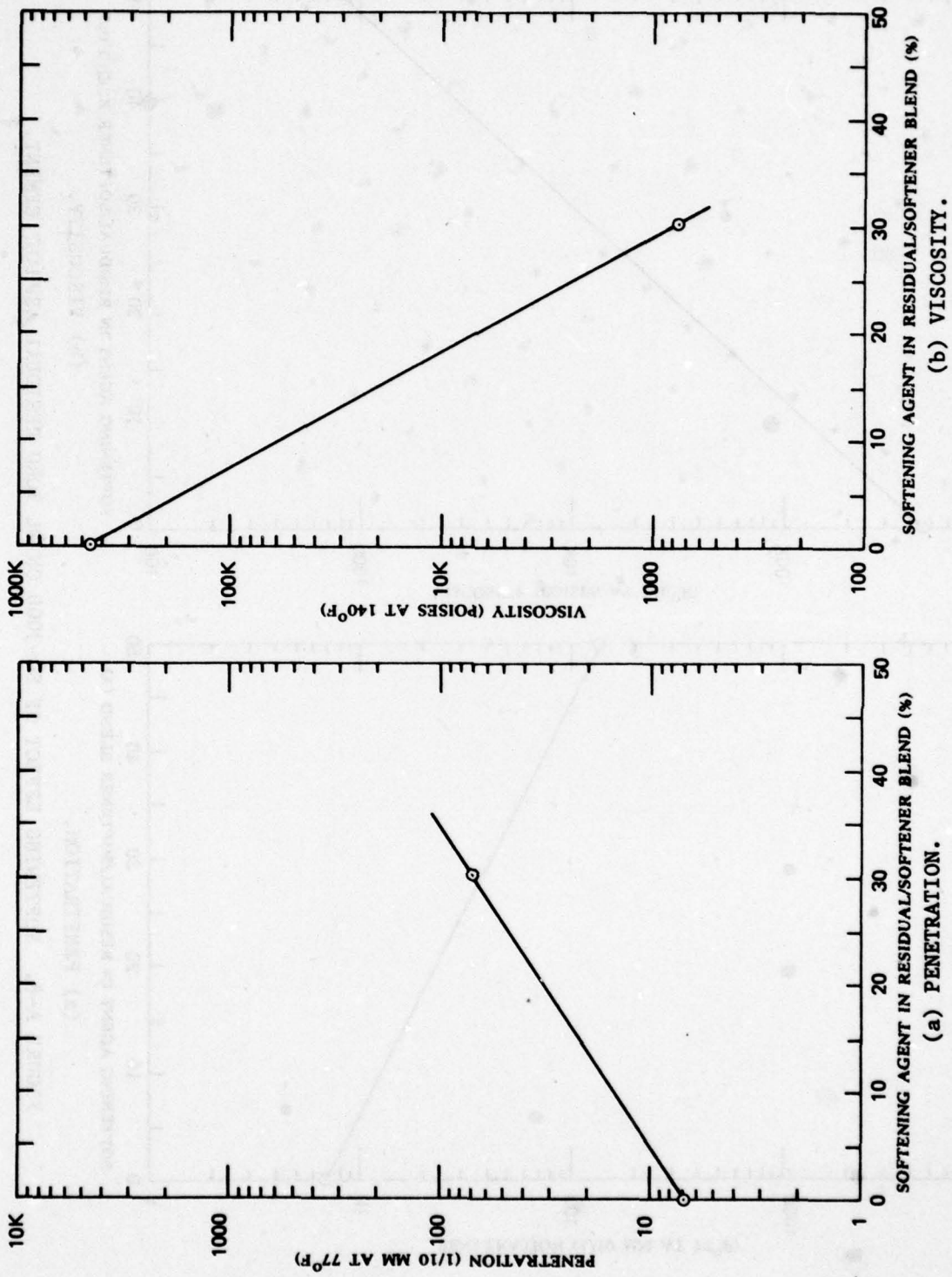


FIGURE A-9. SOFTENING EFFECT OF SUNDEX 790T ON EL TORO RESIDUAL ASPHALT CEMENT.

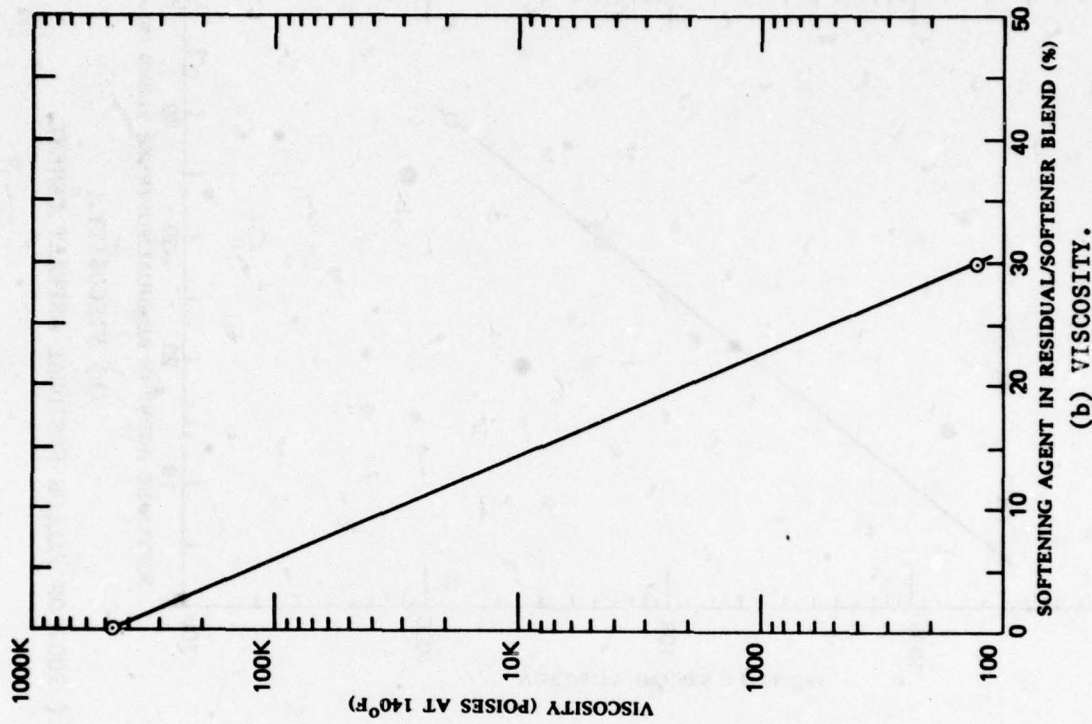
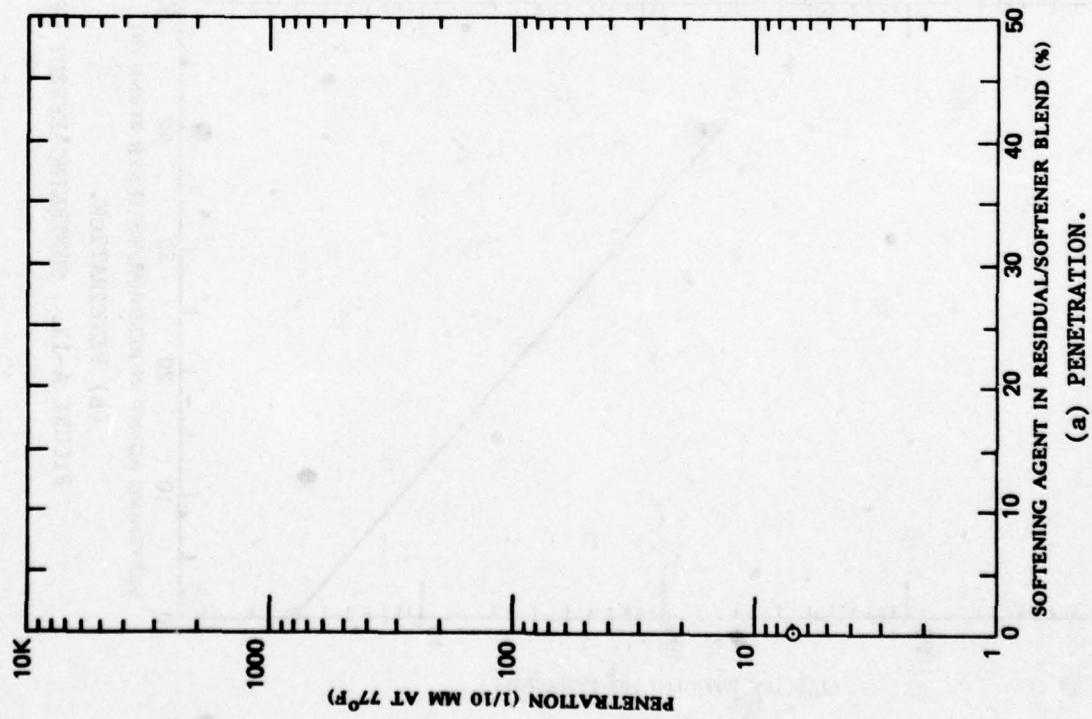
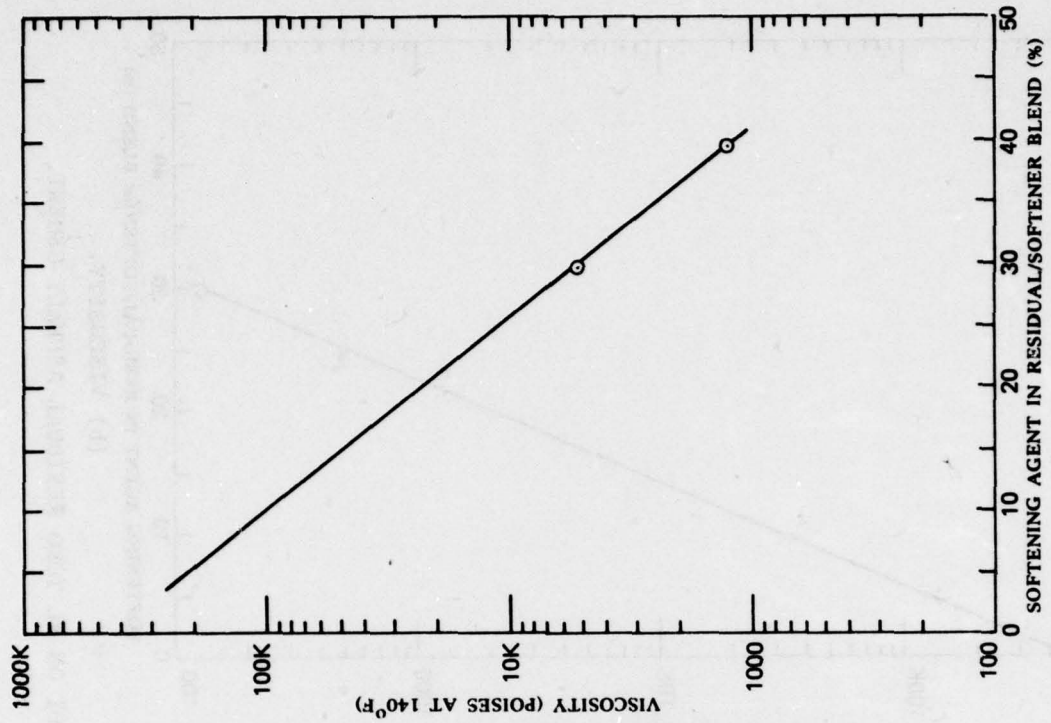
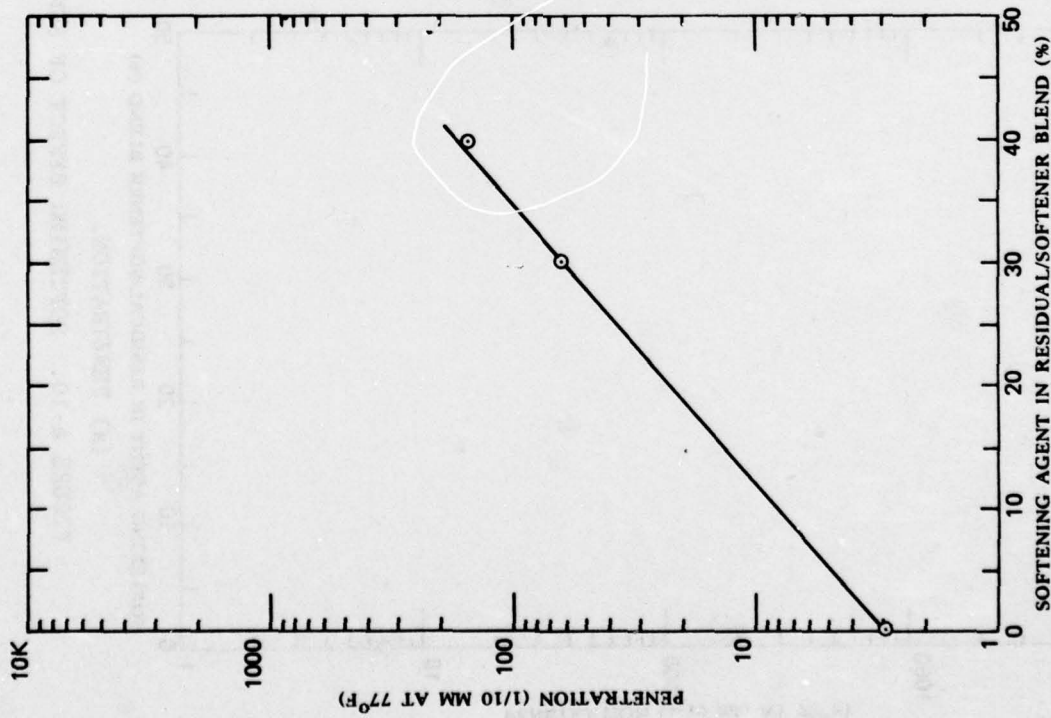


FIGURE A-10. SOFTENING EFFECT OF SUNDEX 840T ON EL TORO RESIDUAL ASPHALT CEMENT.

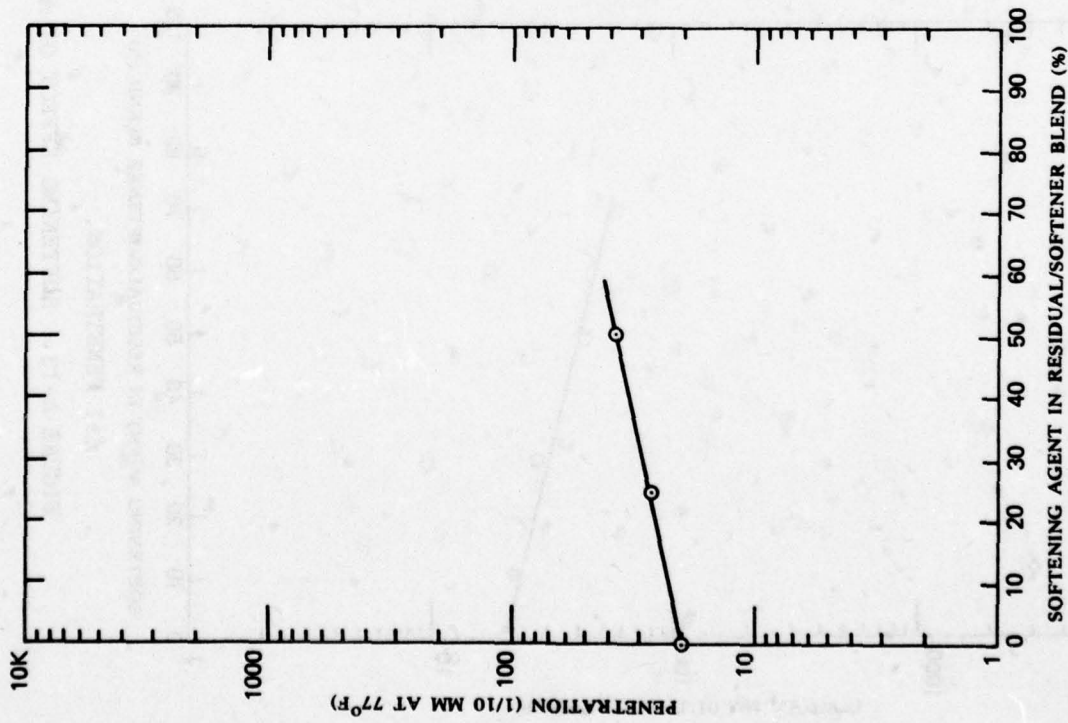


(a) PENETRATION.

