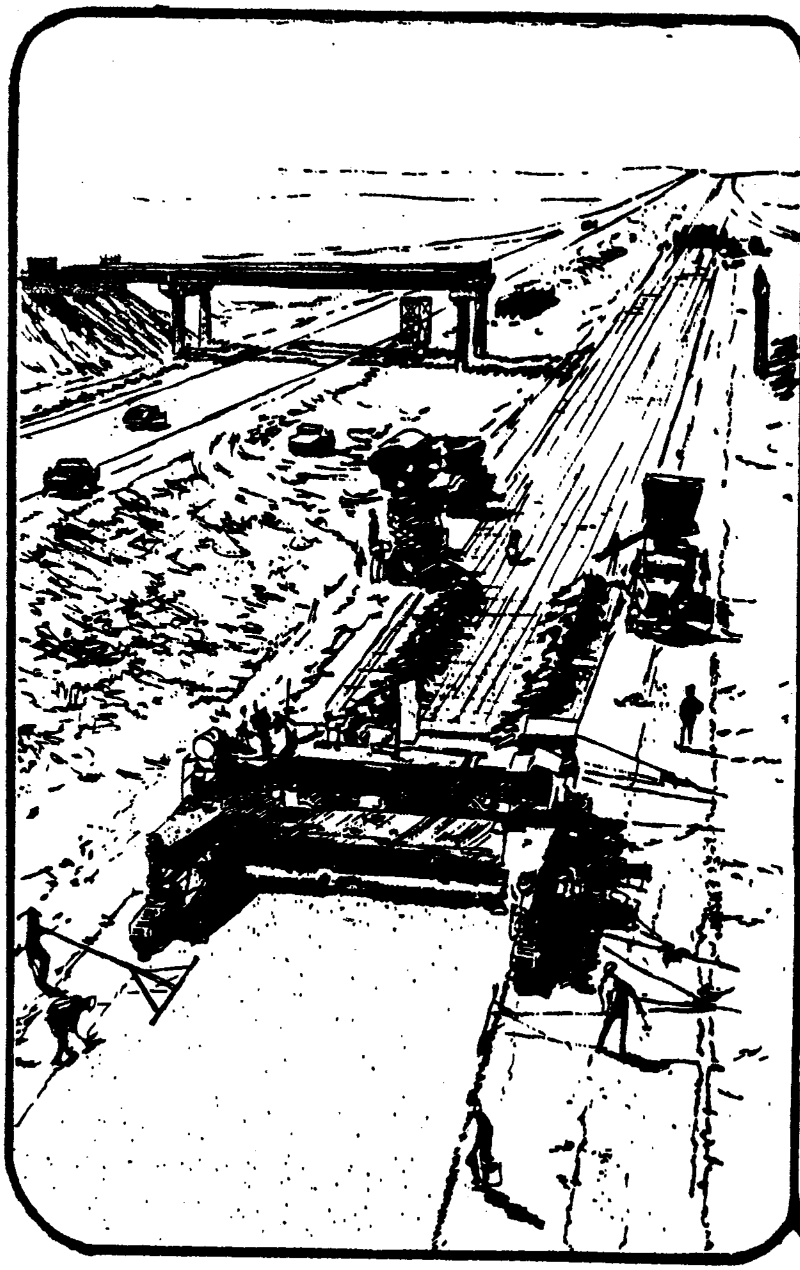
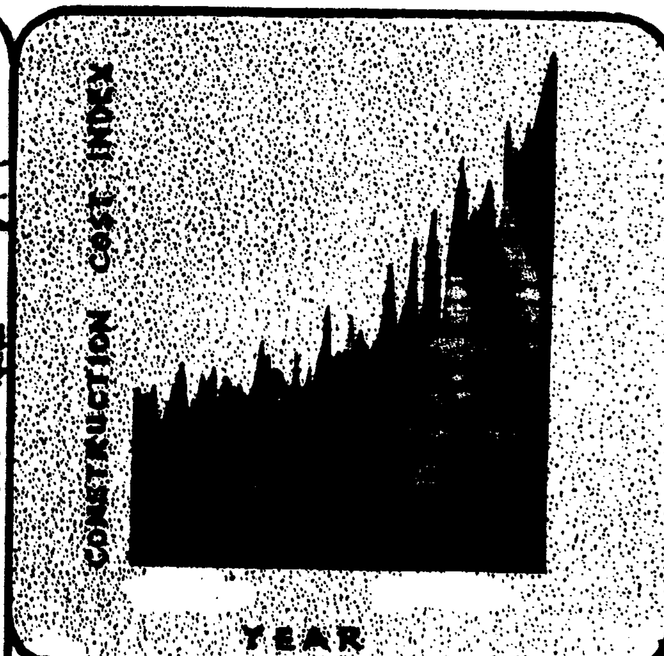
ENGINEERING ECONOMY AND ENERGY CONSIDERATIONS

DESIGN OF RECYCLED ASPHALT CONCRETE MIXTURES

RESEARCH REPORT 214-22

AUGUST 1980





COOPERATIVE RESEARCH PROJECT
2-9-74-214

"ENGINEERING, ECONOMY AND ENERGY CONSIDERATIONS IN DESIGN, CONSTRUCTION AND MATERIALS"

TEXAS STATE DEPARTMENT OF HIGHWAYS AND PUBLIC TRANSPORTATION

AND

TEXAS TRANSPORTATION INSTITUTE
TEXAS A&M UNIVERSITY

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DESIGN OF RECYCLED ASPHALT CONCRETE MIXTURES

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Research Report 214-22

Engineering, Economy and Energy Considerations in Design,
Construction and Materials

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Sponsored by

State Department of Highways
and Public Transportation

August 1980

Texas Transportation Institute
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INTRODUCTION

The recycling of old bituminous bound pavements in central plant operation has gained popularity since 1976. Procedures for the design of these mixtures have not been standardized; however, several producers and user-producer groups have published guides for design purposes (1-6). A mixture design method is outlined below based on these references together with information collected by the authors on studies sponsored by the Texas State Department of Highways and Public Transportation, the National Cooperative Highway Research Program and the Federal Highway Administration. The method outlined should be considered as the existing state-of-the-art as of July, 1980. Improvements in this design methodology are expected over the next several years.

