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BASE STABILIZATION WITH FOAMED ASPHALT

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Interim Report
June 1979

Prepared in cooperation with
U. S. Department of Transportation,
Federal Highway Administration

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16. Abstract

This report describes a study of foamed asphalt aggregate mixtures used in base stabilization.

Foamed asphalt stabilized base is a mixture of wet unheated mineral aggregates and asphalt cement mixed while the asphalt cement is in a foamed state. The Asphalt cement is brought to a foamed state by addition of small amounts (1.0 to 2.0 percent) of cold water piped into the hot asphalt cement line. The cold water is converted to steam by contact with the hot asphalt cement, thereby foaming the mixture. The foam is developed in a foaming chamber and sprayed through special nozzles into a pugmill type mixing chamber where it is mixed with unheated, damp aggregates. This mixture is then placed on the roadway with conventional construction equipment. At this point the material looks like and has the characteristics of wet untreated aggregate. After curing, the material appears more like an asphalt treated base.

A range of strength coefficients for foamed asphalt treated base of 0.12 to 0.34 has been established by this limited study.

Test results indicate that foamed asphalt mixes do offer a viable alternative in the construction of treated bases.

The construction projects selected for the next phase of this study will evaluate the performance of the process under actual field conditions in order to finalize construction specifications for the foamed asphalt process.

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Frank Abel, Supervising Highway Engineer, was the Principal Investigator for the project. He wrote the research proposal and organized and supervised the laboratory testing.

Joe Procter, Acting Flexible Pavement Engineer conducted the computer analysis and with Frank Abel developed the method of strength coefficient calculation.

Dick Hines, an Engineer in Soils, assisted Frank Abel in writing this report.

John Shelly with the assistance of Bruce Miller, conducted the laboratory testing.

P. J. Ruckels and H. W. Richardson, from Continental Oil Company, have been instrumental in involving the Colorado Highway Department in the foamed asphalt base stabilization process. The Continental Oil Company built a laboratory foaming device and loaned it to Colorado for use during this evaluation process.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimetres
psi, pounds (force) per square inch	6894	pascals
Fahrenheit (F)	5/9 (F-32)	Celsius degrees

DEFINITIONS

1. Foamed Asphalt - Hot asphalt cement brought to a foamed state in a foaming chamber by addition of small amounts of cold water (1.0 to 2.0 percent) to the asphalt cement.

2. Foamed Asphalt Mix - A paving mix of unheated, damp aggregate and foamed asphalt cement which is mixed and placed at ambient temperatures.

3. Hot Mix - A paving mix of hot, dry aggregate and hot asphalt cement which is mixed and placed hot.

4. Cutback Mix - A paving mix of unheated aggregate and diluted asphalt cement which is diluted with a diluent, mixed and placed at ambient temperatures.

5. Emulsion Mix - A paving mix of unheated, wet aggregate and emulsified asphalt cement that is mixed and placed at ambient temperatures.

6. Strength Coefficient - A number representing the relative strength of a material used as part of a pavement structure.

7. Stabilometer R Value (stability) - A numerical value expressing the measure of the ability of an aggregate or asphalt mix to resist the transmission of vertical load in a lateral or horizontal direction.

8. Modulus - Load per unit area (stress) divided by deformation per unit length (strain). Measures the stiffness of the paving material.

9. Immersion-Compression - A test to determine the moisture susceptibility of asphalt paving mixes. The index of retained strength which results from this test is the ratio of unconfined compressive strength of laboratory molded mix specimens with and without water immersion for a specified time.

10. Freeze-Thaw Conditioning - A test to determine the long range moisture susceptibility of asphalt mixes. Mix specimens are vacuum saturated, frozen, then immersed in warm water. This specimen is compared to an unconditioned specimen to determine the retained strength.

11. Dynaflect - A device which applies a known dynamic load to a pavement and measures the resulting deflection basin.

INTRODUCTION

Environmental concerns with regards to reducing the use of energy, conserving natural resources and reducing pollution of the atmosphere, have made highway engineers look for alternate methods of pavement construction. Stabilization with foamed asphalt is such an alternate which can be used effectively to obtain some of these desired ecological results.

Asphalt cement in its natural state and at ambient temperature is too viscous to effectively coat aggregates in mixes made by traditional methods. Some methods of thinning or dispersing the asphalt cement, such as heating, diluting, or emulsifying, must be used to achieve desired coating and mixing. The mixes produced by the traditional methods are called hot mix, cutback mix, and emulsion mix.

Hot mix is a combination of hot asphalt cement and hot, dry mineral aggregate. It must be placed while hot and dry making long storage difficult. Hot mixes produce high quality pavements, but considerable energy is required to dry and heat the aggregate and to heat the asphalt cement.

For cutback mixes, the asphalt cement is diluted by adding a solvent. These solvents are potential fuels that are lost as the mix cures. The curing requirement of cutbacks present construction difficulties and potential environmental problems.

For emulsion mixes, small droplets of emulsified asphalt are dispersed in water. Transportation of the emulsified asphalt to the project includes 40% water which increases energy consumption. Emulsifying chemicals and complex equipment must be used to manufacture emulsified asphalts.

Foamed asphalts may be produced on the job with local water. The haul does not include solvents or water as with cutbacks and emulsions. Unheated, damp aggregate may be used saving the energy used for drying and heating of aggregate required for hot mixes. Figure 1 summarizes procedures for three mixing methods.

Foamed asphalt stabilized base is a mixture of damp, unheated mineral aggregate and asphalt cement mixed while the asphalt cement is in a foamed state. The asphalt cement is brought to a foamed state by adding small amounts (1.0 to 2.0 percent) of cold water piped into the hot asphalt cement line. The cold water is converted to steam by contact with the hot asphalt cement, thereby foaming the asphalt cement. The foam is produced in a foaming

Figure 1 Asphalt Cement Mixing Methods

	AGGREGATE	ASPHALT CEMENT	LAYDOWN	HAUL	SPECIAL PROCESSING OF ASPHALT
HOT MIX	Hot	Hot	Hot Dry	Asphalt 100 %	No
EMULSION MIX	Cold	Cold	Cold Wet	Asphalt 60 % Water 40 %	Yes
FOAM MIX	Cold	Hot	Cold Wet	Asphalt 100 %	No

chamber and sprayed through special nozzles into a pugmill type mixing chamber where it is mixed with the wet, cold aggregate (see Figure 2).

Foamed asphalt stabilized bases have been used in Australia since the late 1960's as an effective and economical means of stabilizing marginal quality pavement materials. Professor Csanyi of Iowa State University developed the process of foaming asphalt using steam.[2] In 1968 the patent rights to operate the Csanyi process were acquired by Mobil of Australia. In 1970, Mobil of Australia developed a new process to foam asphalt.[3,4] In this new process cold water is used to foam the asphalt instead of steam. Mobil was granted a patent in Australia and the patent has now been extended into 14 other countries around the world.

By 1977 there were at least five continuous mix foam plants in Australia with production rates varying from 150 to 300 tons per hour. The process is also used in portable plants for processing insitu material.