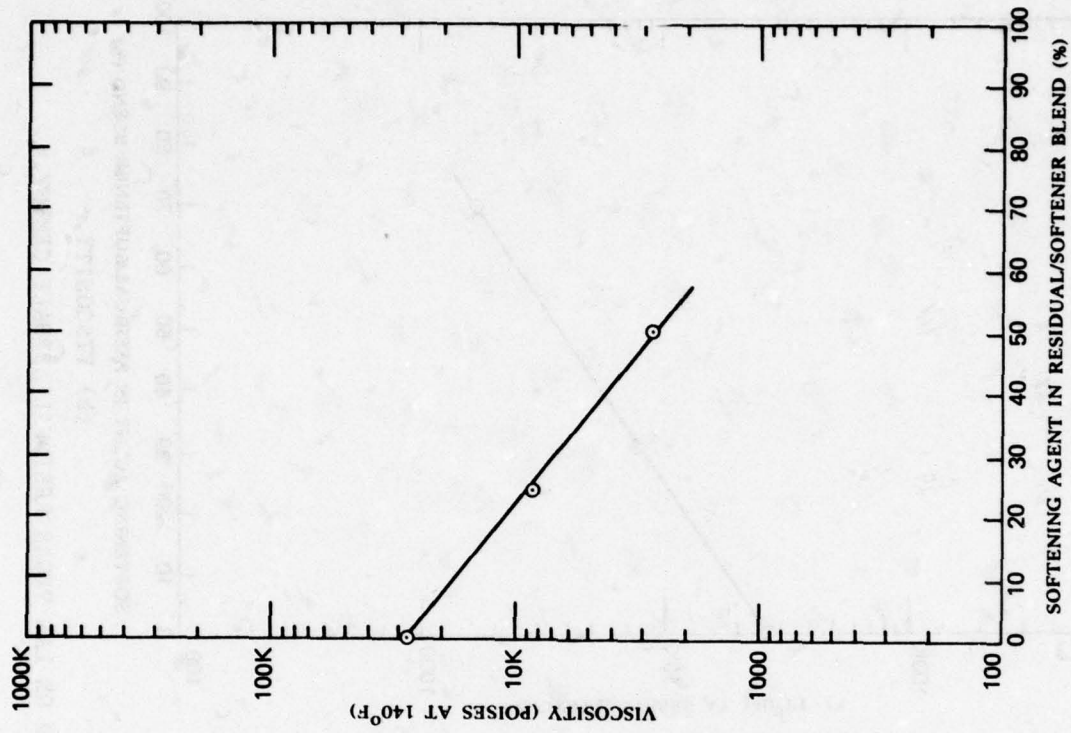


(b) VISCOSITY.

FIGURE A-11. SOFTENING EFFECT OF PAXOLE 1007 ON FALLON RESIDUAL ASPHALT CEMENT.

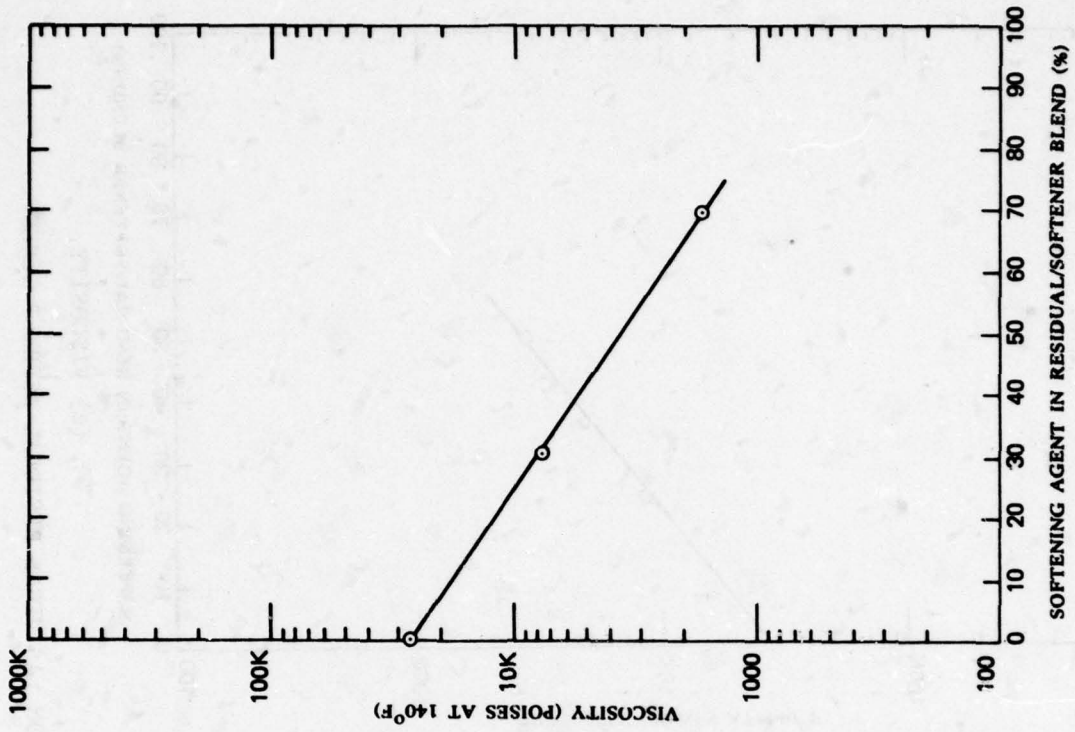


(a) PENETRATION.

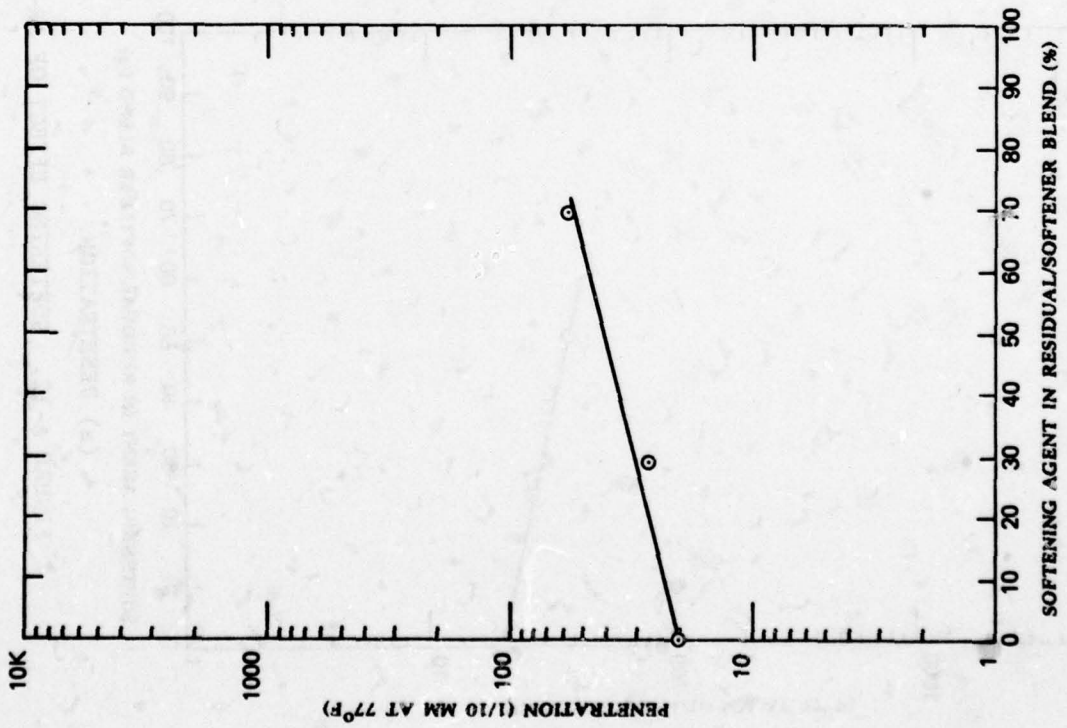


(b) VISCOSITY.

FIGURE A-12. SOFTENING EFFECT OF AR-1000 ON LAS VEGAS RESIDUAL ASPHALT CEMENT.

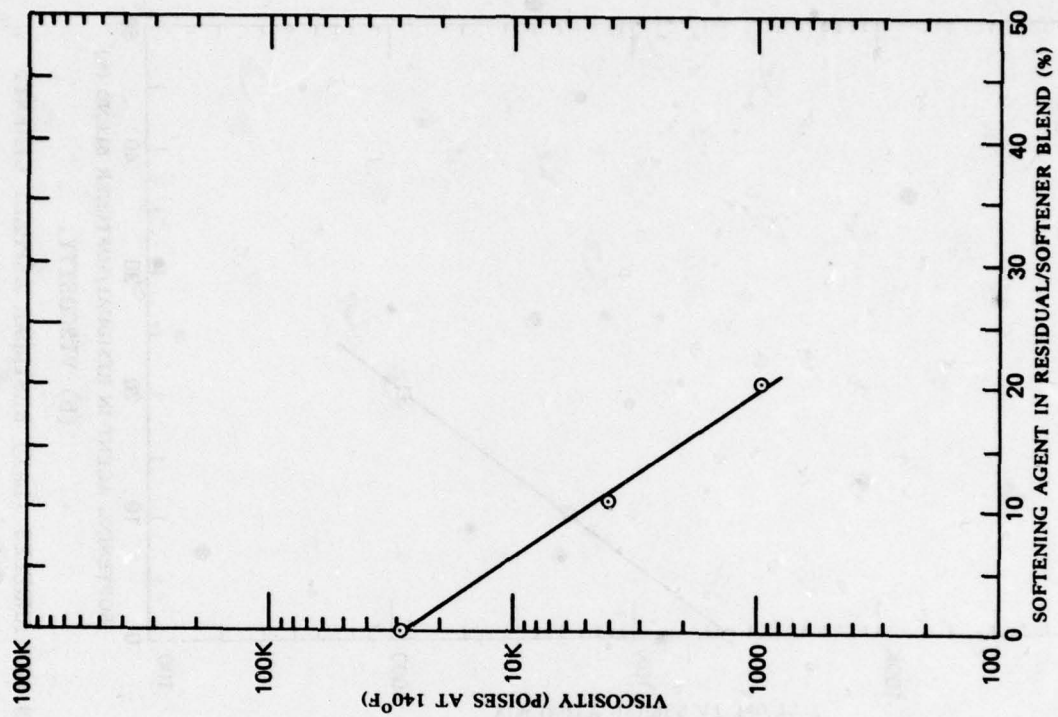


(a) PENETRATION.

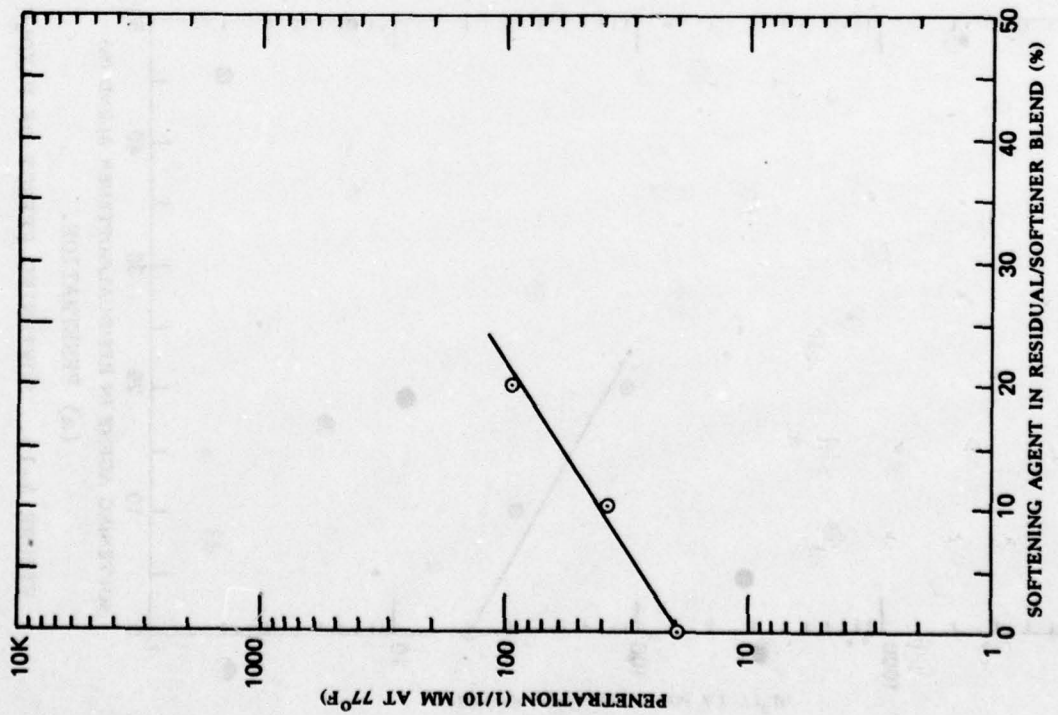


(b) VISCOSITY.

FIGURE A-13. SOFTENING EFFECT OF AR-2000 ON LAS VEGAS RESIDUAL ASPHALT CEMENT.

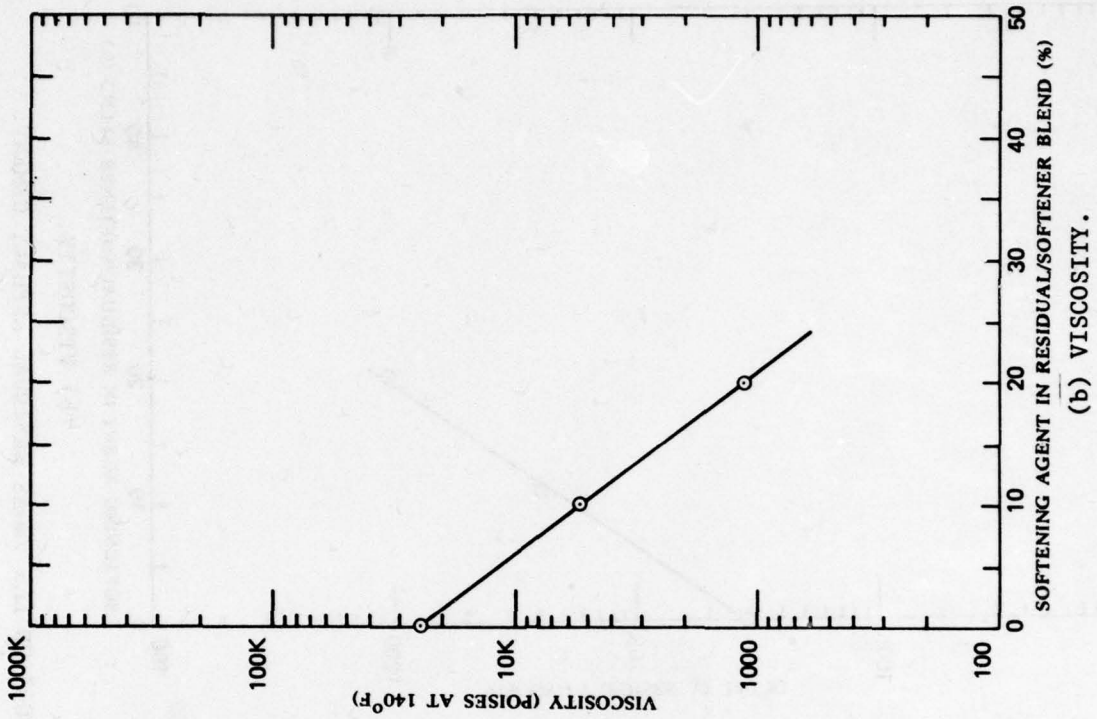


(a) PENETRATION.