RECYCLING MODIFIERS

Asphalt binders present in recycled pavements often contain physical and chemical properties which make the "old" asphalt undesirable for reuse without modification. Materials have been developed to restore these old binders to a condition suitable for reuse. This concept is not new and has been the subject of a number of extensive studies during the last several years (1-8).

Materials used to alter properties of asphalt cements have been called softening agents, reclaiming agents, modifiers, recycling agents, fluxing oils, extender oils, aromatic oils, etc. Most of the major oil companies market products of this type. The term "modifier" will be used to designate this type of material in this report and originates from ASTM Subcommittee

D 4.37 (Modifier Agents for Bitumen in Pavements and Paving Mixtures). The general definition of modifier is "a material when added to asphalt cement that will alter the physical-chemical properties of the resulting binder." A more specific definition has been developed by the Pacific Coast User-Producer Group for the term "recycling agent". A "recycling agent" is a hydrocarbon product with physical characteristics selected to restore aged asphalt to requirements of current asphalt specifications. It should be noted that soft asphalt cements, as well as specialty products, can be classified as recycling agents or modifiers.

The purpose of the modifier in asphalt pavement recycling is to:

1. Restore the recycled or "old" asphalt characteristics to a consistency level appropriate for construction purposes and for the end use of the mixture,

2. Restore the recycled asphalt to its optimum chemical characteristics for durability,

3. Provide sufficient additional binder to coat any new aggregate that is added to the recycled mixture and

4. Provide sufficient additional binder to satisfy mixture design requirements.

The design method outlined below allows the engineer to select the types and amount of bituminous modifiers to produce the desired mixture.

MIXTURE DESIGN METHOD

The proposed method is applicable for both hot and cold recycling operations and includes modifiers such as softening agents, rejuvenators, flux oils and soft asphalt cements. The method consists of the following general steps:

1. Evaluation of salvaged materials,
2. Determination of the need for additional aggregates,
3. Selection of modifier type and amount,
4. Preparation and testing of mixtures and
5. Selection of optimum combinations of new aggregates and asphalt modifiers.

The overall philosophy of this approach is to utilize the recycled materials, new aggregate and modifier to produce a mixture with properties as nearly like a new asphalt concrete mixture as possible. Standard test methods have been utilized where possible. The mixture design procedure is shown in Figure 1 and has been modeled after that suggested in references 1 to 6. The circled numbers on the flow diagram refer to the steps presented below.

Field Samples (1)

Representative field samples should be obtained from the pavement to be recycled. A visual evaluation of the pavement should be made together with a review of construction and maintenance records to determine significant differences in the material to be recycled along the pavement section. Roadway sections with significant differences in materials should not be lumped together because uniformity and predictability of results will be impaired. Locations within a project can be determined on a random basis using the procedure outlined in Reference 11. At least 5 or 6 locations should be used as a minimum and a total composite sample of about 200 lbs. is recommended for laboratory evaluation. If desired, core samples may also be obtained and used for comparison of original and recycled properties such as stability and resilient modulus (M_R) (12).

Extract and Recover Asphalt and Aggregate (2)

Extraction and Recovery tests should be performed at each location sampled. Results of these tests (penetration, viscosity, asphalt content) together with thickness measurements made from the cores should help determine the uniformity of the section under consideration for recyling. Sufficient asphalt should be recovered to permit blending with asphalt modifiers for further testing.

Aggregate Properties (3)

Aggregate recovered from the samples in step (2) above should be tested for gradation and durability such as Los Angeles Abrasion and Polish Value if the recycled mixture is to be utilized as a surface course. These data can be used to establish project uniformity together with the recovered asphalt data obtained in step (2).

New Aggregate (4)

New aggregate may have to be added to the mixture for one or more of the following purposes:

1. Satisfy gradation requirements,
2. Skid resistance requirements for surface courses,
3. Air quality problems associated with hot central plant recycling,
4. Thickness requirements,

5. Improved stability, durability, flexibility, etc. and

6. To allow the addition of sufficient modifier to restore the aged asphalt to specification requirements.

Gradation requirements for recycled mixtures should be those presently required by the specifying agency or those in ASTM D 3515.

To provide initial and long lasting skid resistance for the recycled bituminous surface course, it may be necessary to blend coarse non-polishing aggregate with the recycled pavement. It appears as if 40 percent by volume of the plus No. 4 fraction should be non-polishing to provide the desired skid performance on moderate to high traffic volume facilities.

Air quality regulations for hot central plant operations necessitate the use of a minimum of about 30 to 40 percent by volume new aggregate. This requirement will be gradually reduced as equipment manufacturers and contractors improve the hot recycling operation.

Replacing the recycled pavement with a thicker section of asphalt stabilized material may be required from a structural pavement design standpoint. This can be accomplished by blending new aggregate with the recycled material or by the addition of layers of new asphalt stabilized materials. If hot central plant operations are to be used, it appears practical to blend the new aggregate with the recycled pavement.