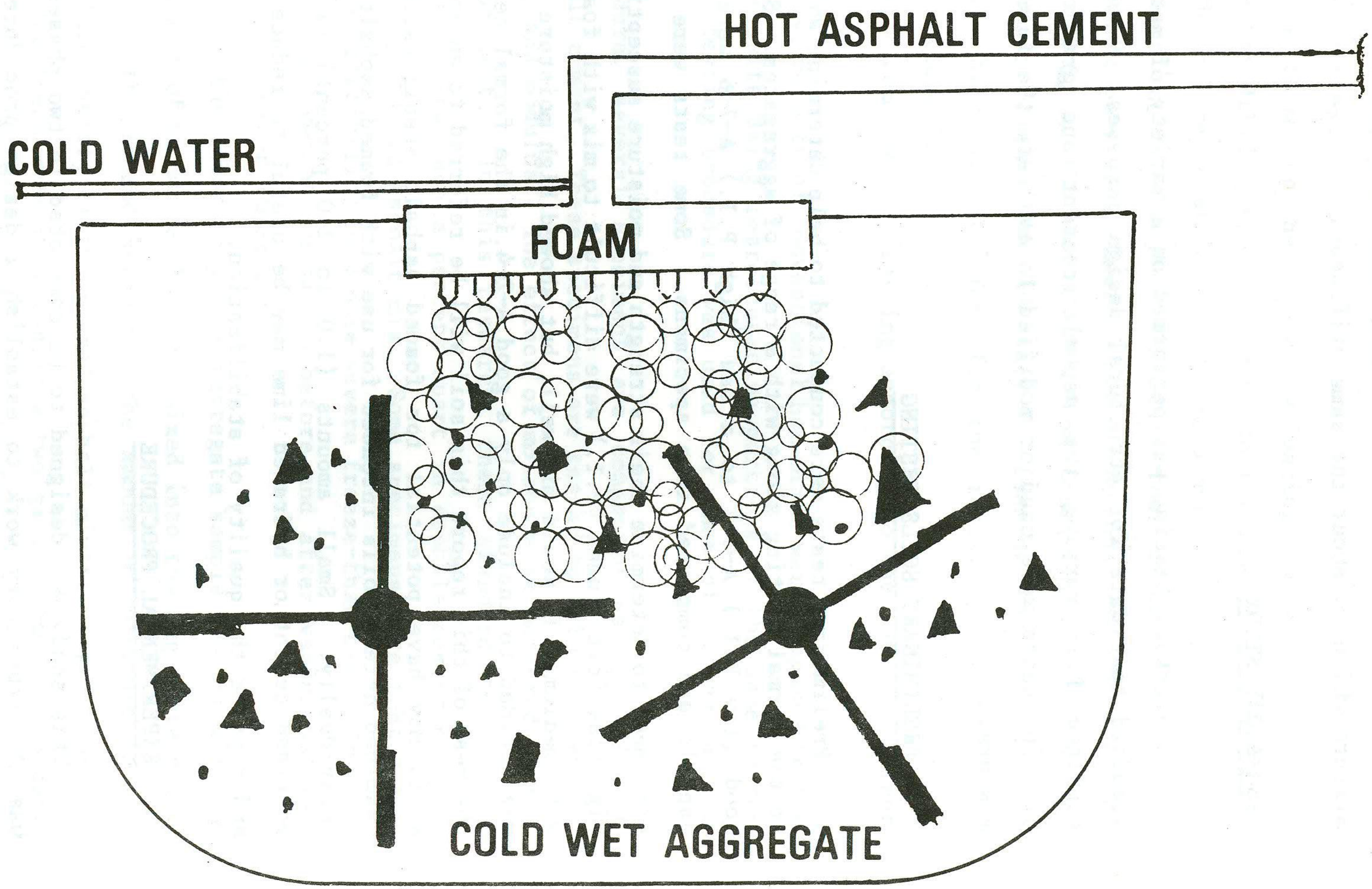
A paper by R. H. Bowering and C. L. Martin (Mobil Australia)[5] was presented at the 1976 Association of Asphalt Paving Technologists meeting in New Orleans, which describes work done in Australia. The Mobil process has also been used extensively in South Africa.

In the United States the Continental Oil Company has the rights to the foam process. Mr. P. J. Ruckel and H. W. Richardson (Continental Oil Company) have been very instrumental in involving the Colorado Highway Department in the foamed asphalt base stabilization process. The Continental Oil Company built a laboratory foaming device and loaned it to Colorado for use during this evaluation process.

In 1977 Brannan Sand and Gravel Company of Denver, with the cooperation of Continental Oil Company, fabricated a field foaming device. Using this device a foamed asphalt mixture was placed in November 1977 on the haul road to one of Brannan's pits. On this site, several hundred feet in length, a 3 inch hot bituminous surface course was placed over 4 inches of foamed mix. A short section subject to light traffic was left unsealed. A short time later the unsealed section showed excessive raveling of the surface. In April 1978, a crust approximately one inch thick formed on the surface, appearing much like a bituminous base. Below the crust the foamed asphalt mixture had the appearance of a well compacted untreated base. A core was taken in September 1978. The foamed asphalt mixture finally had the appearance of an asphaltic stabilized base, but was very fragile.

Figure 2

SCHEMATIC VIEW OF FOAM ASPHALT PROCESS



Dynaflect[6] tests were taken at this location before construction of the foamed asphalt base, soon after construction and again in September of 1978. The results of the Dynaflect were inconclusive, probably because there is a layer several feet thick of highly densified gravel underneath the foamed mixture which is about the same stiffness.

LABORATORY STUDY

Laboratory testing was performed on a variety of materials to establish standard test data for structural design purposes. A variety of materials resulted from varying the asphalt content and gradation of the mixes. Existing tests were used or modified to evaluate the foamed asphalt pavement mixture.

PRELIMINARY SOILS TESTING

Preliminary tests were conducted to help determine which soils to include in the formal testing along with a range of aggregates. Soils ranging from a good (low P.I.) A-2-4 to a bad (high P.I.) A-7-6 were mixed with foamed asphalt and compacted into specimens. Some tests were conducted on these specimens to determine their strength and moisture susceptibility. Soils with high plasticity index (P.I.) were difficult to mix with foamed asphalt. Soils with medium P.I. would mix well, but showed high moisture susceptibility. It was decided to include only a good A-2-4 in the formal testing. (Throughout the rest of this report this soil will be referred to an an aggregate.) Other soils may have potential for foamed asphalt stabilization but will not be examined here. Soils intended for use with foamed asphalt should be examined individually. Small amounts (1.0 to 2.0 percent) of additives such as portland cement or hydrated lime may be useful to reduce the effect of P.I. and improve the quality of stabilization.

EXPERIMENTAL PROCEDURE

This study was designed to be completed in two phases. The first phase was the laboratory work to establish a design procedure, strength coefficients, and construction specifications for foamed asphalt mixes. The second phase is to construct field projects using foamed asphalt with local materials and evaluating their performance in the environment found in Colorado.

The approach used in the first phase of the study was to conduct laboratory testing on a variety of aggregates combined with asphalt cements having different viscosities.

The first step was to set up the laboratory foaming device. This device was built by Continental Oil Company and loaned to the Division of Highways Materials Branch. The device is shown in Figures 3 and 4.

The materials used in the study consisted of four types of aggregates varying from very good to poor (see Figure 5 for gradations) and three grades of asphalt cements (AC-5, AC-10, and AC-20) from Continental Oil Company. Some testing of asphalt cements for adequacy of foaming was done in the laboratory prior to fabricating mixtures for the research project. The results are shown in Figure 7.

The materials were combined for testing according to the format outlined in Figure 6.

In the laboratory, results of conventional hot mixes were compared to the foamed asphalt mix results using representative portions of the same aggregate. The standard testing procedure was used for much of the evaluation (Appendix C).

In this procedure, several specimens are compacted using different percentages of asphalt cement. These specimens are tested to determine voids, stability, cohesion, and modulus. The effect of moisture is measured by the immersion-compression test. In this research, these standard tests were performed on three specimens each a percent apart in asphalt cement content for both a hot mix and a foamed asphalt mix. Some specimens were tested for long-range moisture susceptibility by a more severe freeze-thaw test. In this test, modulus of each specimen was measured before and after vacuum saturation, freezing and a warm water immersion.

For the foam mix in the laboratory, the aggregate sample was prepared by adding the desired amount of moisture which was mixed into the aggregate prior to the introduction of the foamed asphalt. The amount of moisture in the aggregate can affect the quality of the foamed asphalt mixture significantly.

The laboratory specimens were prepared in a two gallon bowl in a Hobart kitchen mixer. The aggregate was mixed while the foamed asphalt was being introduced. Mixing was continued for two minutes. The test specimens were normally molded as soon as this operation was complete.