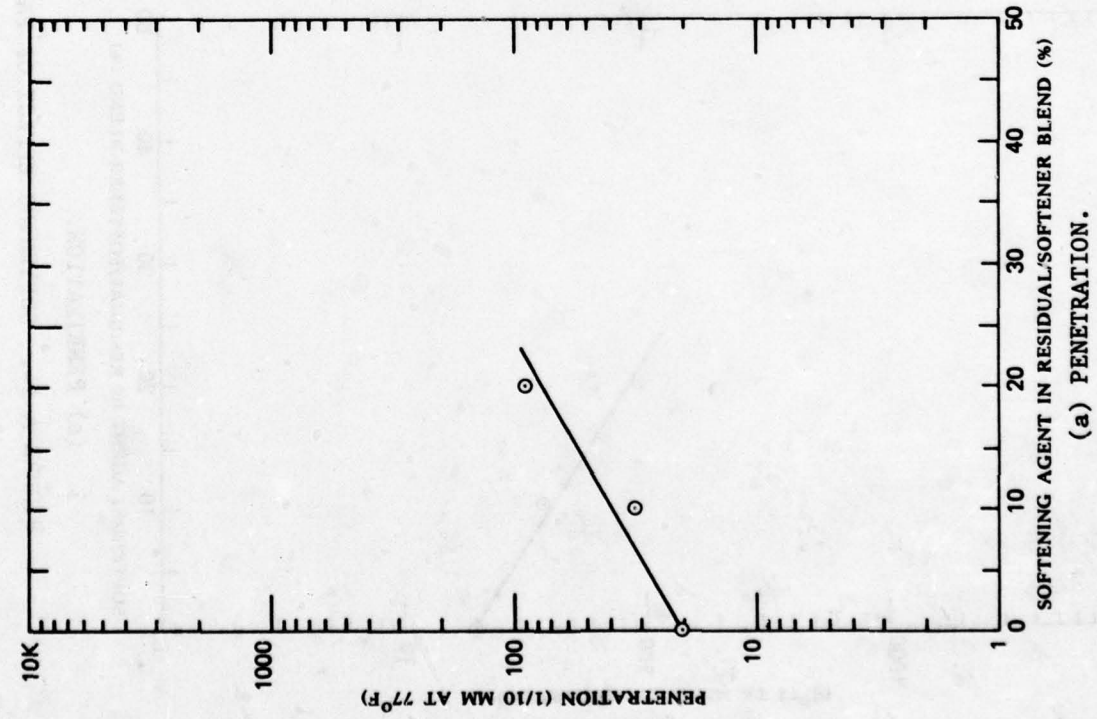


(b) VISCOSITY.

FIGURE A-14. SOFTENING EFFECT OF PAXOLE 1007 ON LAS VEGAS RESIDUAL ASPHALT CEMENT.

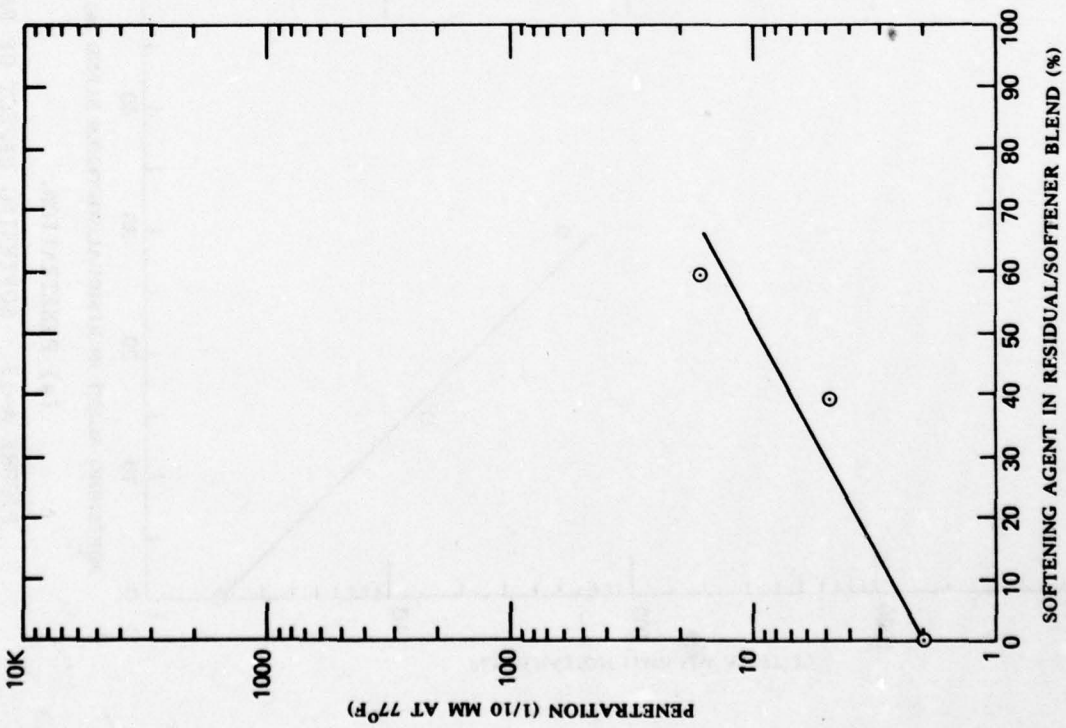


(a) PENETRATION.

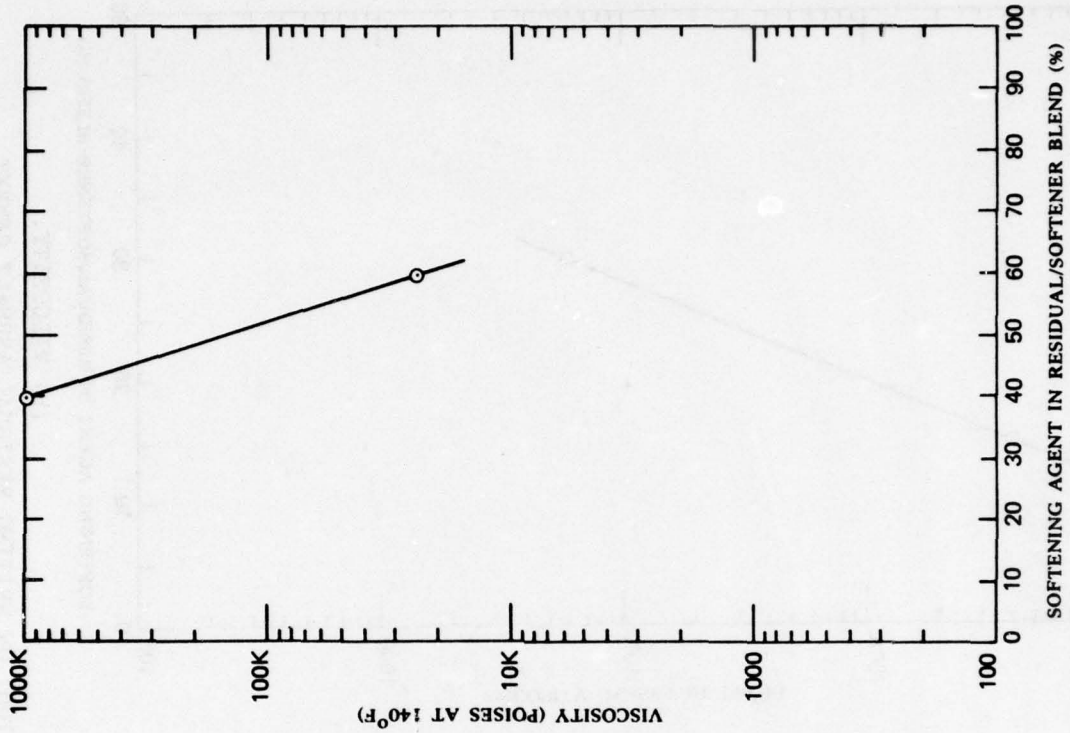


(b) VISCOSITY.

FIGURE A-15. SOFTENING EFFECT OF PAXOLE 1007 ON LOS ANGELES (LAX) RESIDUAL ASPHALT CEMENT.

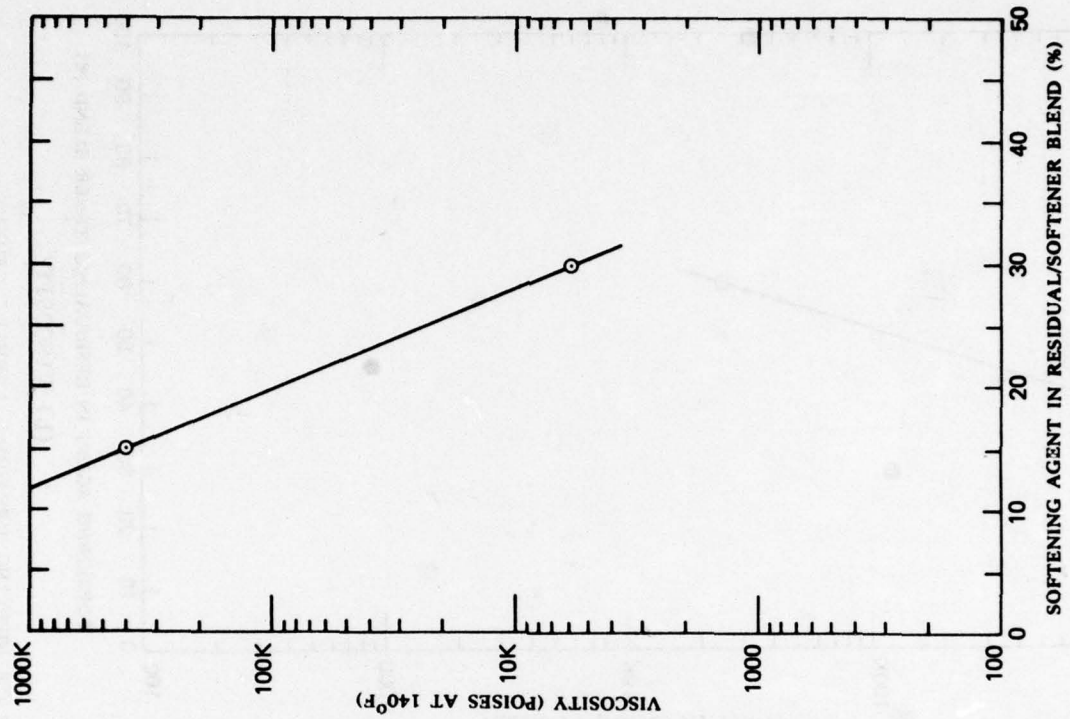


(a) PENETRATION.

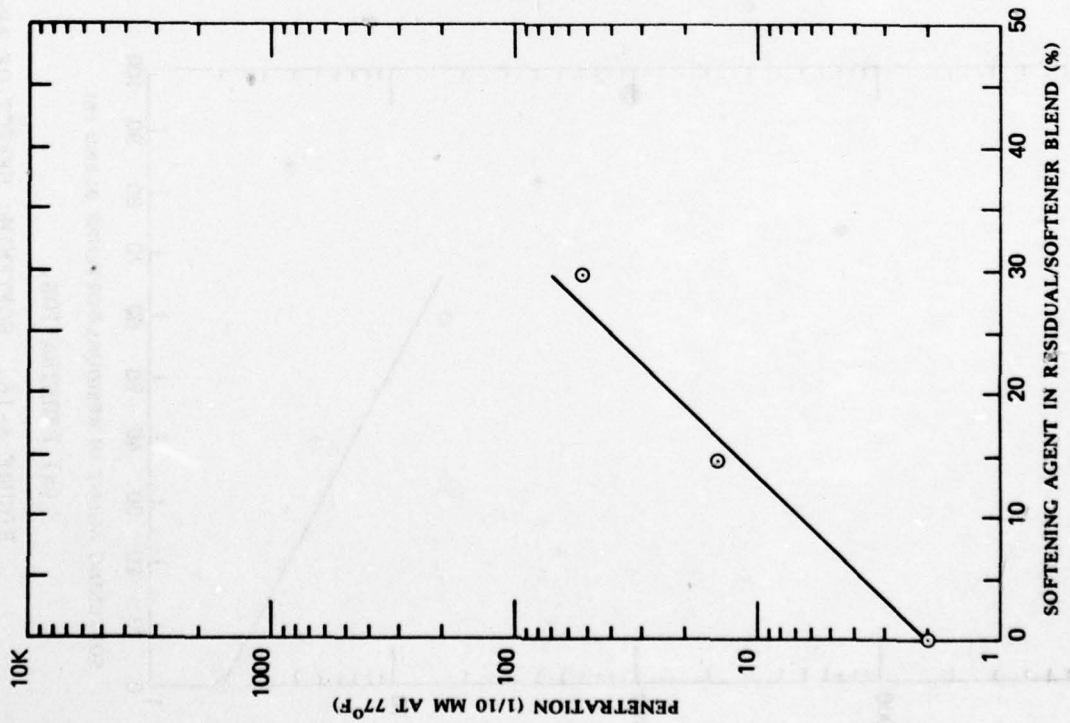


(b) VISCOSITY.

FIGURE A-16. SOFTENING EFFECT OF AR-1000 ON WHITING RESIDUAL ASPHALT CEMENT.



(a) PENETRATION.



(b) VISCOSITY.

FIGURE A-17. SOFTENING EFFECT OF PAXOLE 1007 ON WHITING RESIDUAL ASPHALT CEMENT.

## Appendix B

### DETERMINATION OF AMOUNT AND SUITABILITY OF SOFTENING AGENT

The following steps can be taken to determine the amount and suitability of softening agent to be used in recycling asphalt concrete pavements.

1. Obtain a representative sample of the pavement to be recycled and extract the asphalt binder by one of the methods described in ASTM D2172. Use a sample large enough to provide at least 100 g of recovered asphalt. Determine the asphalt content of the mix and retain the aggregate for further testing. Recover the asphalt from the extraction solvent solution by the Abson Method (ASTM D1856).
2. Select the type of consistency test to be used, viscosity or penetration. For recycling, viscosity is the preferred method as smaller samples are required, and viscosity is a fundamental physical property of asphalt.
3. Divide the recovered asphalt into four samples. Determine the viscosity at 140°F (ASTM D2171) or penetration at 77°F (ASTM D5) of one of the samples of recovered asphalt. To a second sample, add sufficient softener for a 30:70 ratio of softener to recovered asphalt blend. Determine the viscosity or penetration of the softener/asphalt blend. Retain the remaining samples of recovered asphalt for further testing.
4. Plot the results of the viscosity or penetration tests on semi-log graph paper as shown in FIGURES B-1 and B-2.
5. Determine the amount of softening agent for desired consistency. Calculate the amount of softener required in the total mix by multiplying the amount determined from the data plots by the percentage of asphalt found in step 1 and dividing by 100.

Example:

Asphalt content = 5.1%

Softener quantity from FIGURE B-1 = 16.5%

$$\text{Softener required (total mix)} = \frac{5.1 \times 16.5}{100} = 0.84\%$$

6. Mix the required amount of softener as determined in step 5 with one of the remaining samples and verify that the correct viscosity or penetration is obtained. Age this sample by either ASTM D1754 or ASTM D2872 methods and determine if changes in viscosity or penetration meet criteria in TABLE 14.