Asphalt Demand (5)

The asphalt demand (D_T) of the proposed recycled material can be estimated from the following equation:

$$D_T = V_R D_R + V_N D_N \qquad \text{Equation 1}$$

where:

$$D_R = D_{CKE} - A_R \qquad \text{Equation 2}$$

and

D_R = asphalt demand for salvaged or recycled aggregate, percent

D_{CKE} = CKE derived Oil Ratios for salvaged or recycled aggregate, percent

A_R = asphalt content of salvaged or recycled aggregate

D_N = CKE derived Oil Ratios for new aggregate, percent

V_R = volume of recycled aggregate in mixtures

V_N = volume of new aggregate in mixtures

It should be noted that if new aggregate is not utilized, Equation 1 becomes Equation 2.

The asphalt demand determined in this manner should be considered an estimate and can be used as a starting point for mixture design purposes. It should be noted that the asphalt demand will be satisfied by the modifier as specified in Table 1. These modifiers can be softening agents, asphalt cements or blends of softening agents and asphalt cements.

Asphalt Properties (6)

Asphalt recovered from the samples in step (2) above should be tested for penetration at 77°F and viscosity at 140°F. Asphalt content, penetration and viscosity should be determined on all extracted samples. These data can be used to determine project uniformity.

Determine Type and Amount of Modifiers (7) (8). The type and amount of modifiers can be selected by utilizing Figure 2 or 3 and Table 1 or 2 together with a definition of the penetration or preferable viscosity of the binder in the processed recycled mixture and a knowledge of the asphalt demand of the recycled mixture which was obtained in step (5), Equation 1. For example, assume the following:

1. CKE Oil Ratios on extracted salvaged or recycled aggregate, $D_{CKE} = 5.0\%$

2. Percent asphalt in salvaged or recycled material, $A_R = 4.0\%$

3. Viscosity of aged asphalt 20,000 poises

4. Additional new aggregate, $V_N = 30\%$

5. CKE Oil Ratio of new aggregate, $D_N = 6.0\%$

6. Desired viscosity of recycled asphalt = 2,000 poises

From Equations 1 and 2 the following asphalt demand can be calculated:

$$D_T = V_R D_R + V_N D_N \qquad \text{Equation 1}$$

$$D_R = D_{CKE} - A_R \qquad \text{Equation 2}$$

$$D_R = 5.0 - 4.0 = 1.0$$

$$D_T = (.70)\ (1.0) + (.30)\ (6.0)$$

$$D_T = 2.5\%$$

The maximum predicted percent modifier by weight of total binder in the recycled mixture is therefore:

$$\frac{D_T}{V_R A_R + D_T} \times 100$$

$$= \frac{25}{(.70)\ (4.0) + 2.5} \times 100$$

$$= 47\%$$

By use of Figure 1 the viscosity of the modifier can be approximated. The figure is entered with the volume percent of lower viscosity modifier (47%) and the desired viscosity of the recycled binder to locate Point A. Point A is connected with the viscosity of the recovered salvaged binder and the line projected to obtain the viscosity of the modifier. Table 1 indicates that modifier grade RA 5 would likely be suitable.

It should be noted that new asphalt cement and a softer modifier could be utilized to form the new binder provided air quality requirements can be met.

Modifier Tests (9)

Samples of modifiers to be used on the job should be obtained and subjected to tests to establish their conformance to specifications (Table 1 or 2) as well as establish the viscosity of the modifier in order to obtain a more realistic modifier content (Figure 2 or 3).

Blend Modifier with Recovered Asphalt (10)

The modifier which may consist of an asphalt cement and softener should be blended with the recovered asphalt and subjected to viscosity and penetration tests to determine if the predicted viscosity (penetration) of the blend was accurate. It is suggested that two blends, one 5% above and one 5% below the percent recycling agent determined in steps (7) and (8) be made. About 75 to 100 grams of recovered asphalt for each blend should be utilized. A third blend may be required to confirm the desired viscosity or penetration.

Some recycling modifiers may not be compatible with the salvaged asphalt. Therefore, a thin film oven test should be performed on the selected recovered salvaged asphalt-modifier blend. A ratio of the aged viscosity to original viscosity of 3 or less will indicate that the recycling agent is likely compatible with the recovered salvaged asphalt.

Preliminary Mixtures (11)

Five different mixtures of recycled aggregate, new aggregate if desired, and modifier should be fabricated. Three samples of each mixture should be fabricated and subjected to stability testing and tests to determine the air void content. These preliminary tests should vary the percent new asphalt cement and/or the type and amount of modifiers. It is helpful to have an experienced engineer present during the mixing and molding operation as subsequent trial mixtures may depend upon the appearance of the first few trial mixtures. It should be realized that the modifiers often have a delayed softening reaction.

Standard mixing and molding operations should be utilized. An oven curing procedure after mixing and prior to compaction such as that used in California appears to be desirable.

Detailed Mixture Evaluations (12)

The three most promising mixtures evaluated in step (11) should be evaluated in detail for properties which can be used in pavement thickness design and for durability considerations such as water susceptibility. The testing plan as shown in Figure 4 can be used as a guide. The amount of testing will depend upon the capability of the agency considering the recycling project. However, the authors feel that extraction and recovery tests are important as well as resilient modulus tests.

Properties of the extracted and recovered bituminous material from the laboratory prepared and recycled mixture are an indication of the compatibility and durability of the recycling modifiers. Preliminary laboratory testing has indicated that extraction and recovery tests will identify potential problems between the "old" asphalt and the modifier that tests performed on the blend of "old" asphalt and modifier do not identify.