Figure 3 Picture of Foaming Device

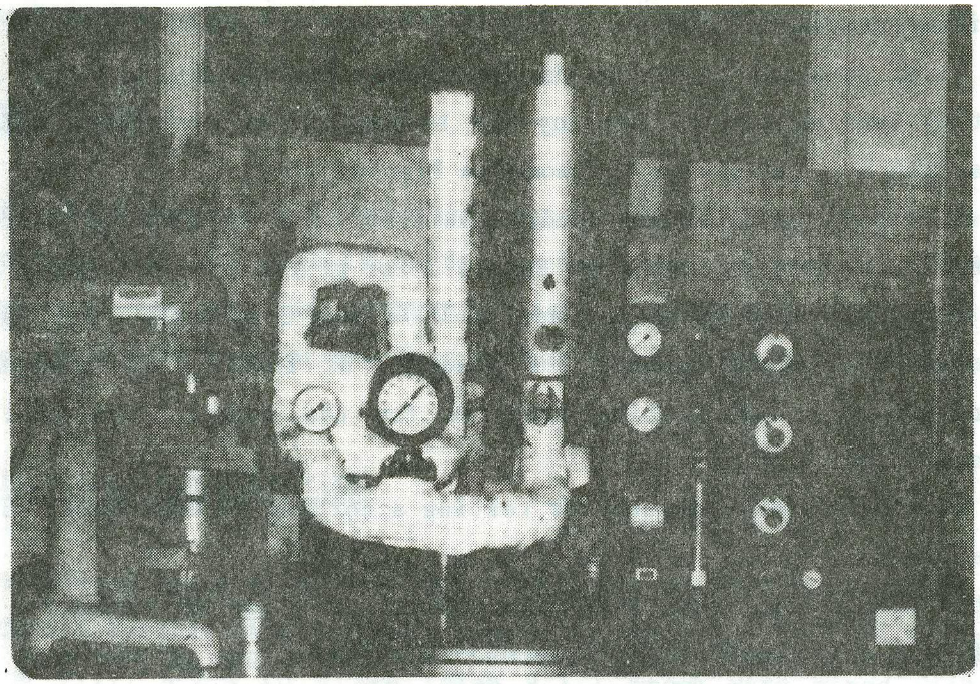


Figure 4 Drawing of Foaming Device

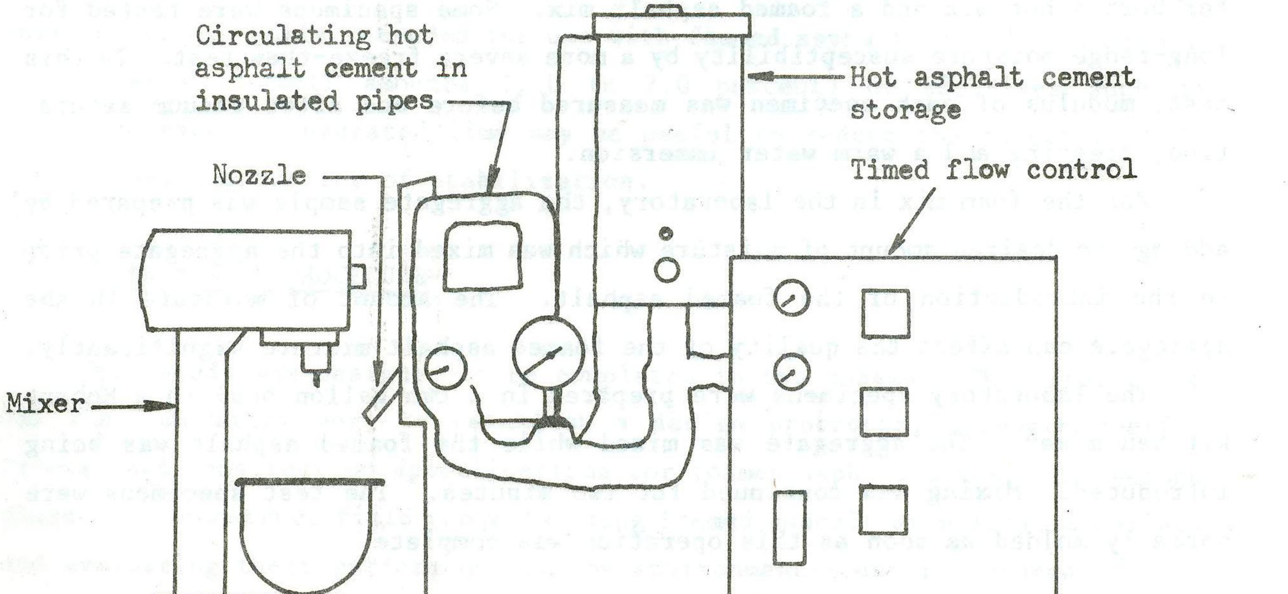
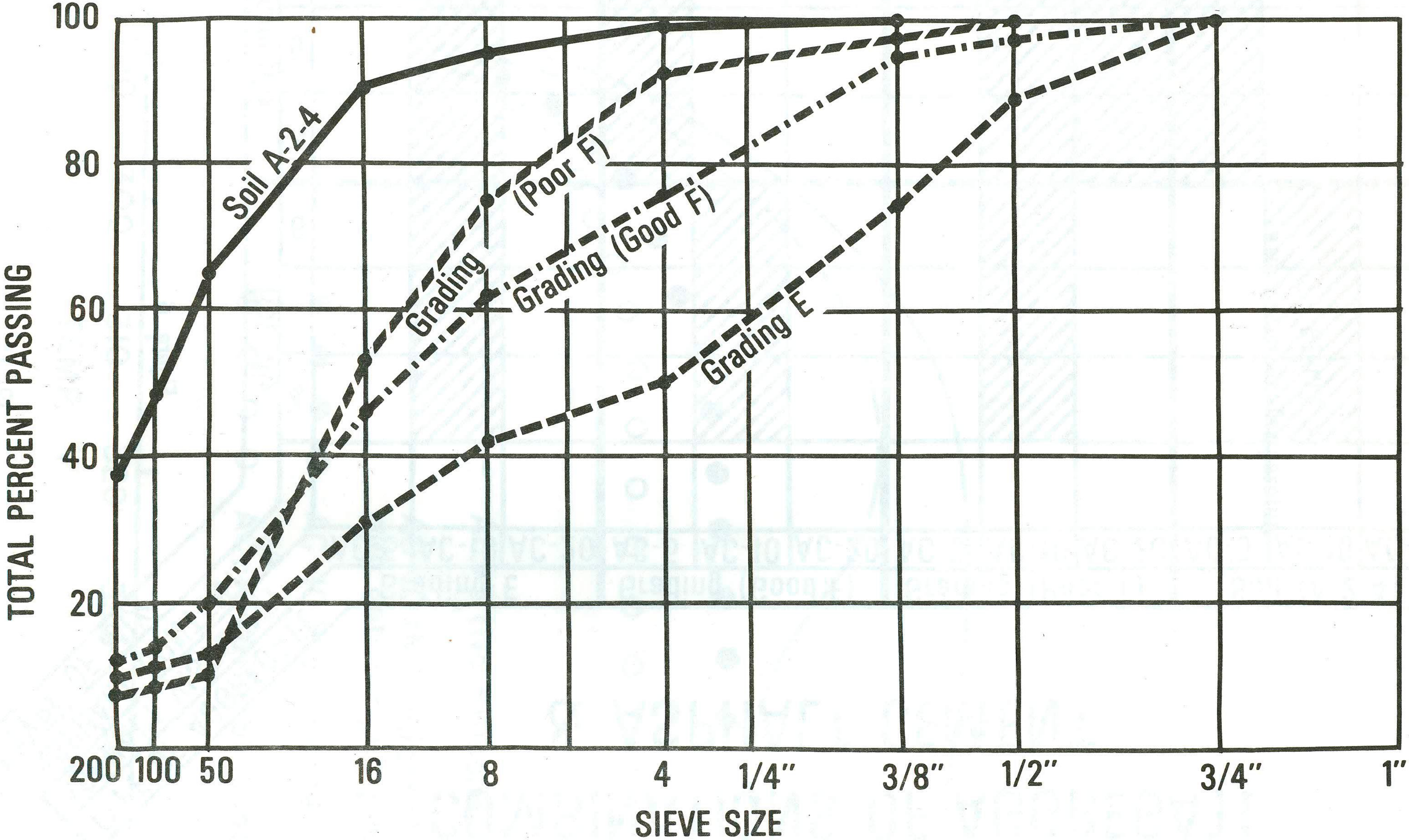