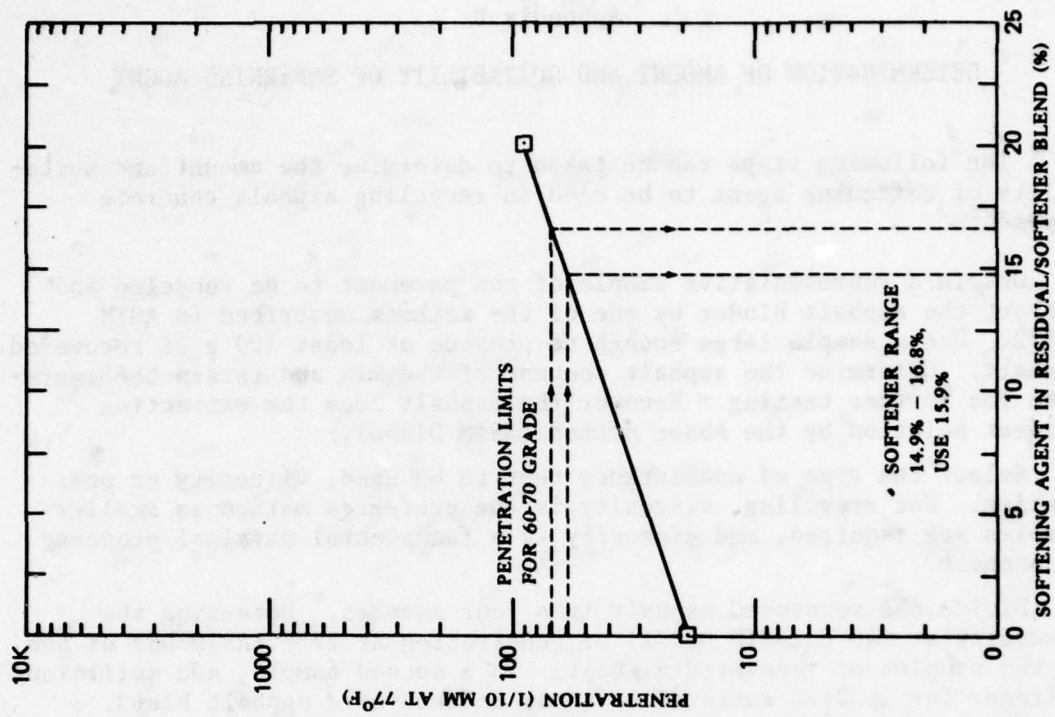


FIGURE B-1. EXAMPLE FOR DETERMINING AMOUNT OF SOFTENING AGENT NEEDED TO OBTAIN AC-20 INITIAL VISCOSITY.

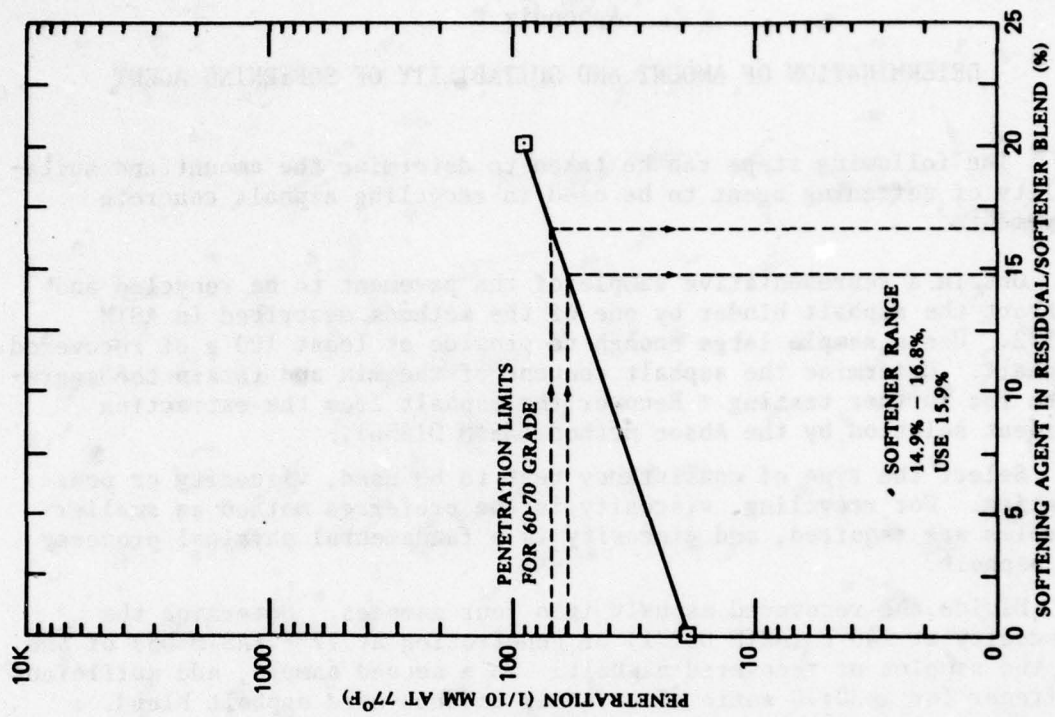


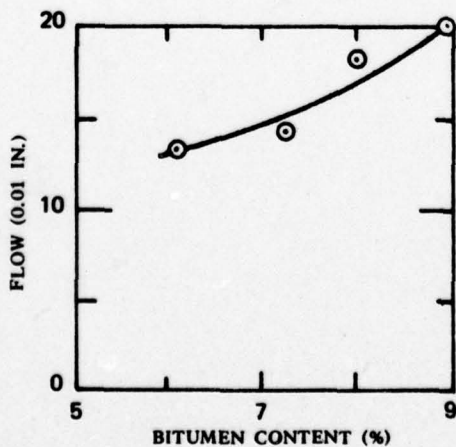
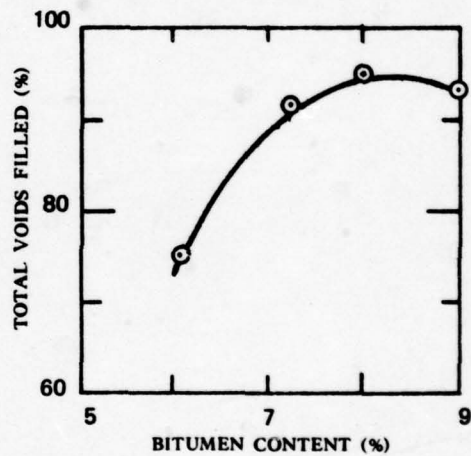
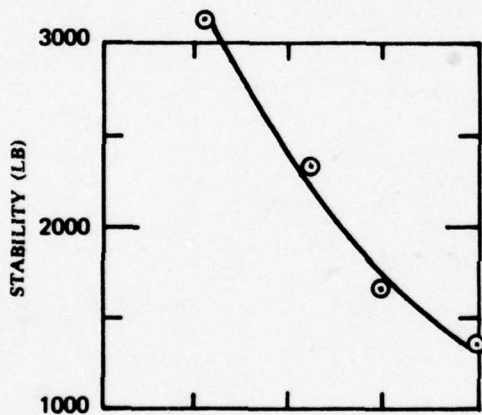
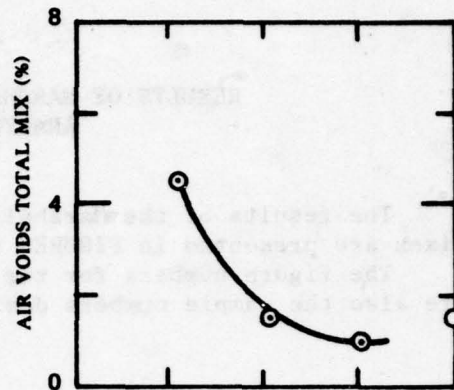
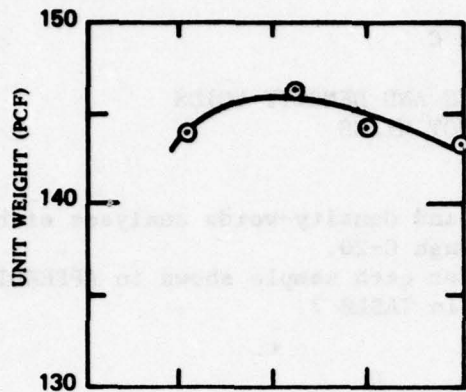
FIGURE B-2. EXAMPLE FOR DETERMINING AMOUNT OF SOFTENING AGENT NEEDED TO OBTAIN 60 TO 70 INITIAL PENETRATION.

Appendix C

RESULTS OF MARSHALL TESTS AND DENSITY-VOIDS  
ANALYSES OF HOT MIXES

The results of the Marshall tests and density-voids analyses of hot mixes are presented in FIGURES C-1 through C-20.

The figure numbers for the plots for each sample shown in APPENDIX C are also the sample numbers designated in TABLE 7.

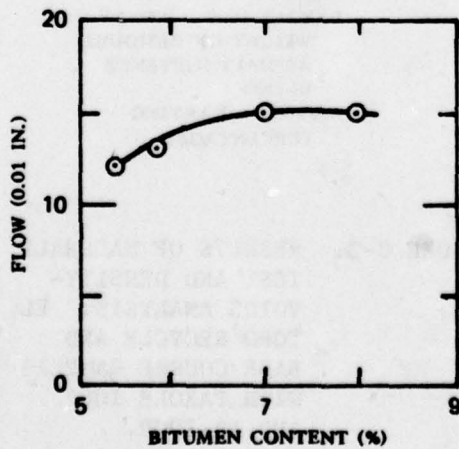
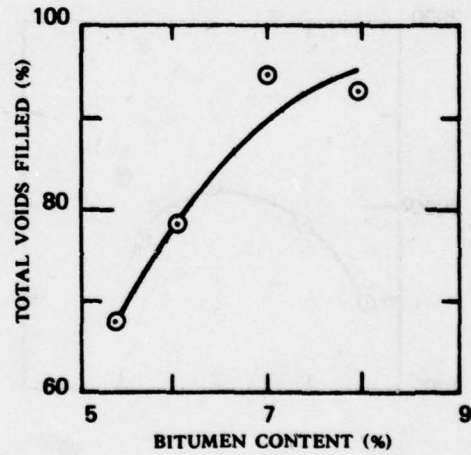
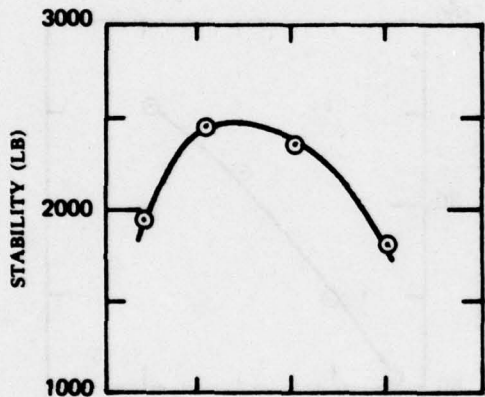
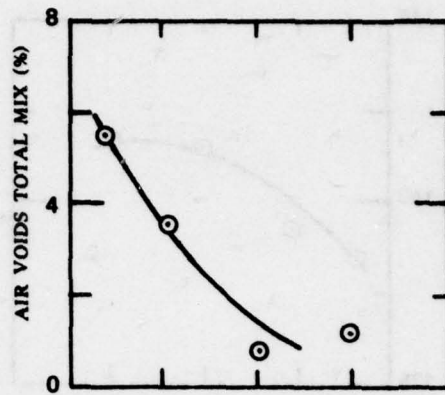
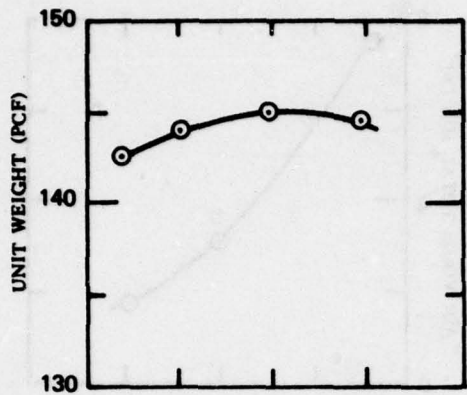


**MIX DESCRIPTION:**

EL TORO CRUSHED SAMPLE  
 PAXOLE 1007 - 27% BY  
 WEIGHT OF RESIDUAL  
 ASPHALT/SOFTENER  
 BLEND  
 AR-2000 - VARYING  
 PERCENTAGES

NOTE: SAMPLE AT 6.0% BITUMEN  
 CONTENT HAS 11.7% PAXOLE

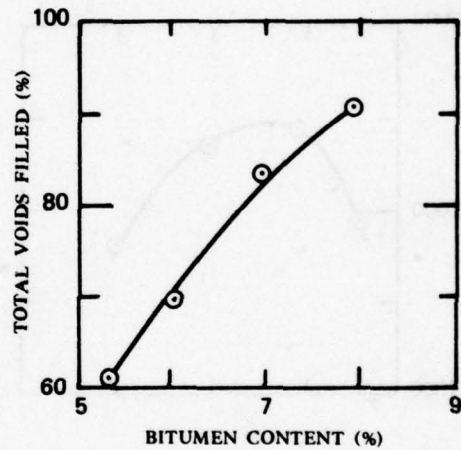
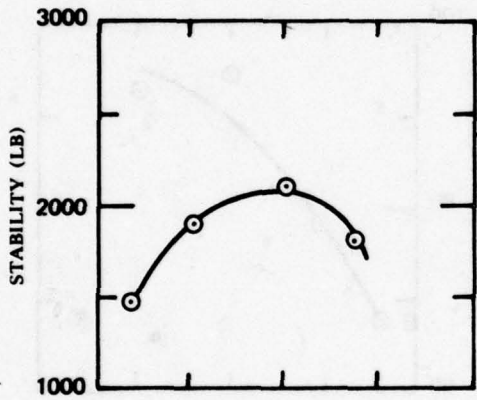
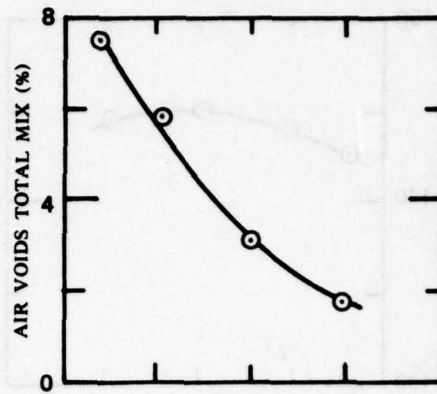
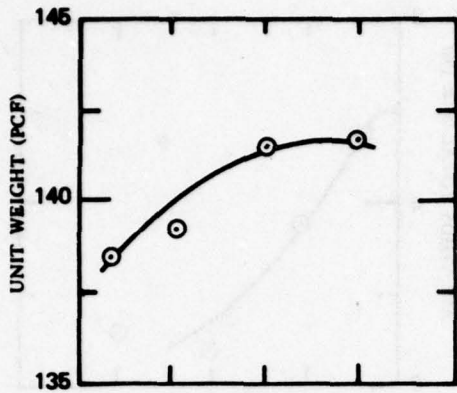
FIGURE C-1. RESULTS OF MARSHALL  
 TEST AND DENSITY-  
 VOIDS ANALYSIS: EL  
 TORO SAMPLES WITH  
 PAXOLE 1007 AND  
 AR-2000.