The resilient modulus appears to be the best single test to identify the effect of the modifier on the mixture. This test is sensitive to the properties of the binder and will help define the amount of modifier required to produce a binder of known consistency. Resilient modulus values of the order of 200,000 to 400,000 psi (measured at 77°F, 0.1 second load duration) are typical of recycled mixtures blended with modifiers to produce binders equivalent to AC-10 asphalt cements.

Select Optimum Mixture Design (13)

The optimum mixture design should be based on results of steps (11) and (12) and economic and energy considerations. Reference 11 can be used as a general guide. In general, final mixture designs should be based on stability requirements and air void criteria; however, the resilient modulus versus temperature relationship should be considered.

The resilient modulus should be below about 900,000 psi (77°F and 0.1 second load duration).

Mixture Containing Emulsified Modifiers

The above discussion has been primarily directed toward the use of hot central plant operations. Recycling in central plants or in place with emulsified modifiers is also an alternative that is considered on a number of projects. The design of mixtures containing emulsions required special considerations as outlined below.

The step by step procedure outlined on Figure 1 and used for hot mixes is suggested for use with the following exceptions:

1. The properties of the base modifier should be used in step (7) to determine the type and amount of emulsified modifier to be used,

2. The modifier sample tested in step (9) should be subjected to those tests required for specification compliance. Table 2 contains an example specification for emulsified modifiers,

3. The base modifier should be used for the blends prepared in step (10). Tests should be performed as outlined in step (10),

4. Mixing and testing of recycled mixtures containing emulsified modifiers should be performed according to procedures outlined in reference 13. Of the 11 methods identified in the reference it is suggested that The Asphalt Institute Method be utilized with Texas gyratory compaction substituted for the Hveem Kneading compaction. Curing of the samples prior to testing is critical and should be closely followed and

5. Criteria for mixture designs are shown on Table 3. These criteria should be used on an interim basis.

CONCLUSIONS AND RECOMMENDATIONS

1. Procedures for the design of recycled mixtures have been outlined. The methods outlined are considered to be the existing state-of-the-art and will be improved as additional laboratory and field research is completed.

2. Interim specifications for recycling agents have been suggested. These specifications have been adopted by the Pacific Coast User-Producer Group.

3. The laboratory mixture design should be considered as the starting point for the field mixture. Changes in the field should be based on laboratory test results and field workability requirements. It is important that portable laboratories be present at all large recycling projects. As a minimum these laboratories should be capable of performing the following tests.

   a. Texas gyratory compaction

   b. Air void content determination

   c. Hveem stability

   d. Binder extraction and recovery tests

   e. Binder viscosity and penetration

   f. Aggregate gradation

REFERENCES

1. Davidson, D. D., Canessa, W. and Escobar, S. J., "Recycling of Substandard or Deteriorated Asphalt Pavements - A Guideline for Procedures", Vol. 46, AAPT, 1977.

2. "Asphalt Pavement Recycling Using Salvaged Materials", West Coast User Producer Group, preliminary copy, May, 1978.

3. Davidson, D. D., Canessa, W., Escobar, S. J. "Practical Aspects of Reconstituting Deteriorated Bituminous Pavements", STP 662, ASTM, November, 1978.

4. Dunning, R. L. and Mendenhall, R. L., "Design of Recycling Asphalt Pavements and Selection of Modifiers", STP 662, ASTM, November, 1978.

5. Kari, W. J., Santucci, L. E. and Coyne, L. D., "Hot Mix Recycling of Asphalt Pavements", Vol. 48, AAPT, 1979.

6. Escobar, S. J. and Davidson, D. D., "Role of Recycling Agents in the Restoration of Aged Asphalt Cements", Vol. 48, AAPT, 1979.

7. Anderson, D. I., Peterson, D. E., Wiley, M. L. and Betenson, W. B., "Evaluation of Selected Softening Agents Used in Flexible Pavement Recycling, "Report No. FHWA-TS-79-204, Federal Highway Administration, April, 1978.

8. Brownie, R. B., and Hironaka, M. C. "Recycling of Asphalt Concrete Airfield Pavements", Naval Civil Engineering Laboratory, Port Hueneme, California, April, 1978.

9. Kari, W. J., et. al. "Prototype Specifications for Recycling Agents Used in Hot-Mix Recycling" Vol. 49, AAPT, 1980.

10. Canessa, W., "Cyclogen™ for Recycling of Deteriorated Asphalt Pavements Either On-Site or Off-Site", Witco Chemical Corp., Bakersfield, California, November, 1977.

11. Asphalt Institute Manual Series 2 (MS-2), 1969.

12. Schmidt, R. V., "A Practical Method for Determining the Resilient Modulus of Asphalt-Treated Mixes", Highway Research Record No. 404, Highway Research Board, 1972.

13. "A Basic Asphalt Emulsion Manual, Volume 2: Mix Design Methods", The Asphalt Institute, January, 1979.

Table 1 - Proposed Specifications for Hot Mix Recycling Agents[1].

	ASTM Test Method	RA 5 Min.	RA 5 Max.	RA 25 Min.	RA 25 Max.	RA 75 Min.	RA 75 Max.	RA 250 Min.	RA 250 Max.	RA 500 Min.	RA 500 Max.
Viscosity @ 140°F, cSt	D 2170 or 2171	200	800	1000	4000	5000	10000	15000	35000	40000	60000
Flash Point COC, °F	D 92	400	-	425	-	450	-	450	-	450	-
Saturates, wt. %	D 2007	-	30	-	30	-	30	-	30	-	30
Residue from RTF-C Oven Test @ 325°F	D 2872[2]										
Viscosity Ratio[3]	-	-	3	-	3	-	3	-	3	-	3
RTF-C Oven Weight Change ± %	D 2872[2]	-	4	-	4	-	2	-	2	-	2
Specific Gravity	D 70 or D 1298	Report		Report		Report		Report		Report	

1. The final acceptance of recycling agents meeting this specification is subject to the compliance of the reconstituted asphalt blends with current asphalt specifications.