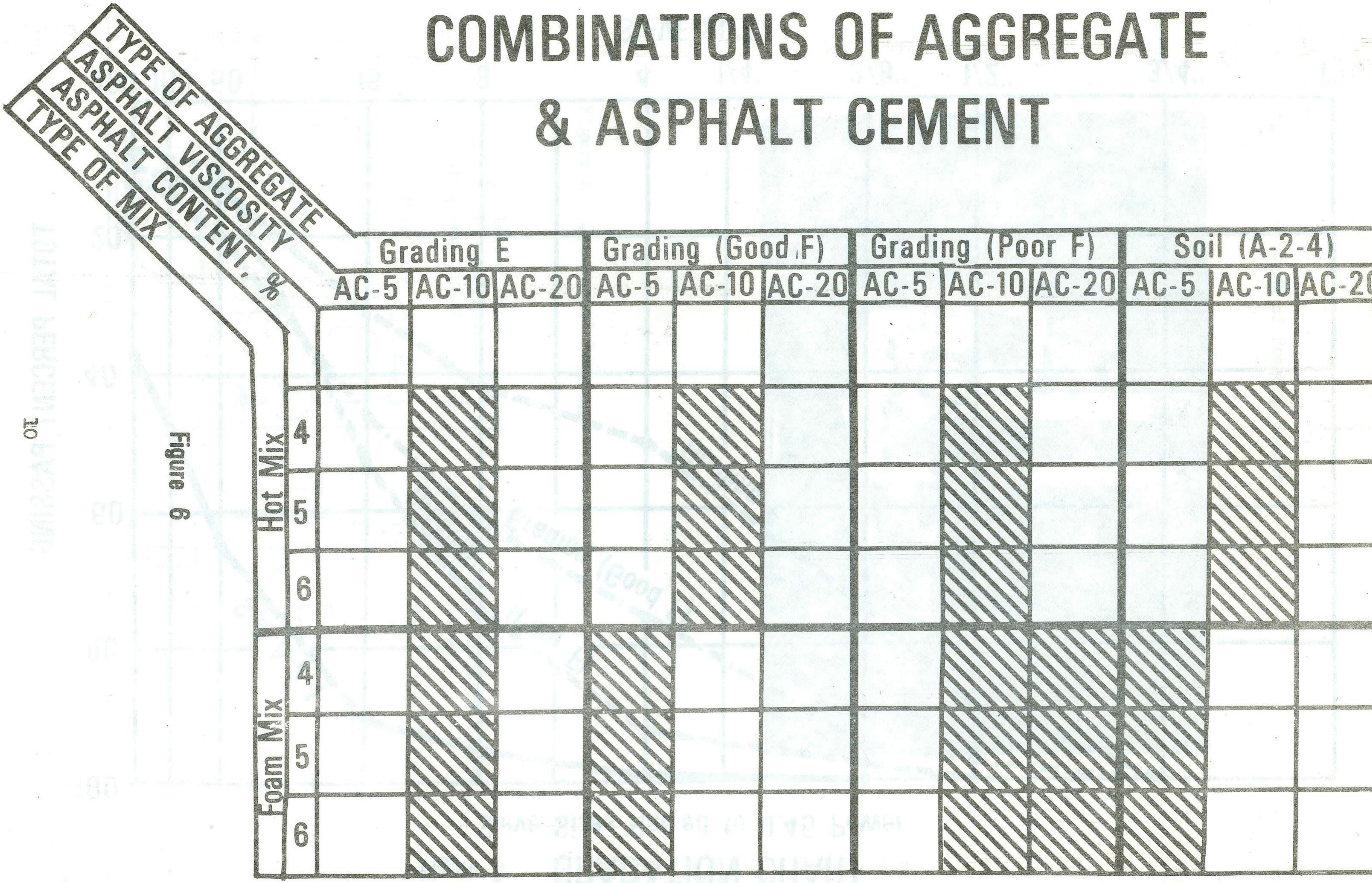
Figure 5 **GRADATION CHART**

Sieve Sizes Raised to 0.45 Power



GRADATION OF AGGREGATES TESTED

COMBINATIONS OF AGGREGATE
& ASPHALT CEMENT

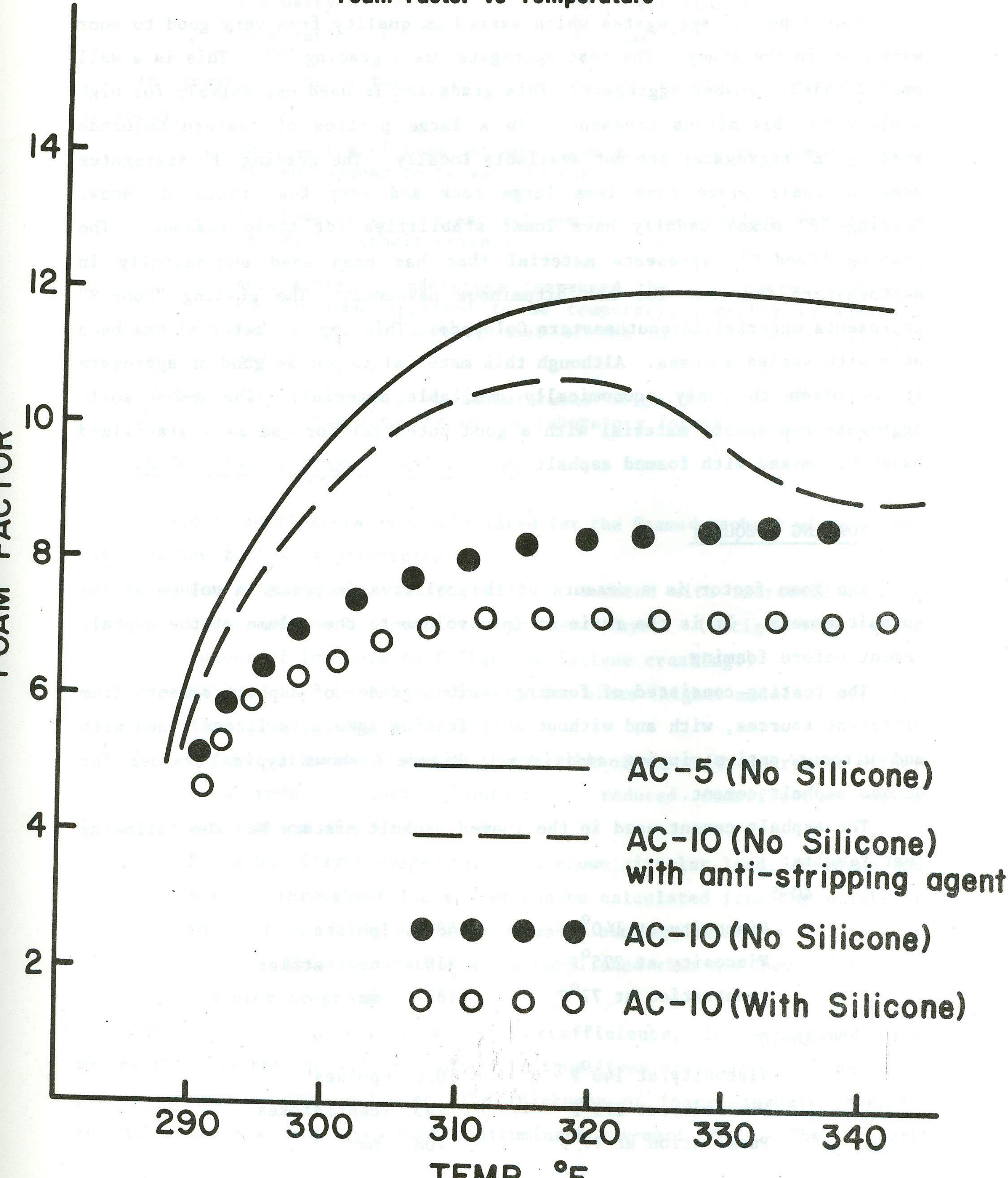


Note: The cross hatched areas indicate combinations tested

Figure 6

FIGURE 7

Foam Factor vs Temperature



AGGREGATES

Four types of aggregates which varied in quality from very good to poor were used in the study. The best aggregate was a grading "E". This is a well graded, hard, crushed aggregate. This gradation is used extensively for high quality hot bituminous pavement. In a large portion of eastern Colorado grading "E" aggregates are not available locally. The grading "F" aggregates used in their place have less large rock and very few fractured faces. Grading "F" mixes usually have lower stabilities for these reasons. The grading "Good F" represents material that has been used successfully in northeastern Colorado for hot bituminous pavement. The grading "Poor F" represents material in southeastern Colorado. This type of material has been used with varied success. Although this material is not as good an aggregate it is often the only economically available material. The A-2-4 soil-aggregate represents material with a good potential for use as a stabilized base when mixed with foamed asphalt.

FOAMING ADEQUACY

The foam factor is a measure of the relative increase in volume of the apshalt cement. It is the ratio of foam volume to the volume of the asphalt cement before foaming.

The testing consisted of foaming various grades of asphalt cements from different sources, with and without anti-foaming agents (silicone), and with and without anti-stripping additives. Figure 7 shows typical values for Conoco asphalt cement.

The asphalt cement used in the foamed asphalt mixture had the following test results:

AC-5			
	Viscosity at 140°F	480	poises
	Viscosity at 275°F	210	centistokes
	Penetration at 77°F	180	mm
AC-10			
	Viscosity at 140°F	1020	poises
	Viscosity at 275°F	285	centistokes
	Penetration at 77°F	108	mm

AC-20

Viscosity at 140°F	1890	poises
Viscosity at 275°F	380	centistokes
Penetration at 77°F	74	mm

In general, the information contained in Figure 7 indicates the following:

1. The quality of foam obtained from asphalt cement with silicone did not appear to be satisfactory.

2. The lower viscosity asphalt cements foamed better than the high viscosity asphalt cements.

3. Anti-stripping additives increased the foam factor, however, the increase appeared to be temporary, probably because the heat tends to destroy most of the affect of anti-stripping agents.

4. Asphalt cements at temperatures below 300°F (149°C) did not foam satisfactorily in the laboratory foamer.

CALCULATION OF STRENGTH COEFFICIENT

Strength coefficients were calculated for the foamed asphalt mixes on the basis of the following principles.

1. For a given mix, fatigue life is reduced with increased tensile strain at the bottom of the pavement layer. (Fatigue life is the number of loadings to failure by fatigue cracking.)
2. Fatigue life is reduced for stiffer mixes (higher modulus) with the same tensile strain.
3. Fatigue life is reduced as the percent of air voids increases either from reduced asphalt content or reduced densification or a combination of these.
4. For a multilayer system, under a known circular load, stresses and strains throughout the system can be calculated from the moduli of the layers. A highway under a loaded tire approximates this type of system. This calculation was accomplished with the Chevron n- layer computer program.[7]

For this calculation of strength coefficients, it is assumed that pavement layers are equivalent if their fatigue lives are the same. The above principles are used to calculate the thickness of foamed asphalt pavement equivalent to a 4 inch layer of hot bituminous pavement (HBP). The strength coefficient of the foamed asphalt pavement is calculated by dividing the strength coefficient of the HBP (0.44) by the ratio of the layer thicknesses. For example if 8 inches of a foamed asphalt pavement was equivalent to 4 inches of HBP the strength coefficient of the foamed asphalt pavement would be 0.44 ÷ 2 or 0.22.