**MIX DESCRIPTION:**

EL TORO CRUSHED - 75%  
 MINUS 3/4 IN. A.C.  
 AGGREGATE - 25%  
 PAXOLE 1007 - 27% BY  
 WEIGHT OF RESIDUAL  
 ASPHALT/SOFTENER  
 BLEND  
 AR-2000 - VARYING  
 PERCENTAGES

**FIGURE C-2. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: EL TORO RECYCLE AND AC AGGREGATE SAMPLES WITH PAXOLE 1007 AND AR-2000.**



**MIX DESCRIPTION:**

EL TORO CRUSHED - 75%  
 BASE COURSE - 25%  
 PAXOLE 1007 - 27% BY  
 WEIGHT OF RESIDUAL  
 ASPHALT/SOFTENER  
 BLEND  
 AR-2000 - VARYING  
 PERCENTAGES

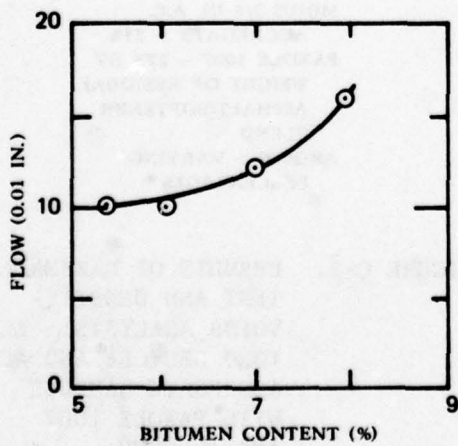
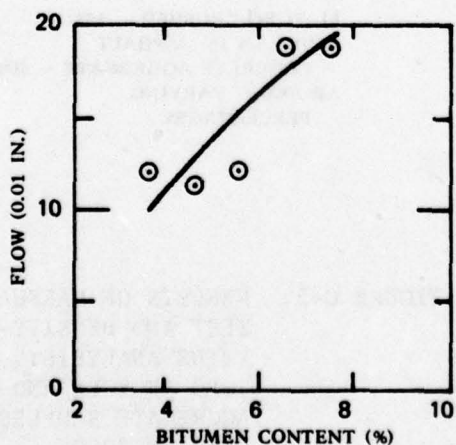
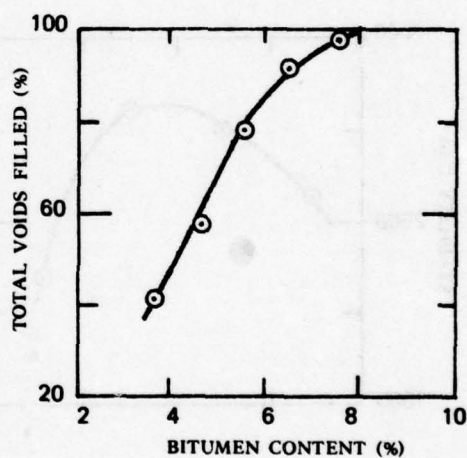
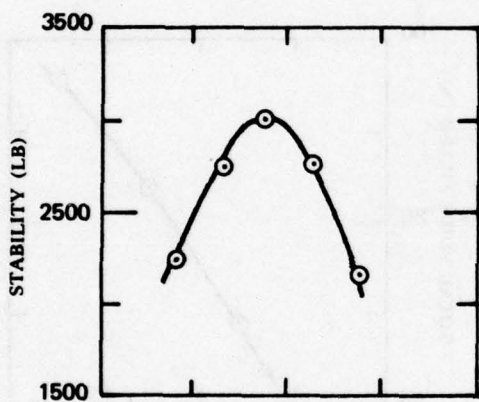
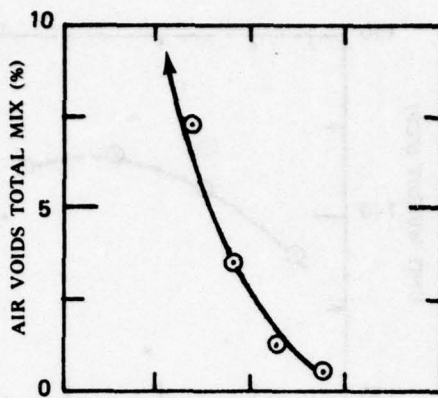
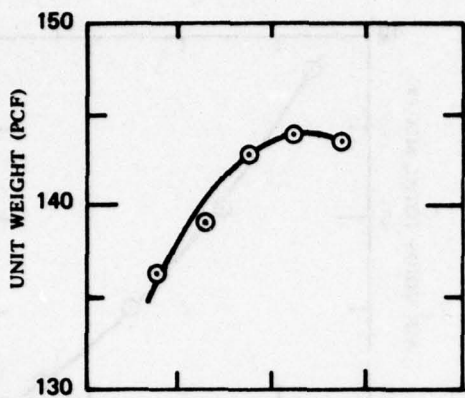


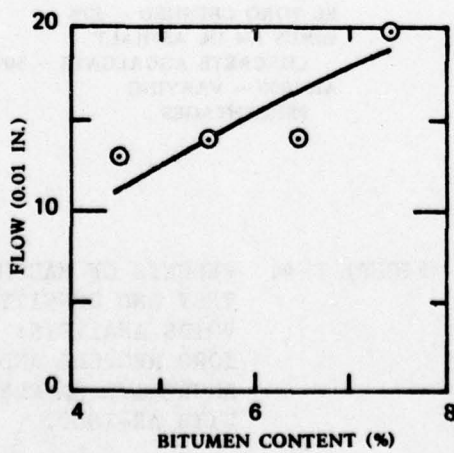
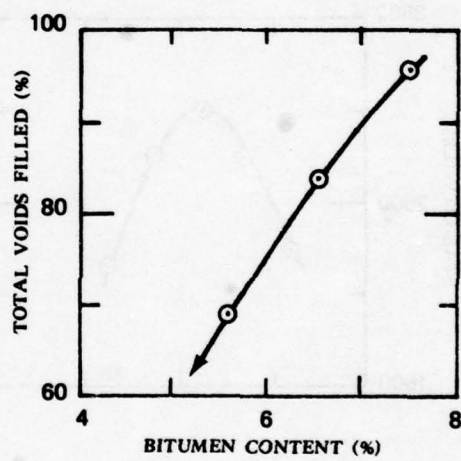
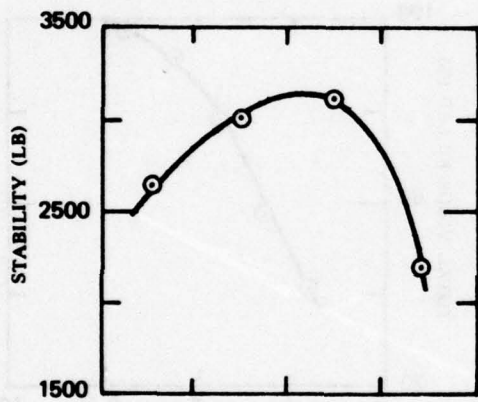
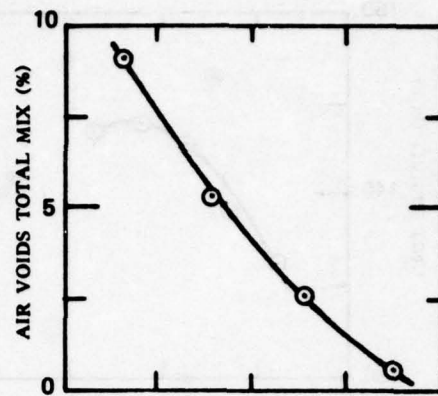
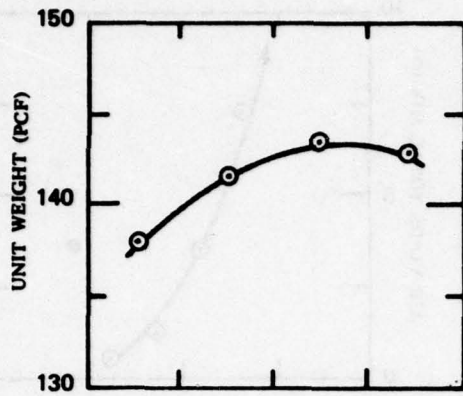
FIGURE C-3. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: EL TORO RECYCLE AND BASE COURSE SAMPLES WITH PAXOLE 1007 AND AR-2000.



**MIX DESCRIPTION:**

EL TORO CRUSHED - 50%  
 MINUS 3/4 IN. ASPHALT  
 CONCRETE AGGREGATE - 50%  
 AR-1000 - VARYING  
 PERCENTAGES

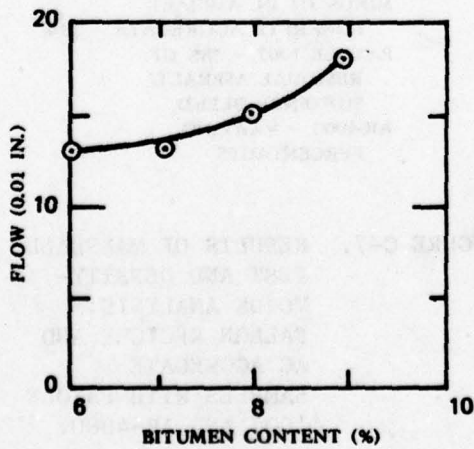
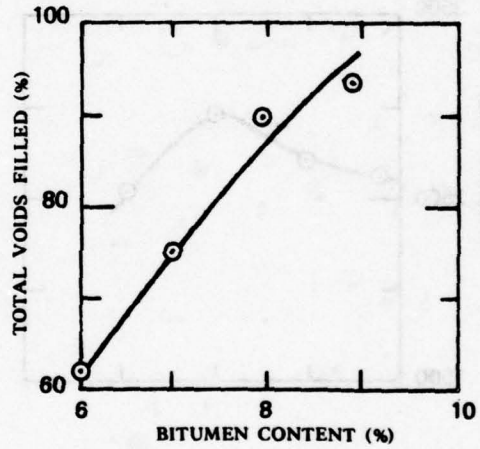
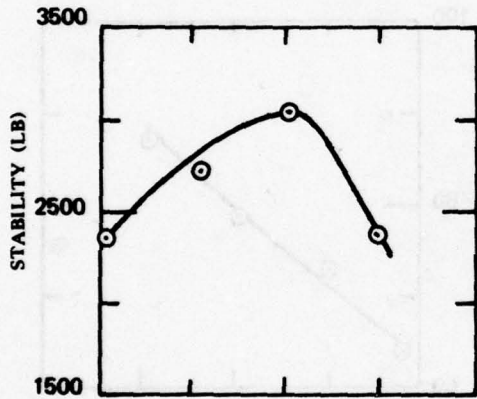
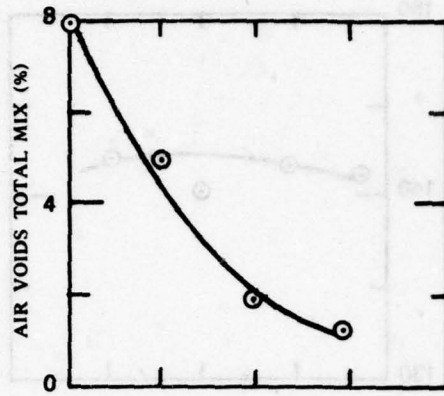
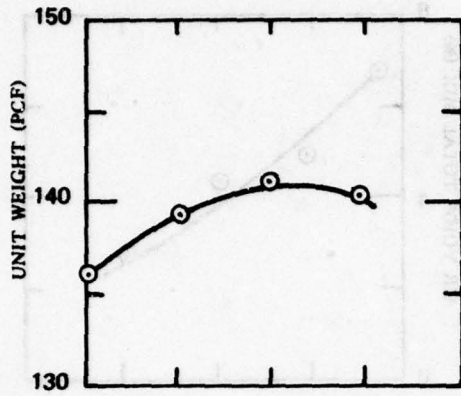
FIGURE C-4. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: EL TORO RECYCLE AND AC AGGREGATE SAMPLES WITH AR-1000.



**MIX DESCRIPTION:**

EL TORO CRUSHED - 50%  
 MINUS 3/4 IN. ASPHALT  
 CONCRETE AGGREGATE - 50%  
 AR-2000 - VARYING  
 PERCENTAGES

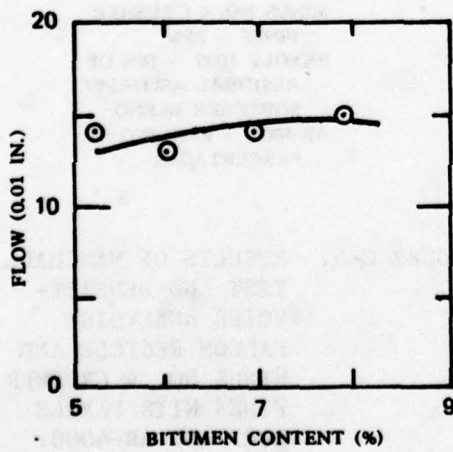
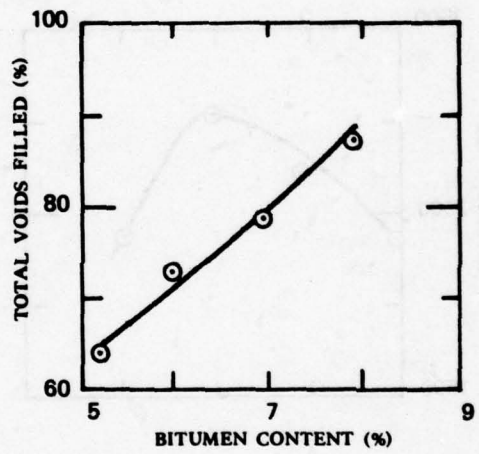
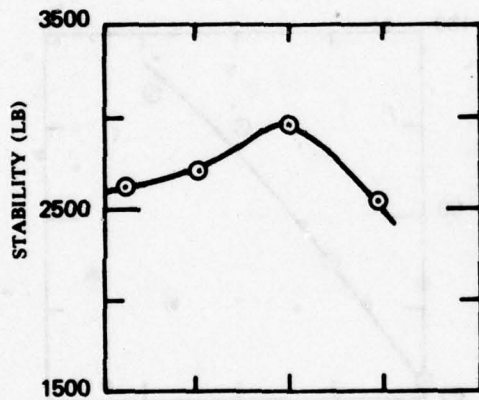
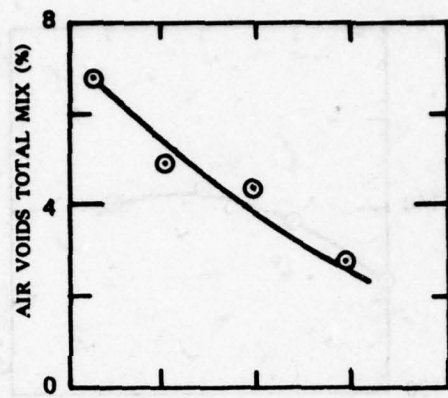
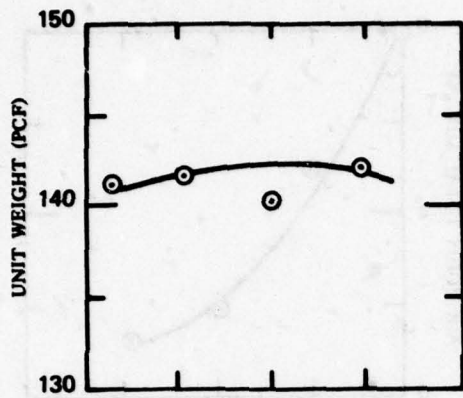
FIGURE C-5. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: EL TORO RECYCLE AND AC AGGREGATE SAMPLES WITH AR-2000.