2. The use of ASTM D 1754 has not been studied in the context of this specification, however, it may be applicable. In cases of dispute the reference method shall be ASTM D 2872.

3. $\text{Viscosity Ratio} = \dfrac{\text{RTF-C Viscosity at 140°F, cSt}}{\text{Original Viscosity at 140°F, cSt}}$

After Reference 9

Table 2 - Interim Specifications for Emulsified Modifiers.

Property	Function and Purpose	Test Method	Specifications
Viscosity @ 77°F, SFS	Ease of Handling	ASTM D 244-76	15-85
Pumping Stability	Prevention of Premature Breaking	G.B. Method[2]	Pass
Emulsion Coarseness, Percent	Optimal Distribution	Sieve Test, ASTM D 244-76 (MOD[3]	0.1 Max.
Sensitivity to Fines, Percent	Adequate Mixing Life	Cement Mixing, ASTM D 244-76	2.0 Max.
Particle Charge	Preferential affinity to Asphalt	ASTM D 244-76	Positive
Concentration of Oil Phase, Percent	Assurance of Oil Content and for Calculations	ASTM D 244-76 (MOD)[4]	60 Min.

1. Oils used for emulsions must meet specifications listed in Table 1.

2. Pumping stability is determined by charging 450 ml of emulsion into a one-liter beaker and circulating the emulsion through a gear pump (Roper 29,B22621) having 1/4" inlet and outlet. The emulsion passes if there is no significant oil separation after circulating ten minutes.

3. Test procedure identical with ASTM D 244 except that distilled water shall be used in place of two percent sodium oleate solution.

4. ASTM D 244 Evaporation Test for percent of residue is modified by heating 50 gram sample to 300°F until foaming ceases, then cooling immediately and calculating results.

After Reference 10.

Table 3. Test Methods.

Test Method		Base or Temporary Surface		Permanent Surface	
		Dense Graded	Open Graded	Dense Graded	Open Graded
Coating, %		50 min.	50 min.	75 min.	75 min.
Run-off, % Residual Asphalt		N. A.	0.5 max.	N. A.	0.5 max.
Wash-off, % Residual Asphalt		N. A.	0.5 max.	N. A.	0.5 max.
Combined (Run-off and Wash-off), %		N. A.	0.5 max.	N. A.	0.5 max.
Resistance R_t-Value @ 73 ± 5°F (23 ± 2.8°C)	Early Cure*	70 min.	N. A.	N. A.	N. A.
	Fully Cured + Water Soak**	78 min.	N. A.	N. A.	N. A.
Stabilometer S-Value @ 140 ± 5°F** (60 ± 2.8°C)		N. A.	N. A.	30 min.	N. A.
Cohesiometer C-Value @ 73 ± 5°F (23 ± 2.8°C)	Early Cure*	50 min.***	N. A.	N. A.	N. A.
	Fully Cured + Water Soak**	100 min.***	N. A.	N. A.	N. A.
Cohesiometer C-Value @ 140 ± 5°F** (60 ± 2.8°C)		N. A.	N. A.	100 min.	N. A.

*Cured in the mold for a total of 24 hours at a temperature of 73 ± 5°F (23 ± 2.8°C).

**Cured in the mold for a total of 72 hours at a temperature of 73 ± 5°F (23 ± 2.8°C) plus vacuum desiccation.

***Applicable to temporary wearing surface only.

Note: Besides meeting the above requirements, the mix must be reasonably workable (i.e., not too stiff or sloppy).

After Reference 13.