Calculation of equivalent layer thickness proceeds as follows. The modulus of the HBP and the foamed asphalt are measured using a device which applies a vertical load and measures horizontal extension of a compacted specimen.[8] These moduli are used with the Chevron n- layer computer program to calculate the tensile strain at the bottom of the pavement layer for 4 inches of HBP and several assumed thicknesses of foamed asphalt pavement. The fatigue lives for these pavements are found by entering charts in "Thickness Design Procedure for Asphalt and Emulsified Asphalt Mixes"[9] with the tensile strain and modulus. These fatigue lives are corrected for air void and asphalt cement content using an equation in the same reference. The thickness of foamed asphalt pavement with the same corrected fatigue life as the 4 inch HBP is chosen as equivalent to this HBP layer. The strength coefficient of the foamed asphalt is found by dividing the strength coefficient of the HBP by the ratio of the thicknesses.

DISCUSSION OF RESULTS

Test results for foamed asphalt mixes and hot mixes are compared in Appendix A. In most cases the foamed asphalt mixes show higher stability and modulus values than the hot mixes when samples are cured the same way. However, the foamed asphalt mix is much more susceptible to water damage. In most cases the foamed asphalt specimens either fell apart or were too damaged to be tested when subjected to the immersion-compression test or the freeze-thaw test. The immersion-compression test and the freeze-thaw test were too severe for the foamed asphalt mixes. Experience here has shown that lean emulsified asphalt stabilized aggregates respond in about the same way to these severe tests. The immersion-compression test and the freeze-thaw test were developed for hot mixes and do not appear to be appropriate for foamed asphalt mixes. A less severe moisture susceptibility test needs to be developed for relative rating of foamed asphalt mixes.

The asphalt cement proposed for use should be tested for its foaming characteristics before any mixes are produced. Many factors affect the quality and quantity of the foam produced. The source, viscosity, additives, and temperature of the asphalt cement can all affect the foaming characteristics. The temperature of the asphalt cement has to be at least 300°F (149°C) to produce acceptable foam. Low viscosity asphalt cement usually foams better than high viscosity asphalt cement. Anti-foaming agents (silicone) added by some manufacturers to the asphalt cement can be a problem.

Mixes of soil and foamed asphalt may have a great potential for foamed asphalt base stabilization. The soil-aggregate included in this study was a good A-2-4(o) (AASHTO Designation). Plastic soils might be improved by addition of small amounts of additives, such as hydrated lime (1 to 2 percent), added to the soil before mixing with the foam.

Foamed asphalt stabilization appears to be well suited for finer grained aeolian sand aggregates like those found in Eastern Colorado. In Metropolitan areas where aggregates are mined on a commercial basis, stockpiles of reject materials have been developed over the years. These stockpiles also appear to be well suited for foamed asphalt stabilization.

Foamed asphalt mixes using well graded good quality aggregates may not be economically justified. Indications are that hot mixes made by using good quality aggregates are significantly better than the foamed asphalt mixes.

Table 12 shows strength coefficients for materials used in pavement design in Colorado. The proposed values for foamed asphalt base have been included in this table. Table 11 shows strength coefficients calculated for the materials used in this study. The foamed asphalt mix using grading "E" aggregates had a strength coefficient of 0.27. This is not as good as the 0.44 obtained for the hot mix, but is considerably better than the 0.14 which would be obtained for the untreated aggregates. A strength coefficient of 0.25 was calculated, for the foamed mix with the grading F (good) aggregate. This is lower than the 0.34 obtained for the hot mix but better than the 0.12 for the untreated aggregate. The strength coefficient for the grading "F" (poor) hot mix was 0.25 and for the foamed asphalt mix 0.13. Even though the strength coefficient for the foamed asphalt mix was low (.13) it was apparent that the untreated material had been significantly improved. The foamed asphalt appeared to perform well with the soil-aggregate. The 0.34 obtained with the foamed asphalt was the same as the hot mix strength coefficient. The test results obtained on the soil for both the hot mix and the foam mix were higher than expected.

CONCLUSIONS

Foamed asphalt can be used to effectively stabilize roadway bases. Foamed asphalt base construction is a viable alternate to plant mix bituminous base and emulsified asphalt treated base. The foamed asphalt process is relatively simple and does not require major investments in new equipment. The process is ecologically desirable, because of the lower energy use and the economical use of marginal aggregates. Binder costs are not increased by diluents and additional manufacturing costs. Transportation costs should be less. No diluents as in cutbacks, or water in emulsions, have to be hauled from the source to the mixing plant. The foamed asphalt mix can be compacted immediately after laydown. Traffic can use the roadway after compaction is completed. The mix can be stockpiled and placed at a later date. The mix is not subject to leaching of the binder by rain. Placed mix can be reworked, if desired, for several days. Based on this laboratory study, foamed asphalt mixes do not appear suitable for high quality wearing courses, since the lack of coating of the larger aggregates would probably cause raveling of the surface.

Any asphalt cement intended for foaming should be checked for adequacy of foaming. The design procedure for use of foamed asphalt has not been fully developed. This procedure must examine the moisture susceptibility of the mix in a realistic manner.

Reasonable strength coefficients were calculated for the foam mixes tested. These coefficients ranged from 0.12 to 0.34.

IMPLEMENTATION

Several projects are planned to be constructed using foamed asphalt base stabilization in the second phase of this research. Specifications have been written for the use of foamed asphalt in these projects. These specifications will be modified on the basis of experience gained in the field.

REFERENCES

1. Robert P. Lottman, "Predicting Moisture-Induced Damage to Asphaltic Concrete," University of Idaho, Moscow, Idaho, February 1974.

2. Ladis H. Csanyi, "Foamed Asphalt in Bituminous Paving Mixtures," HRB Bulletin 160, January 1957.

3. R. H. Bowering, "Properties and Behavior of Foamed Bitumin Mixtures for Road Building," Highway Engineering in Australia, February 1970.

4. R. H. Bowering, D. T. Currie, IRF VII World Congress, Munich, 1973.

5. R. H. Bowering, C. L. Martin, "Foamed Bitumen-Production and Application of Mixtures Evaluation and Performance of Pavements," AAPT Annual Meeting, February 1976.

6. Gilbert Swift, "Dynaflect - A New Highway Deflection Measuring Instrument," SIE, Inc., Fort Worth, Texas.

7. J. Michelow, "Analysis of Stresses and Displacements in an n-Layered Elastic System Under a Load Uniformly Distributed on a Circular Area," Chevron Research Company, Richmond, California, September 1963.

8. Mark III Resilient Device, Retsina Company, Richmond, California.

9. L. E. Santucci, "Thickness Design Procedure for Asphalt and Emulsified Asphalt Mixes," Chevron Research Company, Richmond, California.

APPENDIX A

LABORATORY TEST RESULTS

TABLE 1 TEST RESULTS

	HOT MIX			FOAMED ASPHALT MIX		
Date		7-18-78			7-18-78	
Type of Aggregate		Grading E			Grading E	
Type of Asphalt Cement		AC-10			AC-10	
Type of Cure		140°F			3 days at 140°F	
Asphalt Content, (% Total Mix)	4	5	6	3	4	5
Percent Voids	10.6	7.0	4.0	16.7	13.6	13.0
Percent Moisture	-	-	-	3.7	2.6	2.6
Stabilometer "S" Value	44	40	41	64		48
Cohesiometer	131	157	149	245		147
Modulus X 1000						
Before Cure						
After Cure	327	405	341	824	600	660
Moisture Susceptibility Test						
Modulus X 1000	351	318	291			
Retained Strength	9	16	49			
Unconfined Compression Strength						
Wet, psi						
Dry, psi						
Index of Retained Strength						

TABLE 2 TEST RESULTS

	HOT MIX				FOAMED ASPHALT MIX		
Date		7-18-78				7-18-78	
Type of Aggregate		Grading E				Grading E	
Type of Asphalt Cement		AC-10				AC-10	
Type of Cure		140°F				3 days at room temperature	
Asphalt Content, (% Total Mix)	4	5	6	5.5	3	4	5
Percent Voids	10.6	7.0	4.0		16.1	13.6	10.5
Percent Moisture	0	0	0		3.7	2.6	2.6
Stabilometer "S" Value	44	40	41			51	
Cohesiometer	131	157	149			156	
Modulus X 1000							
Before Cure					31	25	41
After Cure	327	405	341		1716	935	524
Moisture Susceptibility Test							
Modulus X 1000	351	318	291			Samples collapsed	
Retained Strength	9	16	49				
Unconfined Compression Strength							
Wet, psi				295			
Dry, psi				399			
Index of Retained Strength				75			

TABLE 3 TEST RESULTS

	HOT MIX			FOAMED ASPHALT MIX		
Date		7-18-78			7-25-78	
Type of Aggregate		Grading "Good F"			Grading "Good F"	
Type of Asphalt Cement		AC-10			AC-10	
Type of Cure		140°F			3 days at 140°F	
Asphalt Content, (% Total Mix)	4.5	5.5	6.5	3	4	5
Percent Voids	10.5	8.2	5.7	13.5	11.0	9.7
Percent Moisture	-	-	-	4.8	4.8	4.7
Stabilometer "S" Value	39	40	32		48	
Cohesiometer	132	137	150		187	
Modulus X 1000						
Before Cure						53
After Cure	338	356	387	1370	780	414
Moisture Susceptibility Test						
Modulus X 1000	331	336	337			
Retained Strength, %			10		Samples collapsed	
Unconfined Compression Strength						
Wet, psi						
Dry, psi					417	
Index of Retained Strength						