**MIX DESCRIPTION:**

FALLON CRUSHED - 75%  
 MINUS NO. 4 CRUSHER  
 FINES - 25%  
 PAXOLE 1007 - 28% OF  
 RESIDUAL ASPHALT/  
 SOFTENER BLEND  
 AR-4000 - VARYING  
 PERCENTAGES

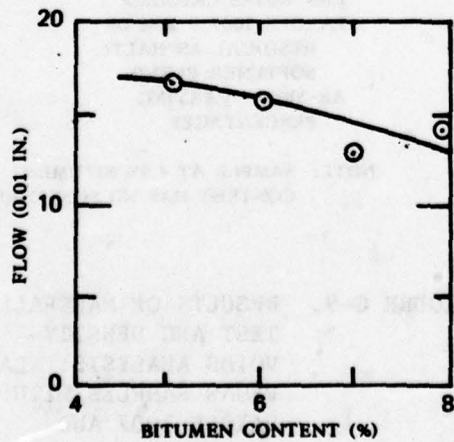
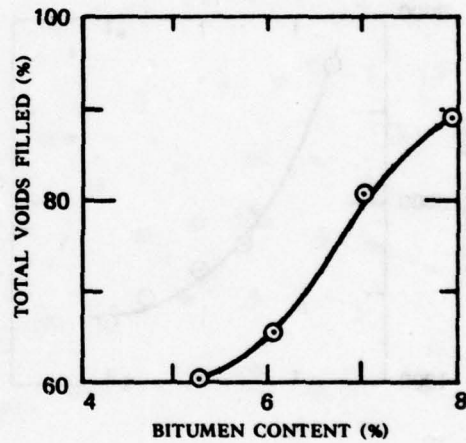
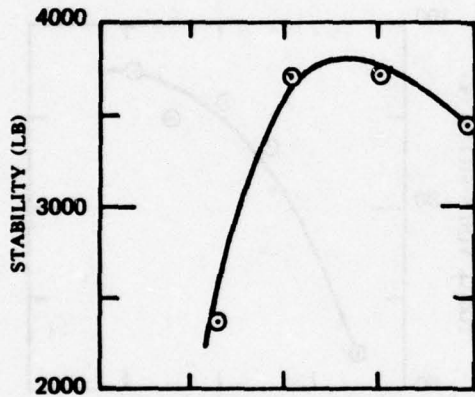
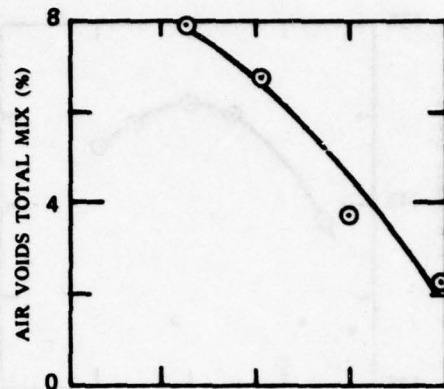
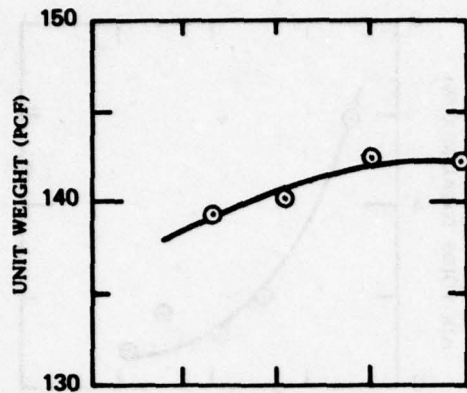
**FIGURE C-6. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: FALLON RECYCLE AND MINUS NO. 4 CRUSHER FINES WITH PAXOLE 1007 AND AR-4000.**



**MIX DESCRIPTION:**

FALLON CRUSHED - 75%  
 MINUS 3/4 IN. ASPHALT  
 CONCRETE AGGREGATE - 25%  
 PAXOLE 1007 - 28% OF  
 RESIDUAL ASPHALT/  
 SOFTENER BLEND  
 AR-4000 - VARYING  
 PERCENTAGES

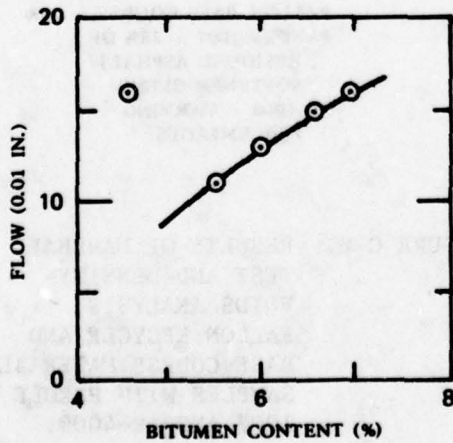
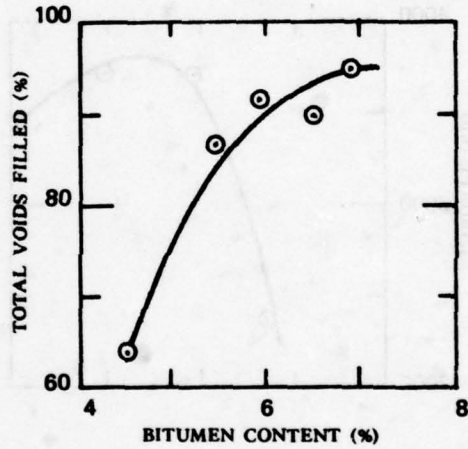
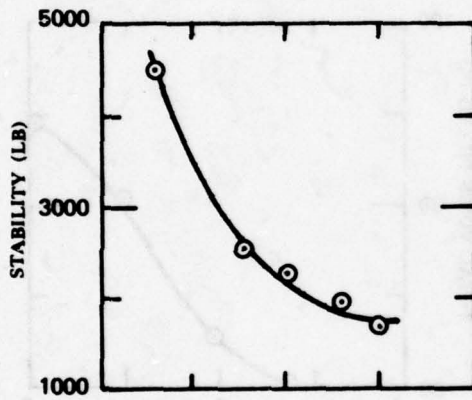
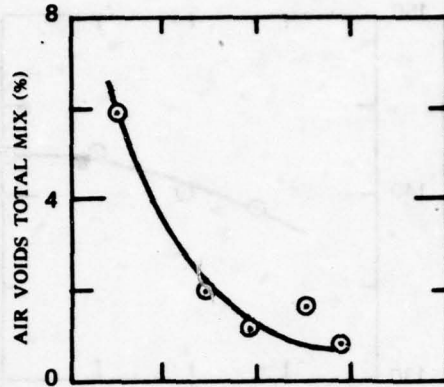
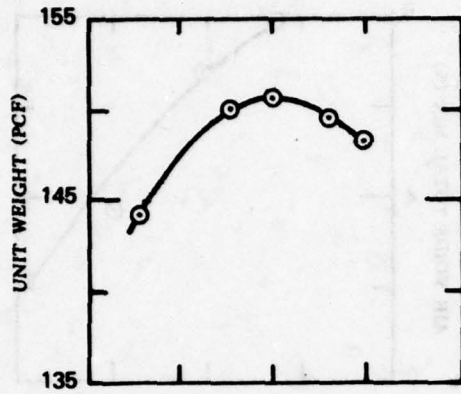
**FIGURE C-7. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: FALLON RECYCLE AND AC AGGREGATE SAMPLES WITH PAXOLE 1007 AND AR-4000.**



**MIX DESCRIPTION:**

FALLON CRUSHED - 75%  
 FALLON BASE COURSE - 25%  
 PAXOLE 1007 - 28% OF  
 RESIDUAL ASPHALT/  
 SOFTENER BLEND  
 AR-4000 - VARYING  
 PERCENTAGES

**FIGURE C-8. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: FALLON RECYCLE AND BASE COURSE MATERIAL SAMPLES WITH PAXOLE 1007 AND AR-4000.**

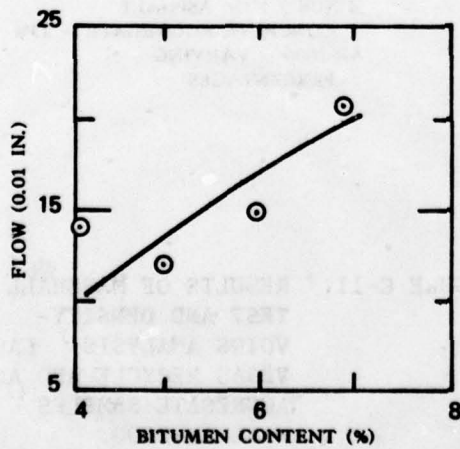
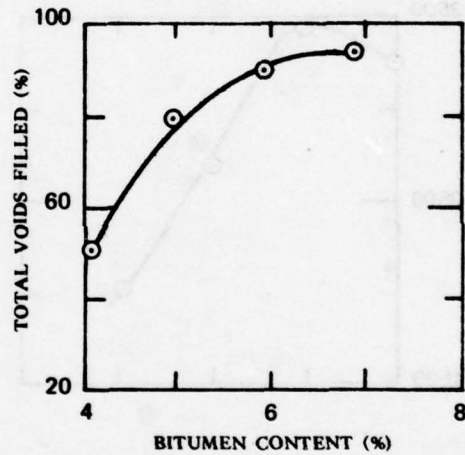
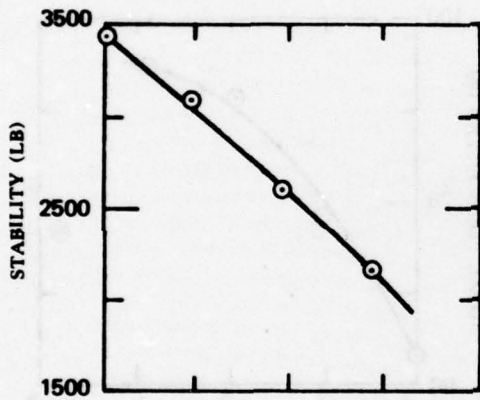
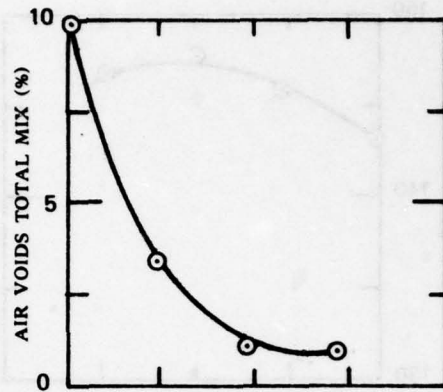
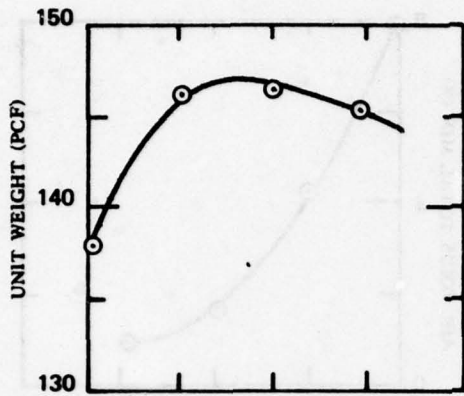


**MIX DESCRIPTION:**

LAS VEGAS CRUSHED  
 PAXOLE 1007 - 20% OF  
 RESIDUAL ASPHALT/  
 SOFTENER BLEND  
 AR-2000 - VARYING  
 PERCENTAGES

**NOTE:** SAMPLE AT 4.5% BITUMEN  
 CONTENT HAS NO SOFTENER

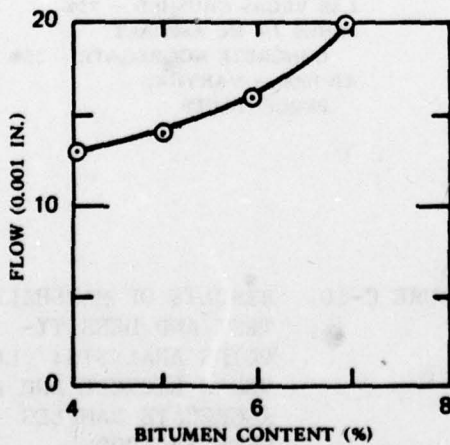
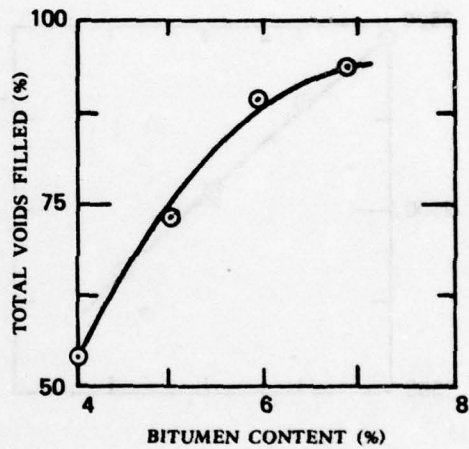
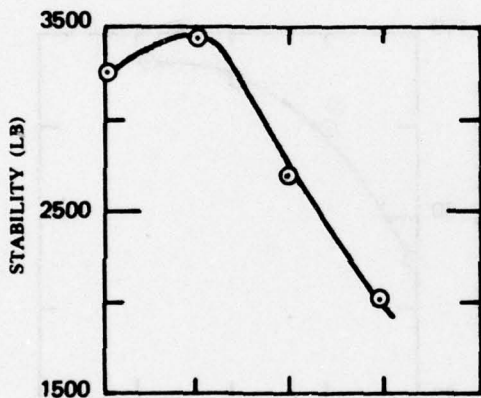
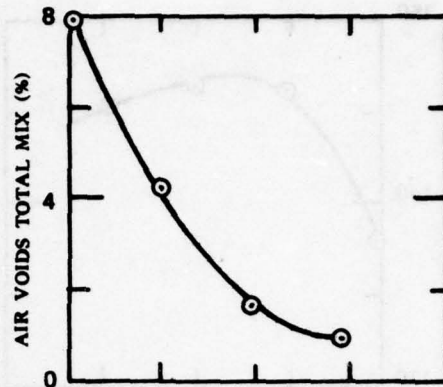
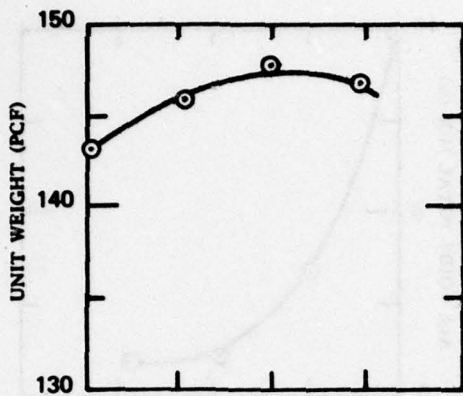
**FIGURE C-9. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: LAS VEGAS SAMPLES WITH PAXOLE 1007 AND AR-2000.**



**MIX DESCRIPTION:**

LAS VEGAS CRUSHED - 75%  
 MINUS 3/4 IN. ASPHALT  
 CONCRETE AGGREGATE - 25%  
 AR-1000 - VARYING  
 PERCENTAGES

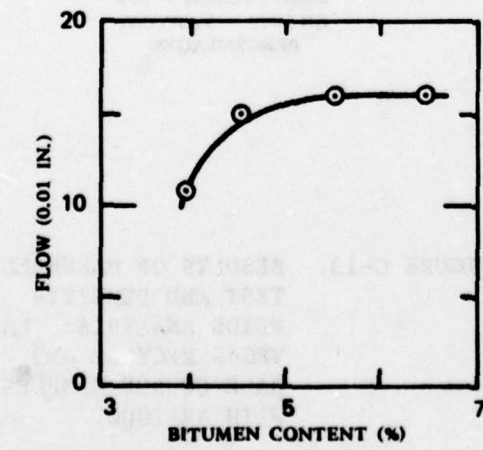
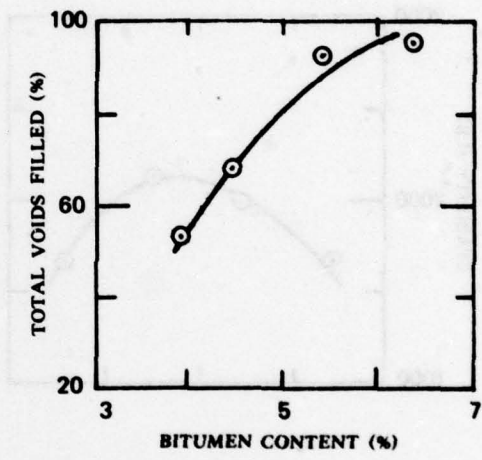
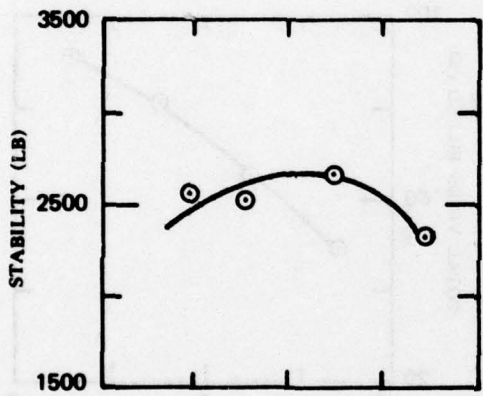
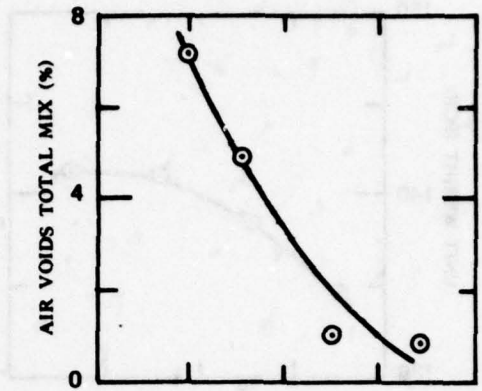
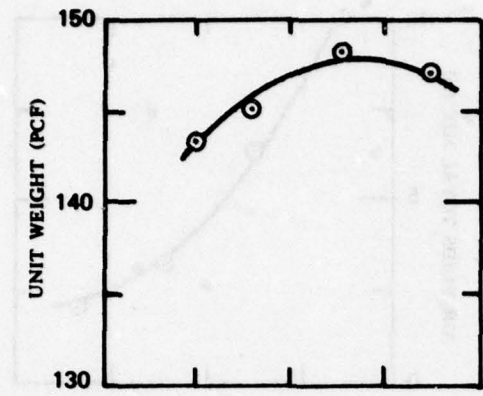
FIGURE C-10. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: LAS VEGAS RECYCLE AND AC AGGREGATE SAMPLES WITH AR-1000.