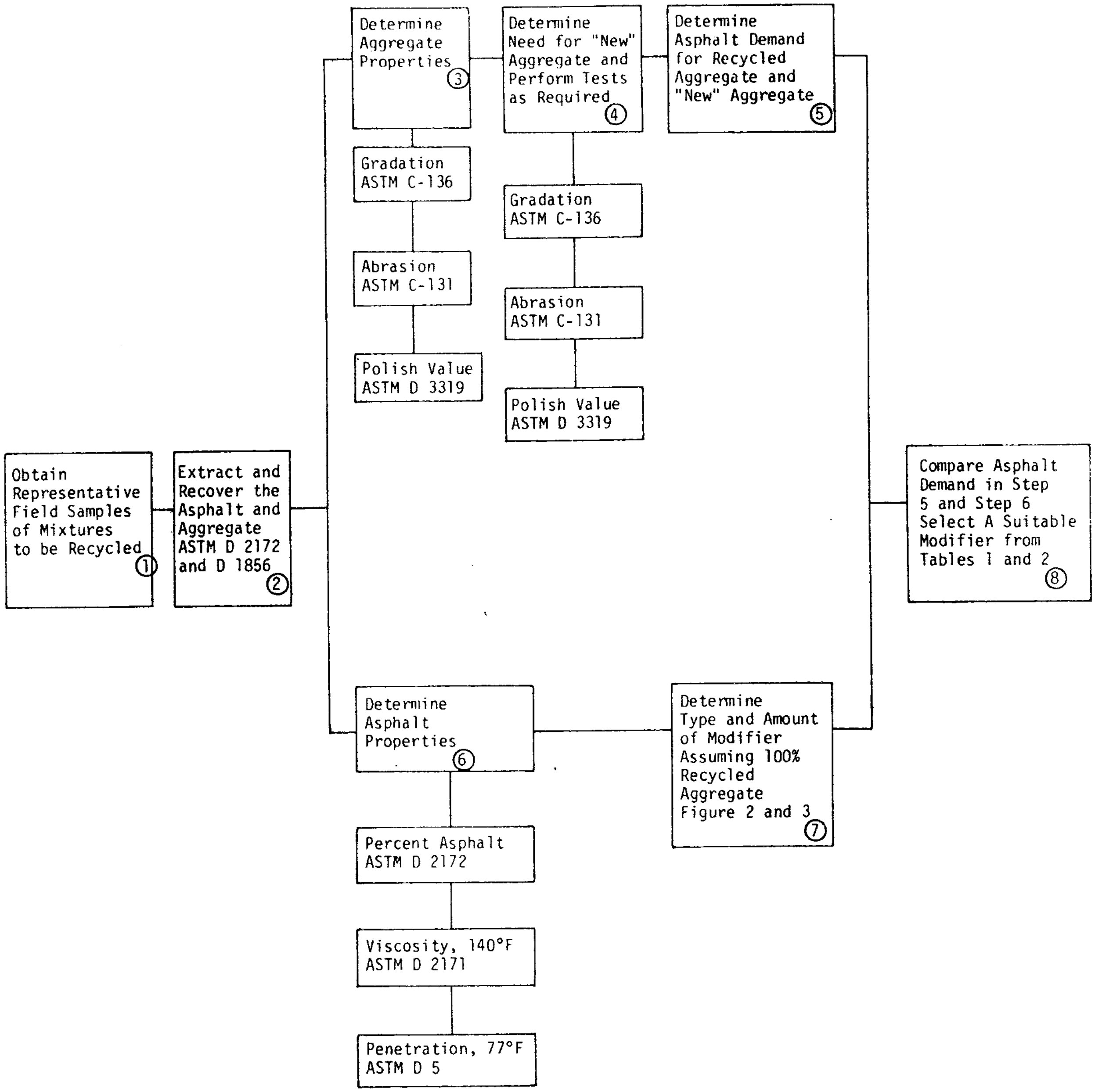


Figure 1: Mixture Design Procedure.

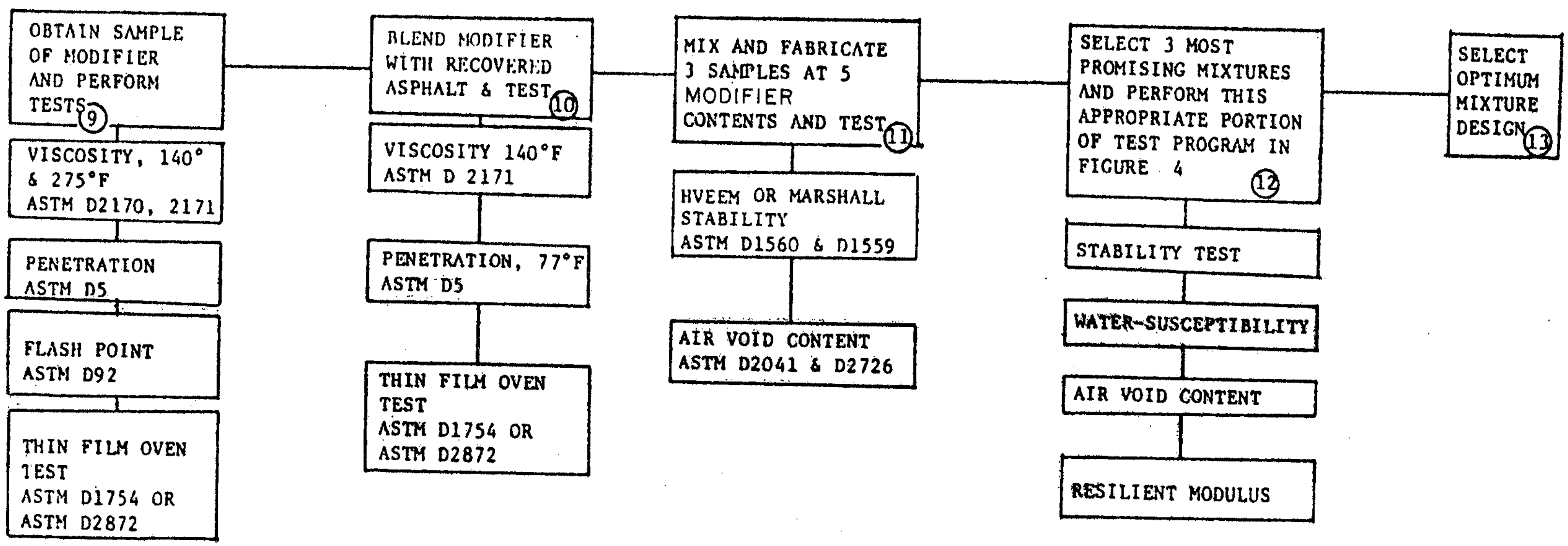


Figure 1 - Continued.