TABLE 4 TEST RESULTS

	HOT MIX			FOAMED ASPHALT MIX		
Date		7-18-78			7-21-78	
Type of Aggregate		Grading "Good F"			Grading "Good F"	
Type of Asphalt Cement		AC-10			AC-5	
Type of Cure		140°F			3 days at room temperature	
Asphalt Content, (% Total Mix)	4.5	5.5	6.5	3	4	5
Percent Voids	10.5	8.2	5.7	13.0	9.6	9.1
Percent Moisture	-	-	-	4.8	4.8	4.7
Stabilometer "S" Value	39	40	32	58		34
Cohesiometer	132	137	150	235		128
Modulus X 1000, psi						
Before Cure				38	51	35
After Cure	338	356	387	600	540	312
Moisture Susceptibility Test						
Modulus X 1000, psi	331	336	337			
Retained Strength, %			10		Sample collapsed	
Unconfined Compression Strength						
Wet, psi			193			
Dry, psi			356			
Index of Retained Strength, %			54			

TABLE 5 TEST RESULTS

	HOT MIX			FOAMED ASPHALT MIX		
Date		7-18-78			7-28-78	
Type of Aggregate		Grading "Poor F"			Grading "Poor F"	
Type of Asphalt Cement		AC-10			AC-20	
Type of Cure		140°F			3 days at room temperature	
Asphalt Content, (% Total Mix)	4	5	6	3	4	5
Percent Voids	17.5	15.1	12.8	18.1	15.7	14.0
Percent Moisture	-	-	-	3.7	3.6	3.4
Stabilometer "S" Value	27	27	28		40	
Cohesiometer	47	50	53		146	
Modulus X 1000						
Before Cure				12		24
After Cure	114	106	133	354	255	231
Moisture Susceptibility Test						
Modulus X 1000						
Retained Strength						
Unconfined Compression Strength						
Wet, psi		60				
Dry, psi		144				
Index of Retained Strength		42				

TABLE 6 TEST RESULTS

	HOT MIX			FOAMED ASPHALT MIX		
Date		7-18-78			7-31-78	
Type of Aggregate		Grading "Poor F"			Grading "Poor F"	
Type of Asphalt Cement		AC-10			AC-20	
Type of Cure		140°F			3 days at 140°F	
Asphalt Content, (% Total Mix)	4	5	6	3	4	5
Percent Voids	17.5	15.1	12.8	18.7	16.5	14.1
Percent Moisture	-	-	-	3.7	3.6	3.4
Stabilometer "S" Value	27	27	28	40		38
Cohesiometer	47	50	53	151		140
Modulus X 1000						
Before Cure						
After Cure	114	106	133	518	525	277
Moisture Susceptibility Test						
Modulus X 1000					Samples collapsed	
Retained Strength						
Unconfined Compression Strength						
Wet, psi		60				
Dry, psi		144			295	
Index of Retained Strength		42				

TABLE 7 TEST RESULTS

	HOT MIX			FOAMED ASPHALT MIX		
Date		7-18-78			7-21-78	
Type of Aggregate		Grading "Poor F"			Grading "Poor F"	
Type of Asphalt Cement		AC-10			AC-10	
Type of Cure		140°F			3 days at 140°F	
Asphalt Content, (% Total Mix)	4	5	6	3	4	5
Percent Voids	17.5	15.1	12.8	19.0	16.6	
Percent Moisture				3.3	3.2	
Stabilometer "S" Value	27	27	28	41		
Cohesiometer	47	50	53	138		
Modulus X 1000						
Before Cure						
After Cure	114	106	133	461	525	
Moisture Susceptibility Test						
Modulus X 1000					Samples collapsed	
Retained Strength						
Unconfined Compression Strength						
Wet, psi		60				
Dry, psi		144			235	
Index of Retained Strength		42				

TABLE 8 TEST RESULTS

	HOT MIX			FOAMED ASPHALT MIX		
Date		7-18-78			7-18-78	
Type of Aggregate		Grading "Poor F"			Grading "Poor F"	
Type of Asphalt Cement		AC-10			AC-10	
Type of Cure		140°F			3 days at room temperature	
Asphalt Content, (% Total Mix)	4	5	6	3	4	5
Percent Voids	17.5	15.1	12.8	19.4	16.0	14.4
Percent Moisture	-	-	-	3.3	3.2	2.9
Stabilometer "S" Value	27	27	28			41
Cohesiometer	47	50	53			129
Modulus X 1000						
Before Cure				14	26	
After Cure	114	106	133	388	327	228
Moisture Susceptibility Test						
Modulus X 1000					Samples collapsed	
Retained Strength						
Unconfined Compression Strength						
Wet, psi		60				
Dry, psi		144				
Index of Retained Strength		42				

TABLE 9 TEST RESULTS

	HOT MIX			FOAMED ASPHALT MIX		
Date	7-19-78			7-24-78		
Type of Aggregate	Soil (A-2-4)			Soil (A-2-4)		
Type of Asphalt Cement	AC-10			AC-5		
Type of Cure	140°F			3 days at 140°F		
Asphalt Content, (% Total Mix)	4	5	6	3	4	5
Percent Voids	21.7	19.7	17.3	12.8	10.7	10.1
Percent Moisture	-	-	-	7.7	6.6	6.6
Stabilometer "S" Value	38	34	37		74	
Cohesiometer	236	212	221		640	
Modulus X 1000						
Before Cure						
After Cure	282	301	308	2367	2179	1555
Moisture Susceptibility Test						
Modulus X 1000				Samples collapsed		
Retained Strength						
Unconfined Compression Strength						
Wet, psi		12				
Dry, psi		378			425	
Index of Retained Strength		3				

TABLE 10 TEST RESULTS

	HOT MIX			FOAMED ASPHALT MIX		
Date		7-19-78			7-21-78	
Type of Aggregate		Soil (A-2-4)			Soil (A-2-4)	
Type of Asphalt Cement		AC-10			AC-5	
Type of Cure		140°F			3 days at room temperature	
Asphalt Content, (% Total Mix)	4	5	6	3	4	5
Percent Voids	21.7	19.7	17.3	12.9	11.1	10.2
Percent Moisture	-	-	-	7.7	6.6	6.6
Stabilometer "S" Value	38	34	37	74		59
Cohesiometer	236	216	221	640		640
Modulus X 1000						
Before Cure				154	197	148
After Cure	282	301	308	640	890	773
Moisture Susceptibility Test						
Modulus X 1000					Samples collapsed	
Retained Strength						
Unconfined Compression Strength						
Wet, psi		12				
Dry, psi		378				
Index of Retained Strength		3				

TABLE 11 STRENGTH COEFFICIENTS

Summary of strength coefficients on aggregates used in this study.

TYPE OF AGGREGATE	STRENGTH COEFFICIENT		
	HOT MIX	FOAM MIX	UNTREATED
Grading E	0.44	0.27	0.14
Grading F (Good)	0.34	0.25	0.12
Grading F (Poor)	0.25	0.13	0.10
Soil (A-2-4(0))	0.34	0.34	0.10

APPENDIX B

PROPOSED SPECIFICATIONS AND PROPOSED STRENGTH COEFFICIENT CHART

PROPOSED SPECIFICATIONS

SECTION 302

FOAMED ASPHALT TREATED BASE

DESCRIPTION

302.01 This work shall consist of aggregate and bituminous material mixed in a central plant, spread and compacted on a prepared surface in accordance with these specifications and in reasonable close conformity with the lines, grades, thicknesses and typical cross sections shown on the plans or established.

MATERIALS

302.02 Composition of Mixtures.
The treated base shall be composed of a mixture of aggregate, water if required, and foamed asphalt. The percentage of foamed asphalt in the produced mixture shall be within ±0.3 percent of that specified, by weight of dry aggregate, on a daily yield basis. Asphalt shall meet the applicable requirements of section 700 for the type specified.

Aggregates shall meet the requirements of subsection 703.03 for the class specified. The aggregate will be accepted immediately preceding addition of foamed asphalt to the mix.

Foamed Asphalt shall consist of hot asphalt cement of the grade specified to which approximately 1½ percent ambient temperature water has added in a foaming chamber of an approved type. Asphalt shall be between 325F and 360F, or as directed at the time of introduction of water. The foaming shall take place immediately before spraying into the pugmill. Proper control techniques shall be used by the contractor to assure adequacy of the foaming process. Should inadequate foam be developed, the work shall be suspended until necessary corrections are made.

CONSTRUCTION REQUIREMENTS

302.03 Weather Limitations.
Foamed asphalt treated base shall be placed only on accepted subgrade or subbase. Aggregate and air temperature shall be at least 50°F unless otherwise permitted. Ice or frozen lumps of aggregate will not be permitted in the mixing operation.

302.04 Mixing and Placing.
Mixing plants shall be equipped with suitable pumps, proportioning devices, metering, or weighing devices and all equipment necessary to produce foamed asphalt and to mix it thoroughly with the aggregate.