**MIX DESCRIPTION:**

LAS VEGAS CRUSHED - 75%  
 MINUS 3/4 IN. ASPHALT  
 CONCRETE AGGREGATE - 25%  
 AR-2000 - VARYING  
 PERCENTAGES

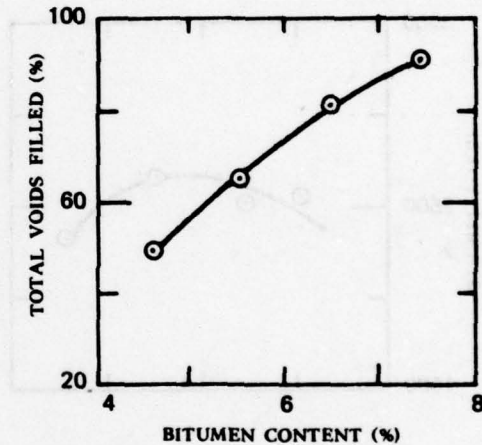
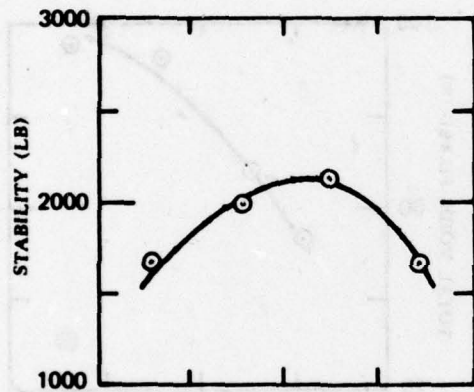
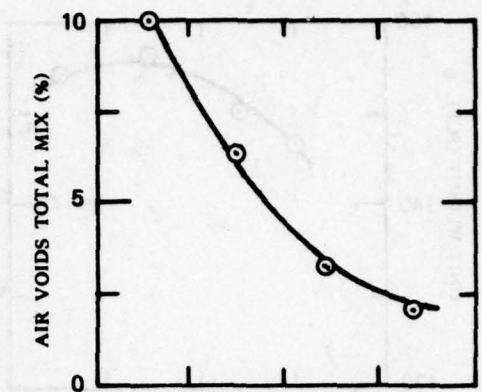
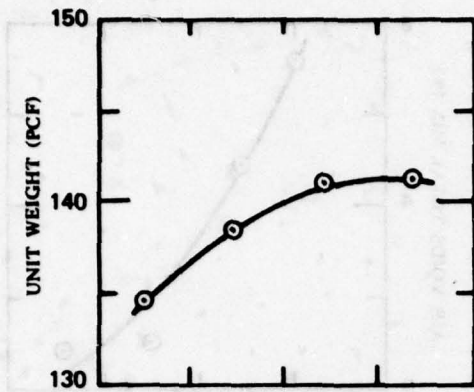
**FIGURE C-11. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: LAS VEGAS RECYCLE AND AC AGGREGATE SAMPLES WITH AR-2000.**



**MIX DESCRIPTION:**

LAS VEGAS CRUSHED - 75%  
 MINUS 3/4 IN. ASPHALT  
 CONCRETE AGGREGATE - 25%  
 PAXOLE 1007 - 14% OF  
 SOFTENER/RESIDUAL  
 ASPHALT BLEND  
 AR-4000 - VARYING  
 PERCENTAGES

**FIGURE C-12. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: LAS VEGAS RECYCLE AND AC AGGREGATE SAMPLES WITH PAXOLE 1007 AND AR-4000.**



MIX DESCRIPTION:  
 LAS VEGAS CRUSHED - 50%  
 BASE COURSE - 50%  
 AR-1000 - VARYING  
 PERCENTAGES

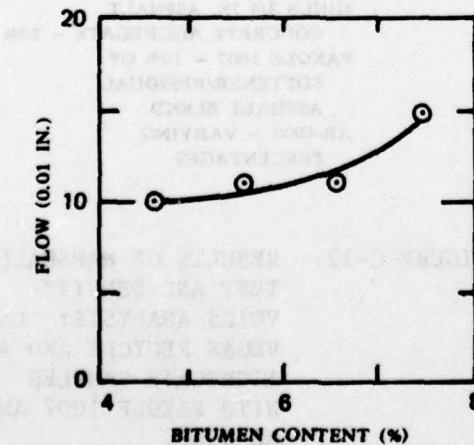
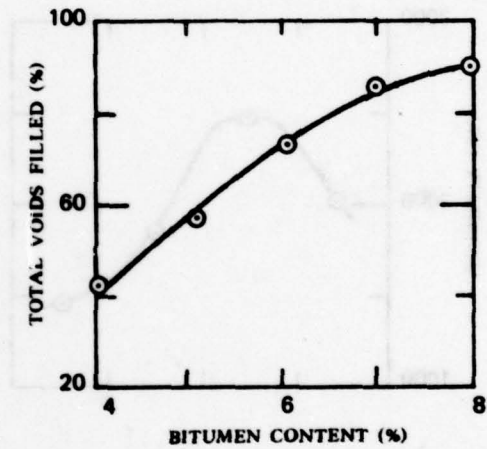
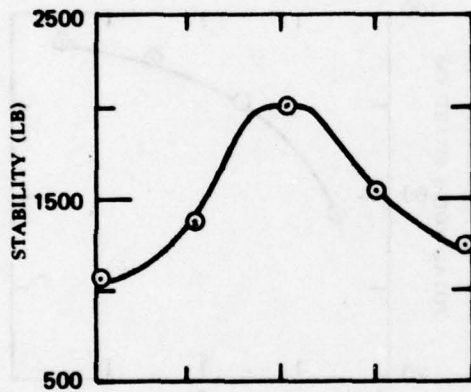
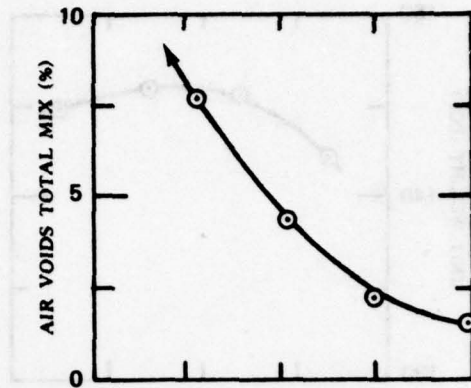
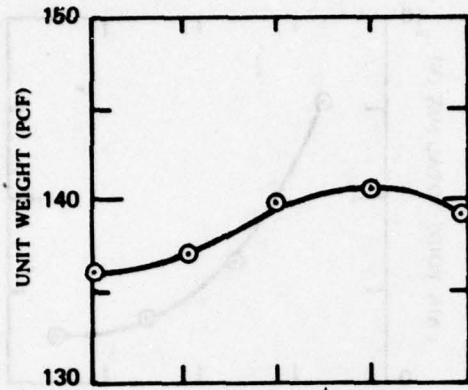
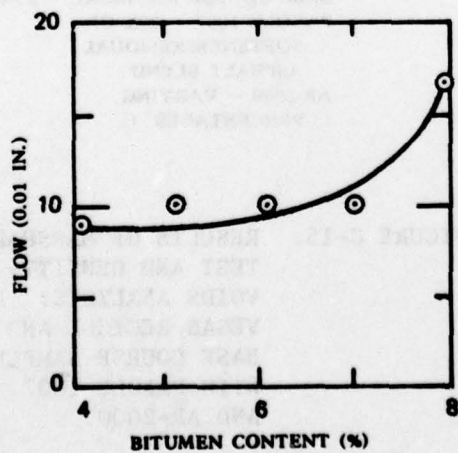


FIGURE C-13. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: LAS VEGAS RECYCLE AND BASE COURSE SAMPLES WITH AR-1000.

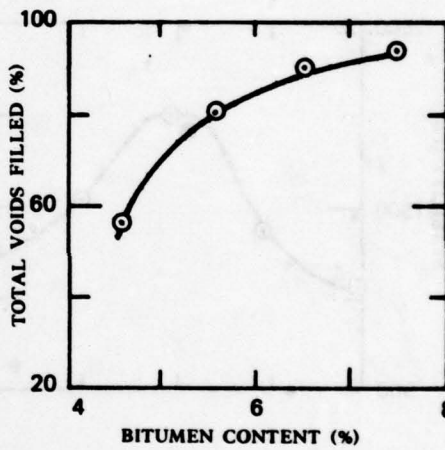
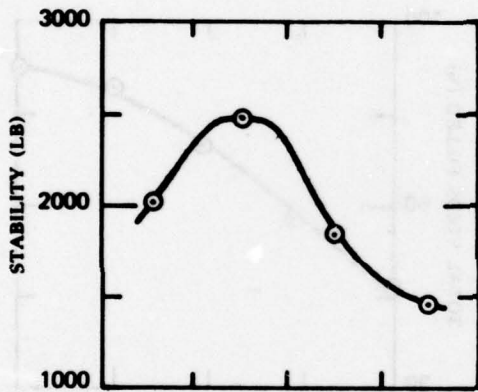
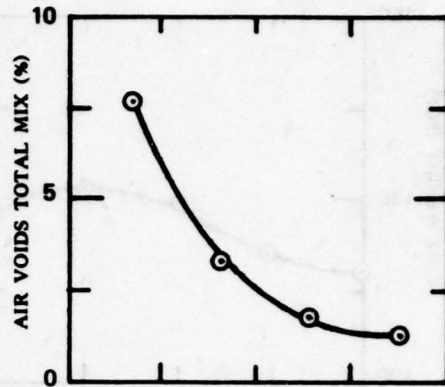
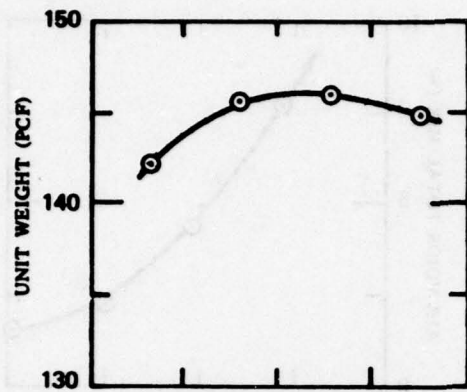


**MIX DESCRIPTION:**

LAS VEGAS CRUSHED - 50%  
 BASE COURSE MATERIAL - 50%  
 PAXOLE 1007 - 20% OF  
 SOFTENER/RESIDUAL  
 ASPHALT BLEND  
 AR-2000 - VARYING  
 PERCENTAGES

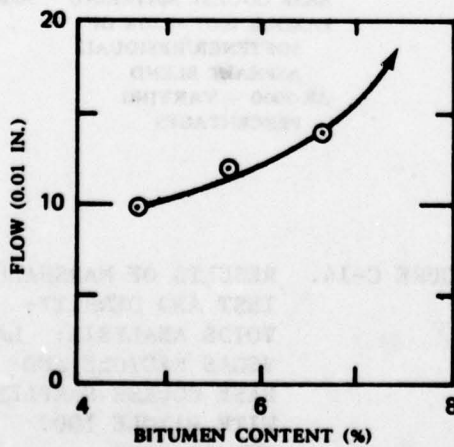


**FIGURE C-14. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: LAS VEGAS RECYCLE AND BASE COURSE SAMPLES WITH PAXOLE 1007 AND AR-2000.**

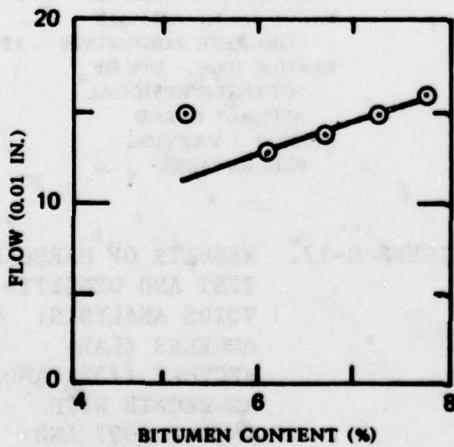
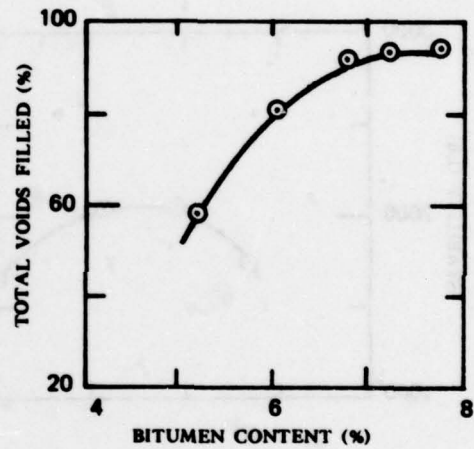
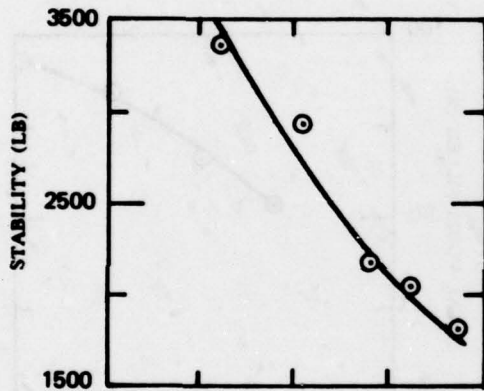
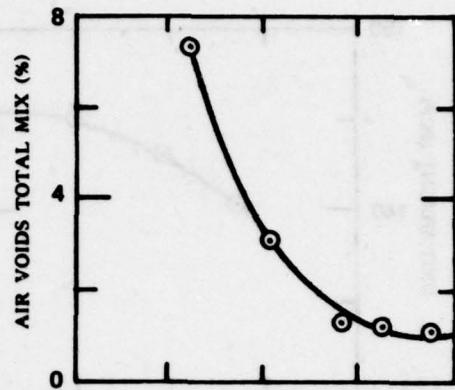
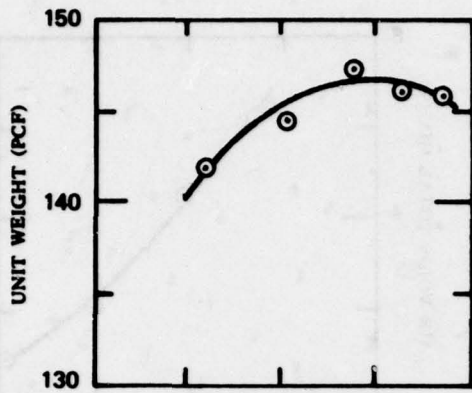


**MIX DESCRIPTION:**

LAS VEGAS CRUSHED - 75%  
 BASE COURSE MATERIAL - 25%  
 PAXOLE 1007 - 20% OF  
 SOFTENER/RESIDUAL  
 ASPHALT BLEND  
 AR-2000 - VARYING  
 PERCENTAGES



**FIGURE C-15. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: LAS VEGAS RECYCLE AND BASE COURSE SAMPLES WITH PAXOLE 1007 AND AR-2000.**