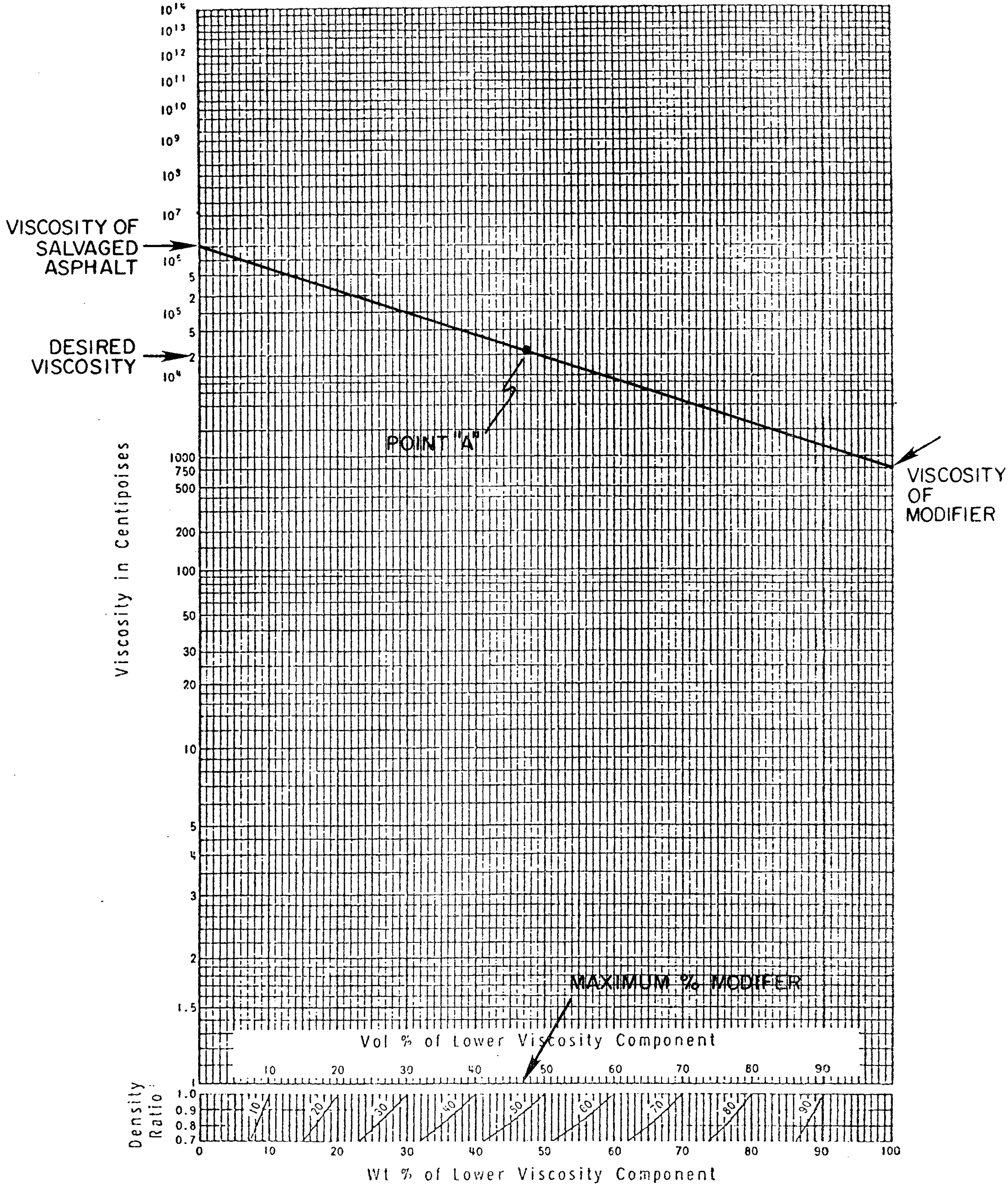
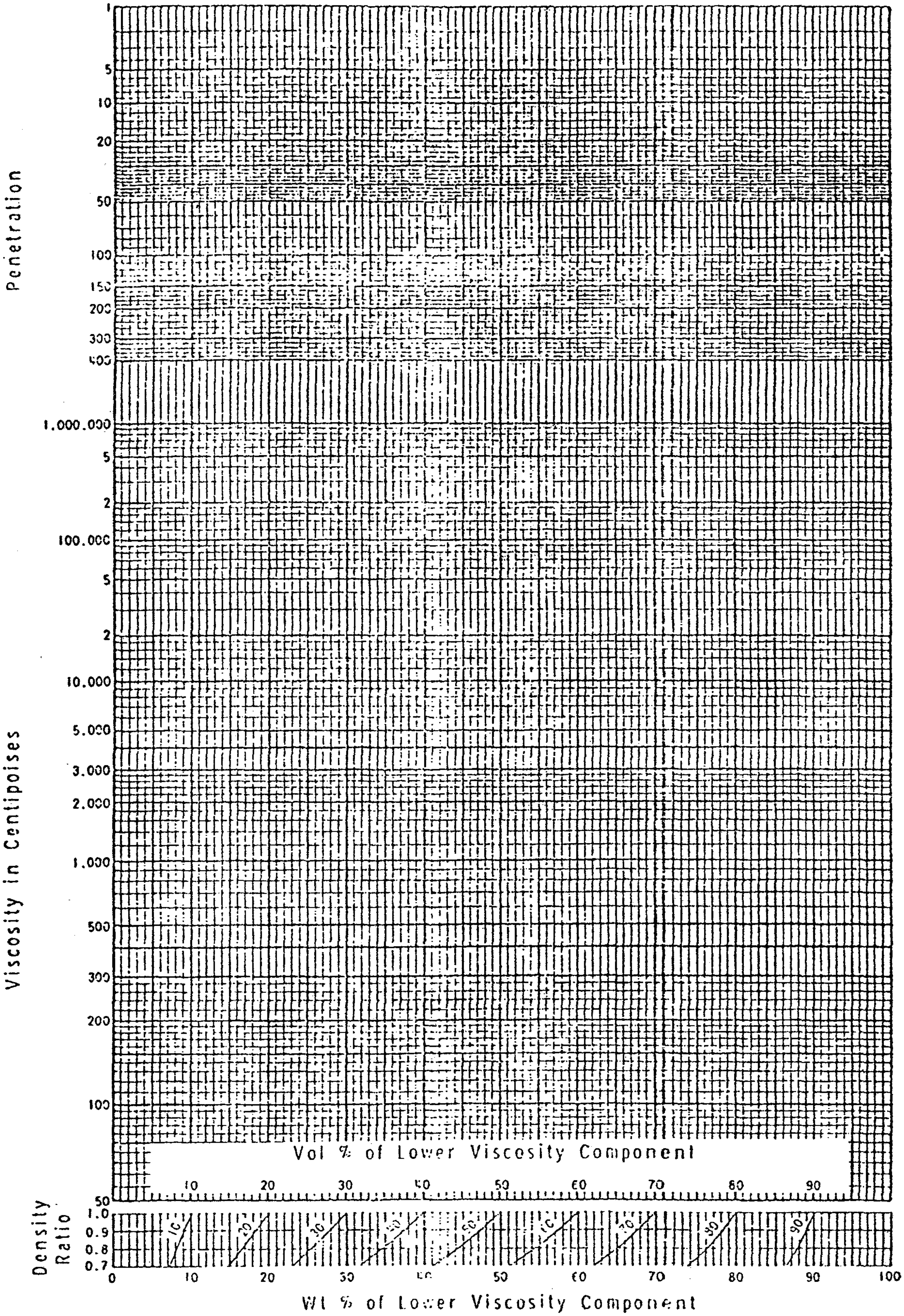