Water shall be added to the aggregate as directed, sufficiently in advance of the introduction of the foamed asphalt to insure uniform dispersion of the water.

Aggregates with moisture contents in excess of that necessary for proper mixing and compaction shall be allowed to drain before use. Stockpiling or other approved methods of reducing the moisture content of the aggregate will be permitted.

The prepared aggregates and foamed asphalt shall be combined in the mixing plant in the specified proportions. The aggregate and foamed asphalt shall be mixed thoroughly. Provisions for varying the mixing time shall be available.

The mixture shall be laid upon an approved surface, spread and struck off to the grade and elevation established. Bituminous pavers shall be used to place the mixture on the roadway.

On areas where irregularities or unavoidable obstacles make the use of mechanical spreading and finishing equipment impracticable, the mixture shall be spread, raked and luted by hand tools. For such areas the mixture shall be dumped, spread and screeded to give the required compacted thickness.

302.05 Compaction.
Compaction of the foamed asphalt treated base shall commence immediately after it has been placed on the roadway, unless otherwise directed. Compaction shall continue until a minimum density of 93 percent of a laboratory specimen made in the proportions of the job-mix formula has been obtained.

METHOD OF MEASUREMENT

302.06 Foamed asphalt treated base will be measured by the ton.

Weight of water and asphalt will not be deducted from the scale weight of the mixture as it leaves the plant. Asphalt Cement and water will not be measured and paid for separately but shall be included in the work.

BASIS OF PAYMENT

302.07 The accepted quantities of Foamed Asphalt Treated Base, of the class specified, will be paid for at the contract price per ton.

Payment will be made under:

Pay Item	Pay Unit
Foamed Asphalt Treated Base (Class ...)	Ton

Haul will not be measured and paid for separately but shall be included in the work.

Table 12

STRENGTH COEFFICIENTS

Note: When the strength coefficient changes during construction due to a change in "R" or "R_t", the thickness index (T.I.) on DOH Form 219 should be based on the new strength coefficient and cover requirements should be adjusted if necessary.

Component	Limiting Test Criteria	Coefficient
Plant Mix Seal		0.25
Hot Bituminous Pavement	$R_t \geq$ 95	0.44
Hot Bituminous Pavement	$R_t =$ 90-94	0.40
Hot Bituminous Pavement	$R_t =$ 87-89	0.35
Hot Bituminous Pavement	$R_t =$ 84-86	0.30
Hot Bituminous Pavement	$R_t \leq$ 83	0.25
Road Mix Bit. Pavement		0.20
FOAMED ASPHALT BASE		0.12 to 0.34 *
Existing Bituminous Pavement		0.20 to 0.44
Plant Mix Bit. Base	$R_t \geq$ 90	0.34
Plant Mix Bit. Base	$R_t =$ 85-89	0.30
Plant Mix Bit. Base	$R_t =$ 80-84	0.25
Plant Mix Bit. Base	$R_t \leq$ 79	0.22
Aggregate Base Course (A.B.C.)	"R" $\geq$ 84	0.14
Aggregate Base Course (A.B.C.)	"R" $=$ 78-83	0.12
Aggregate Base Course (A.B.C.)	"R" $=$ 70-77	0.11
Aggregate Base Course (A.B.C.)	"R" $\leq$ 69	0.10
Emulsified Asphalt Treated A.B.C.	$R_t \geq$ 95	0.23
Emulsified Asphalt Treated A.B.C.	$R_t =$ 90-94	0.20
Emulsified Asphalt Treated A.B.C.	$R_t =$ 84-89	0.15
Emulsified Asphalt Treated A.B.C.	$R_t \leq$ 83	0.12
Cement Treated A.B.C.	7-day test $\geq$ 650 psi	0.23
Cement Treated A.B.C.	7-day test $=$ 400-649 psi	0.20
Cement Treated A.B.C.	7-day test $\leq$ 399 psi	0.15
Hydrated Lime Treated A.B.C.	"R" $\geq$ 84	0.14
Hydrated Lime Treated A.B.C.	"R" $=$ 78-83	0.12
Borrow Material		0.10 **

* PROPOSED VALUES BASED ON LABORATORY WORK ONLY.

** Used only to determine a value of strength for layers of soil and/or borrow material which are located above the soil layer from which the soil support value of the subgrade is determined.

NOTE: The minimum strength coefficient for the Base Course on highways having a current ADT volume of 750 or greater shall be 0.12.

APPENDIX C

COLORADO PROCEDURE FOR THE
DESIGN OF BITUMINOUS PAVEMENTS

COLORADO PROCEDURE L-5105
FOR THE DESIGN OF BITUMINOUS PAVEMENTS
INCLUDING RESILIENT MODULUS AND
HVEEM STABILOMETER

SCOPE

1.1 These methods cover (1) the preparation of bituminous mixtures for test, (2) the resilient modulus (M_r) of compacted bituminous mixtures (3) the resistance to deformation of compacted bituminous mixtures by means of the Hveem Stabilometer, and (4) the cohesion of compacted bituminous mixtures by means of the Hveem Cohesiometer. The results of these tests are used to determine the proper mix design for bituminous pavements.

APPARATUS

2.1 Ovens, capable of maintaining temperatures of 140 ± 5 F and up to 325 ± 5 F.

2.2 Scales or balances, having sufficient capacity and accurate to 1.0 g and 0.1 g.

2.3 Mechanical mixer, complete with accessories.

2.4 Kneading compactor, complete with accessories, including heated loading trough, and capable of exerting controllable pressure up to 500 psi.

2.5 Mold holder and funnel.

2.6 Molds, 4 in. diameter by 5 in. high with 3/8 in. wall thickness.

2.7 Paper disks, of heavy paper, 4 in. diameter.

2.8 Compression testing machine, minimum 50,000 lb capacity.

2.9 Plungers.

2.10 Extruding device, for removing compacted specimens from molds.

2.11 Suspension Apparatus - Wire basket, wire frame, or other apparatus to hold the specimen suspended from balance.

2.12 Container, with an overflow device for immersing the suspended specimen in water while maintaining a constant water level.

2.13 Measuring device, for determining the height of the compacted specimen to the nearest .001 in.

2.14 Hveem Stabilometer, complete with calibration cylinder and accessories.

2.15 Cohesiometer apparatus, with an adequate supply of minus No. 10 plus No. 14 shot.

2.16 Thermostatically controlled cabinet, capable of maintaining a temperature of 77 ± 1.8 F.

2.17 Resilient modulus apparatus.

2.18 Miscellaneous equipment, pans, spatula, thermometers, asbestos gloves.

PREPARATION OF SPECIMEN

3.1 Obtain sieve analyses of the aggregates to be used. Separate the the aggregates into the various size fractions necessary for accurate recombining into test mixtures conforming to the specified grading requirements.

3.2 Determine the theoretical or estimated optimum bitumen content.

NOTE - Normally, laboratory tests will be conducted for four bitumen contents. The incremental change in bitumen content should be 0.5 percent. However, the number of tests and the incremental changes in bitumen contents may be varied to satisfy unusual conditions. Express the percent bitumen as a percentage of the total mix.

3.3 Combine the moisture free aggregate into batches by accumulatively adding each fraction.

NOTE - The total batch weight, including bitumen, shall be that necessary to produce a specimen 4 in. in diameter and 2.5 ± 0.1 in. high. For typical dense graded mixtures, 1150 g total mix is satisfactory. Adjustments will be required for open graded or fine graded aggregates and when aggregate specific gravities are unusually high or low.

3.4 Heat the aggregate to the proper mixing temperature. Place hot aggregate into a pre-heated mixing bowl and weigh the required amount of bitumen, at the proper temperature, into the aggregate.

NOTE - For mixes employing paving grades of asphalt cement, the temperature of the aggregate and asphalt at the time of mixing shall be 250 ± 5 F. For liquid asphalt mixtures (except emulsions) the aggregate may be preheated to a temperature not exceeding 140 ± 5 F prior to mixing. For coal tar mixtures, heat the tar and aggregate separately to a temperature not exceeding 200 ± 5 F. Thoroughly and rapidly mix the aggregate and bitumen using a mechanical mixer.

COMPACTION OF SPECIMENS

4.1 After mixing, return mixture to proper temperature oven for 1 hour. Place the compaction mold, preheated to 140 F, in the mold holder and insert a paper disk 4 in. in diameter on the base of the mold holder. Set funnel on mold assembly. Place the mold assembly into position in the mechanical compactor. Transfer mixture to loading trough of compactor. Adjust ram pressure to where 250 psi will be exerted by the ram foot. Set "control mode" switch to "load B". Keep the tamper foot hot enough to prevent the mix from adhering to it.

4.2 Start compactor to load and partially compact the mix so that it will not be unduly disturbed when the full load is applied. Allow compactor to finish load cycle.

NOTE - The number of blows may vary depending upon the type of material. It may not be possible to accomplish compaction in the mechanical compactor when sandy or unstable materials are used. In these instances use a 40,000 lb static load applied by the double plunger method to complete the compaction.