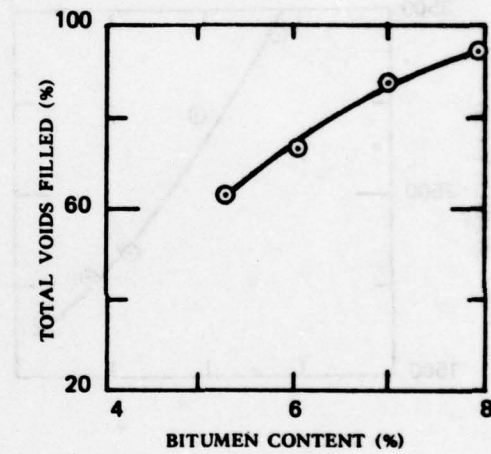
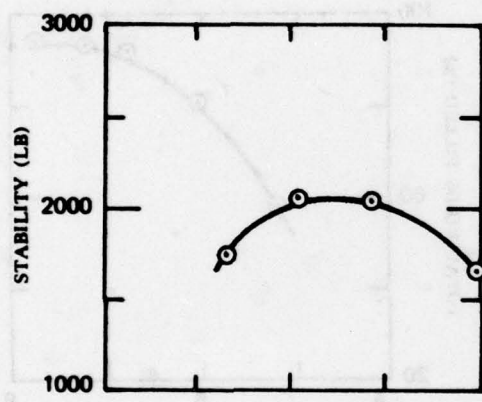
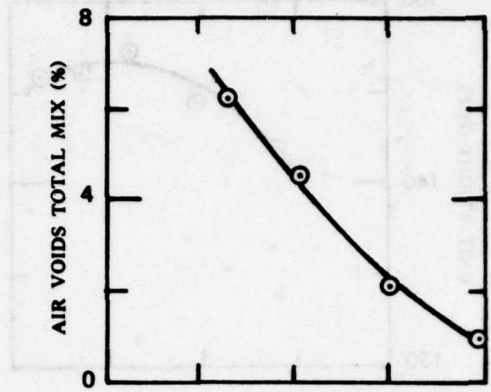
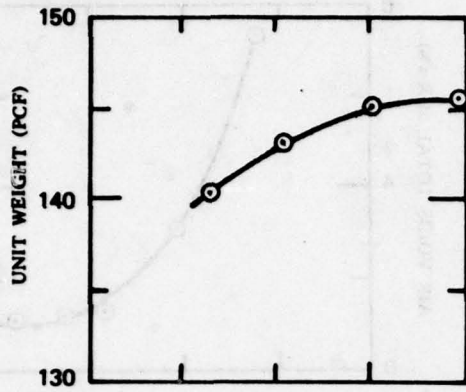


**MIX DESCRIPTION:**

LOS ANGELES CRUSHED  
PAXOLE 1007 - 20% OF  
SOFTENER/RESIDUAL  
ASPHALT BLEND  
AR-2000 - VARYING  
PERCENTAGES

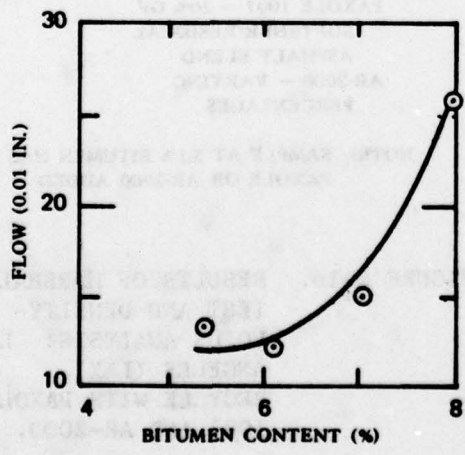
NOTE: SAMPLE AT 5.1% BITUMEN HAS NO  
PAXOLE OR AR-2000 ADDED

FIGURE C-16. RESULTS OF MARSHALL  
TEST AND DENSITY-  
VOIDS ANALYSIS: LOS  
ANGELES (LAX)  
RECYCLE WITH PAXOLE  
1007 AND AR-2000.

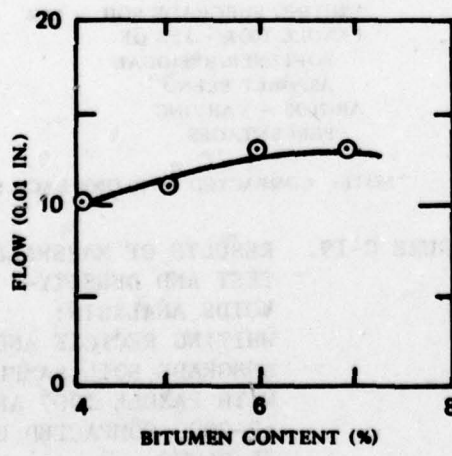
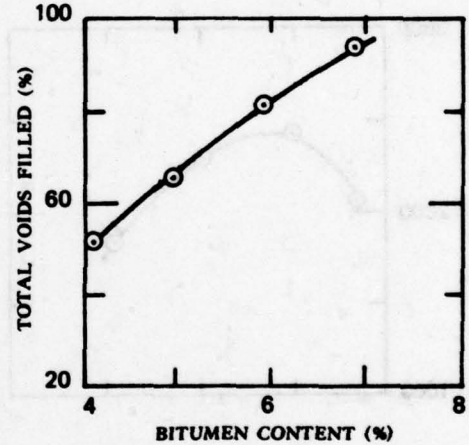
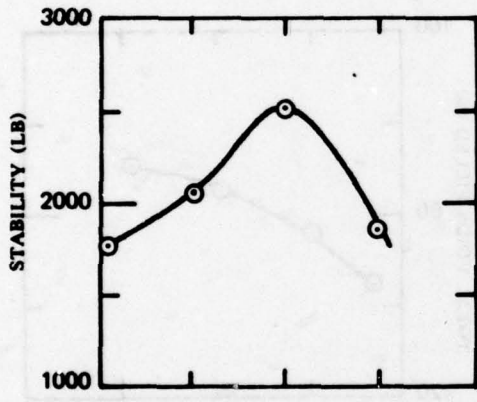
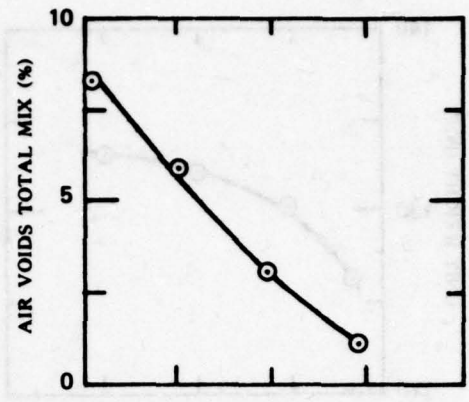
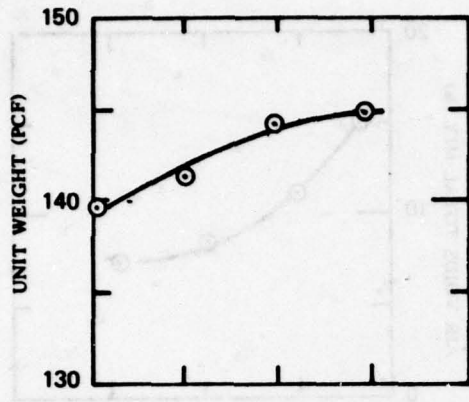


**MIX DESCRIPTION:**

LOS ANGELES CRUSHED - 75%  
 MINUS 3/4 IN. ASPHALT  
 CONCRETE AGGREGATE - 25%  
 PAXOLE 1007 - 20% OF  
 SOFTENER/RESIDUAL  
 ASPHALT BLEND  
 AR-2000 - VARYING  
 PERCENTAGES



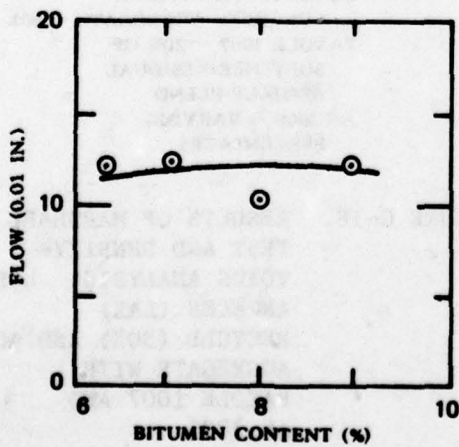
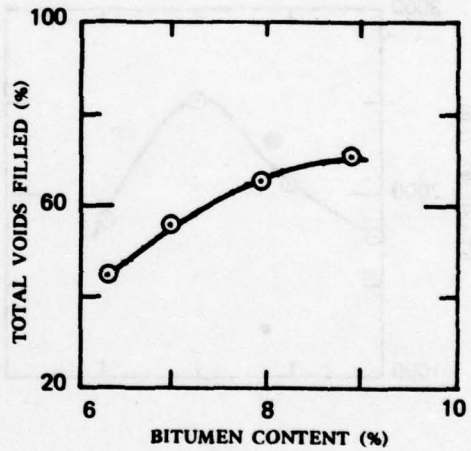
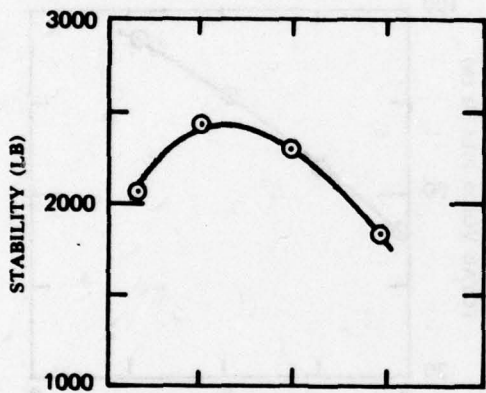
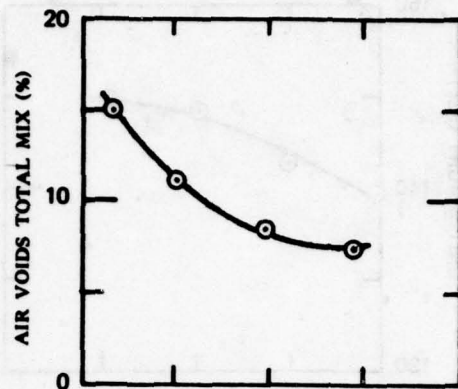
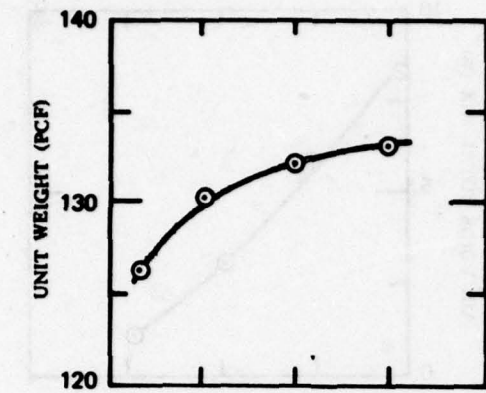
**FIGURE C-17. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: LOS ANGELES (LAX) RECYCLE (75%) AND AC AGGREGATE WITH PAXOLE 1007 AND AR-2000.**



**MIX DESCRIPTION:**

- LOS ANGELES CRUSHED - 50%
- MINUS 3/4 IN. ASPHALT
- CONCRETE AGGREGATE - 50%
- PAXOLE 1007 - 20% OF
- SOFTENER/RESIDUAL
- ASPHALT BLEND
- AR-2000 - VARYING
- PERCENTAGES

**FIGURE C-18. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: LOS ANGELES (LAX) RECYCLE (50%) AND AC AGGREGATE WITH PAXOLE 1007 AND AR-2000.**

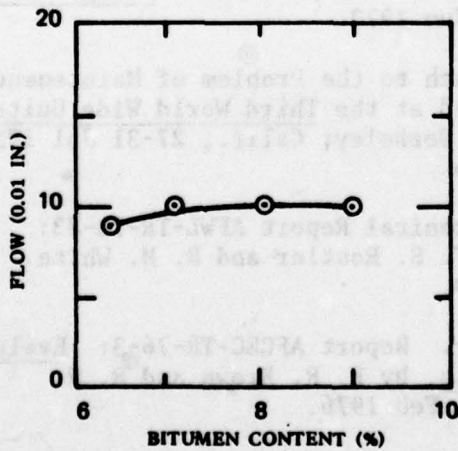
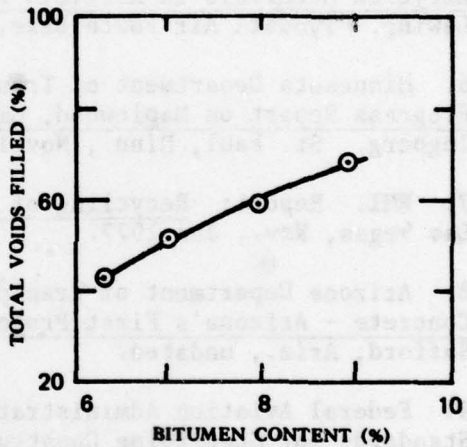
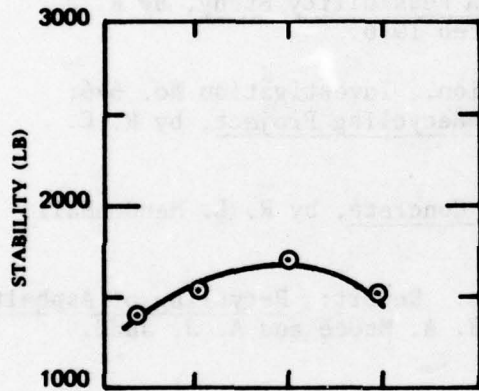
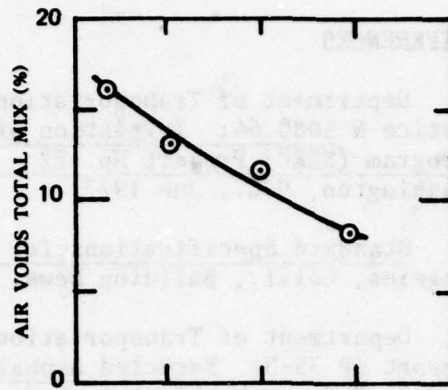
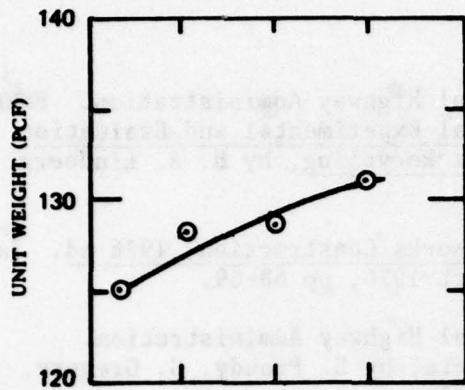


**MIX DESCRIPTION:**

WHITING CRUSHED - 75%  
 WHITING SUBGRADE SOIL - 25%  
 PAXOLE 1007 - 32% OF  
 SOFTENER/RESIDUAL  
 ASPHALT BLEND  
 AR-2000 - VARYING  
 PERCENTAGES

NOTE: COMPACTED 75 BLOWS EACH SIDE

FIGURE C-19. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: WHITING RECYCLE AND SUBGRADE SOIL SAMPLES WITH PAXOLE 1007 AND AR-2000 COMPACTED BY 75 BLOWS.



**MIX DESCRIPTION:**

WHITING CRUSHED - 75%  
 WHITING SUBGRADE SOIL - 25%  
 PAXOLE 1007 - 32% OF  
 SOFTENER/RESIDUAL  
 ASPHALT BLEND  
 AR-2000 - VARYING  
 PERCENTAGES

**NOTE: COMPACTED 50 BLOWS EACH SIDE**

**FIGURE C-20. RESULTS OF MARSHALL TEST AND DENSITY-VOIDS ANALYSIS: WHITING RECYCLE AND SUBGRADE SOIL SAMPLES WITH PAXOLE 1007 AND AR-2000 COMPACTED BY 50 BLOWS.**

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