Figure 2. (After reference 2)



(After reference 2)

Figure 3. Viscosity-penetration blending chart
1 cp = 0.001 Pa·s

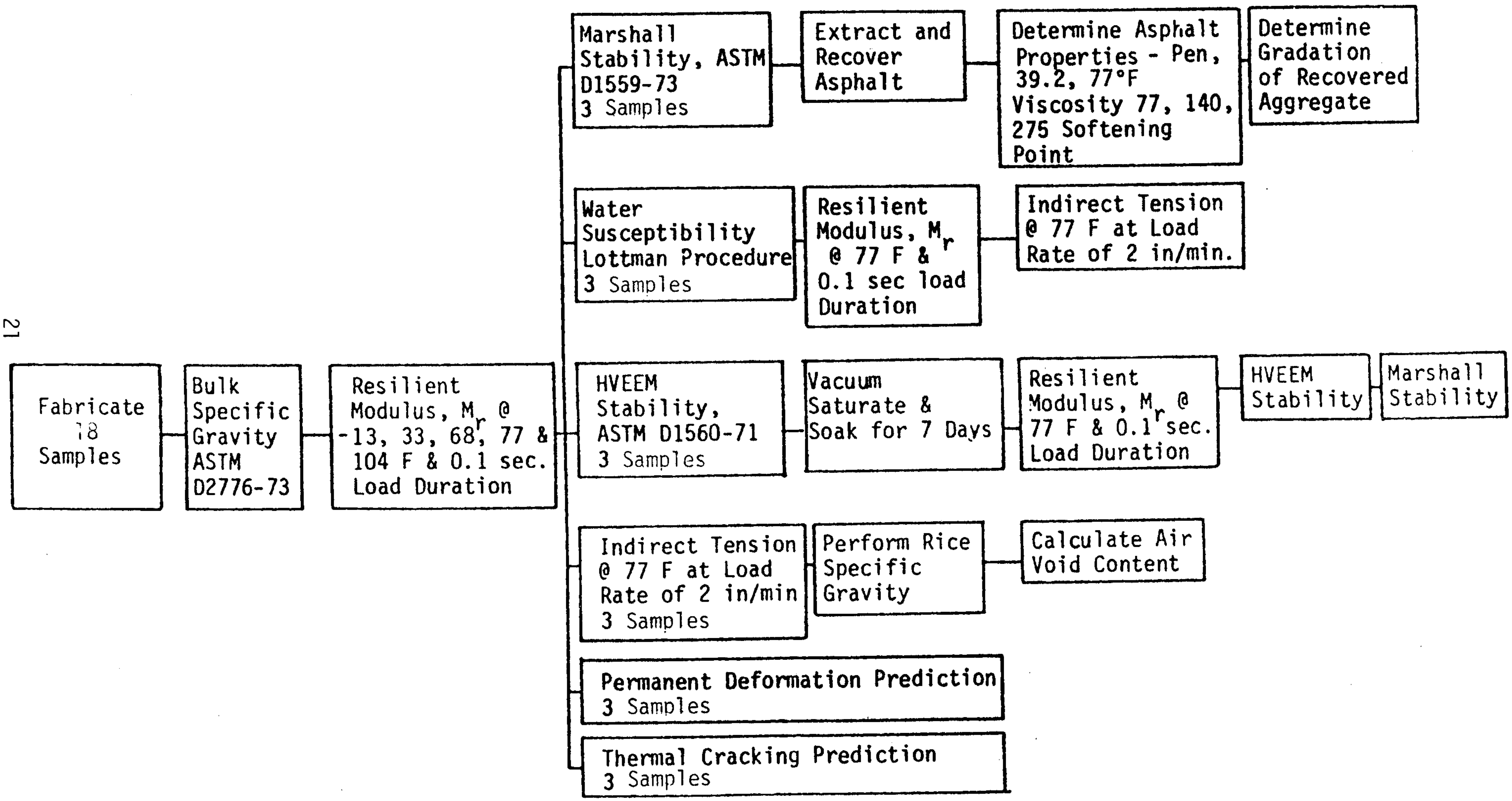


Figure 4. Test Sequence for Mixture Evaluation