4.3 Following partial compaction at 250 psi, raise the compaction pressure to 450 psi and set control mode switch to compact. Normally 90 tamping blows are applied (pre-set counter to 90). Immediately following the compaction, apply a static leveling-off load of 12,600 lb (1000 psi) in the testing machine at a head speed of 0.20 in. per minute. Hold the 12,600 lb load for one minute and release immediately. Cool the specimen in the mold to room temperature. When cool, remove the specimen from the mold by means of the extruding device. Place in 77 F cabinet.

NOTE - Test samples must be stored in 77 F cabinet for a minimum of two hours before proceeding to Section 5. For convenience, the samples are usually stored in 77 F cabinet overnight.

RESILIENT MODULUS TEST (M_r)

5.1 Place yoke assembly on holder.

5.2 Back out screw so that the transducer sensors will clear sample. Back out the four clamping screws and gently insert the sample into the center of yoke. Place sample squarely on the centering strip. Gently tighten the clamping screws, keeping the sample centered and square in the yoke. Tighten only until snug.

5.3 Place the assembly in the loading device, align on the center strip, do not lift by yoke.

5.4 Lift the loading shaft and place the top loading block on the specimen, 180° from the bottom centering strip. Allow the shaft to seat against the ball on top of the loading block.

5.5 Zero the recording meter. Set the multiplier knob to 200 and turn on the meter. Adjust the zero control until the meter reads just above zero.

5.6 Tighten the right transducer advancement screw until an increased meter reading of about 2.0 is obtained. Tighten the left transducer until an additional increase of 2.0 is obtained.

NOTE - Usually 75 lbs load is used on sound, dry samples. However, lower pressure may be required to minimize sample damage. In case of doubt, start with lower load.

5.7 Reset the zero knob to just above zero; i.e., until both the high and low pilot lights are out.

5.8 Set mode switch to operate.

5.9 Record the deflection in micro inches on the meter. If the reading is out of range, change the multiplier to a higher or lower value. Reset the zero knob if one of the indicator pilot lights is on and make another measurement.

5.10 Rotate the sample 90° and repeat measurements. Deflection reading should normally agree within 10%. Sometimes a specimen is non-isotropic and a larger difference exists.

DETERMINATION OF BULK SPECIFIC GRAVITY OF TEST SPECIMENS

6.1 Determine the dry weight in air and designate this weight as A. Determine the weight of the specimen in water following a one minute immersion period. Designate this weight as C. Surface dry the specimen by blotting with a damp towel and determine the surface dry weight in air. Designate this weight as B. Make all weight determinations to the nearest 0.1 g.

6.2 Calculate the bulk specific gravity as follows:

$$\text{Bulk Specific Gravity} = \frac{A}{B-C} \quad \text{where}$$

A = Weight of dry specimen in air, g.

B = Weight of surface dry specimen in air, g.

C = Weight of specimen in water, g.

Calculate and report bulk specific gravity to three decimal places.

CURING OF SPECIMENS

7.1 Following the determination of the bulk specific gravity, remove as much water as possible by wiping or blowing with compressed air. Place specimen in a 140 F oven for a minimum of 1-1/2 hours.

CALIBRATION OF STABILOMETER

8.1 Adjust the bronze nut on the stabilometer stage base so that the top of the stage is 3-1/2 in. below the bottom of the upper tapered ring.

8.2 Pre-heat stabilometer stage base, calibration cylinder, and follower to 140 F for 1-1/2 hours. After removing from oven, set stabilometer on stage base. Insert follower and turn pump handle until a pressure of approximately 40 psi is indicated. Allow to stand until dial pressure reaches equilibrium.

8.3 Place the metal calibration cylinder in the stabilometer. Place a weight on top of the calibration cylinder to hold it firmly in position. Turn the pump handle until a pressure of exactly 5 psi is indicated. Tap the dial lightly with fingers to be sure the needle is resting on 5 psi. Adjust the turns indicator dial to zero. Turn pump handle at approximately two turns per second until the stabilometer dial reads 100 psi.

NOTE - The turns indicator should then read 2.00 ± 0.05 turns. If it does not, the air in the cell must be adjusted by means of the rubber bulb, and the displacement measurement must be repeated after each air change until the proper number of turns is obtained.

STABILOMETER TEST PROCEDURE

9.1 Bring the specimen to a test temperature of 140 ± 5 F.

9.2 Place specimen in stabilometer, making sure that it goes in straight with the tamped end up and that it is firmly seated in a level position on the base.

9.3 Place the follower on top of the specimen and adjust the pump until a horizontal pressure of 5 psi is indicated. The 5 psi pressure should be exact because a deviation of as little as 1 lb has a considerable effect on the final value. See Note in Paragraph 10.3.

9.4 Start the vertical movement of the testing machine at 0.05 in. per minute and continue until a total vertical pressure of 5000 lbs (400 psi) is reached. Record the stabilometer dial reading at exactly 5000 lbs and immediately reduce the vertical load to 1000 lbs (80 psi).

9.5 Turn the displacement pump so that the horizontal pressure is reduced to exactly 5 psi.

NOTE - This will result in a reduction of the vertical load. This is normal and no compensation is necessary.

9.6 Set the turns displacement dial to zero. Turn pump handle at approximately two turns per second until the stabilometer gauge reads 100 psi.

NOTE - Again ignore the change in the vertical load.

9.7 Record the number of turns indicated on the dial as the displacement of the specimen.

NOTE - The turns indicator dial reads in 0.001 in., and each 0.1 in. is equal to one turn. Thus, a reading of 0.250 in., indicates that 2.50 turns were made with the displacement pump. This measurement is known as turns displacement of the specimen.

CALCULATION OF STABILOMETER VALUES

10.1 Calculate the stabilometer value of the specimen by the following formula:

$$S = \frac{22.2}{\frac{P_h D_2}{P_v - P_h} + .222}$$

Where:

P_v = Vertical pressure (normally 400 psi)

P_h = Horizontal pressure (stabilometer dial reading in psi taken when P_v is 400 psi)

D_2 = Turns displacement on the specimen

The attached chart (Figure 1) is used to convert stabilometer dial reading and turns displacement to percent relative stability.

NOTE - These and all following calculations are normally processed by computer.

10.2 Make every effort to fabricate test specimens having an overall height between 2.4 in. and 2.6 in. If for some reason this is not possible, correct the stabilometer value as indicated on the attached chart (Figure 2).

10.3 Calibrate the stabilometer frequently during the day as temperature change has considerable effect upon the pressure exerted within the hydraulic system.

NOTE - Close adherence to the 5 psi initial horizontal pressure is necessary for accuracy of test results. When setting 5 psi horizontal pressure always drop below 5 psi then bring pressure back up to 5 psi and gently tap the dial to remove slack in the dial indicator gear.

COHESIOMETER TEST PROCEDURE

11.1 Calibrate the cohesiometer to allow 1,800 ± 20 g of shot per minute to flow into the receiving bucket.

11.2 If the specimen has been allowed to cool to room temperature following the stabilometer test, place in a 140 F oven for a minimum period of 1-1/2 hours.

NOTE - Normally, the test specimen will be one which has just been subjected to the stabilometer test at a temperature of 140 F. Either replace the specimen in the 140 F oven for a minimum of 5 minutes after removing from the stabilometer or place in the cohesiometer apparatus which is controlled at 140 F for a minimum of 5 minutes before testing.

11.3 Clamp the test specimen firmly in the cohesiometer being certain that it is well centered with the top plates parallel to the surface of the specimen. Tighten clamp nuts until snug, using the fingers only.

11.4 Release flow of shot into the receiver and allow to continue until the specimen either breaks or when the lever arm deflects 1/2 in. from the horizontal.

11.5 Weigh and record the shot in the receiving bucket to the closest gram.

CALCULATION OF COHESIOMETER VALUES (See Note under 10.1)

12.1 Calculate the cohesiometer value as follows:

$$C = \frac{L}{W(.20H + .044H^2)}$$

Where:

C = Cohesiometer value (grams per inch width corrected to a 3 in. height)

L = Weight of shot in grams

W = Diameter of specimen in inches

H = Height of specimen in inches

NOTE - Cohesiometer values may also be obtained by multiplying the weight of shot necessary to break the specimen by factors established for various heights of 4 in. diameter specimens. These factors are as follows:

Height	Factor	Height	Factor
2.20"	.382	2.50"	.322
2.25"	.371	2.55"	.313
2.30"	.360	2.60"	.305
2.35"	.349	2.65"	.297
2.40"	.340	2.70"	.290
2.45"	.331	2.75"	.283

12.2 Check results by making a second break at 90 degrees to the first if cohesiometer values are obtained that are obviously out of line.

NOTE - Assuming that all test details have been closely adhered to, these results may be generally attributed to an unusually large amount of coarse aggregate particles being located in the area of the breaking plane.

CALCULATIONS FOR RESISTANCE VALUE

13.1 Calculate an arbitrary total Resistance Value (R_t) combining both friction and tensile strength as reflected by Stabilometer and Cohesiometer readings as follows:

$$R_t = 100 - \frac{100}{\frac{2.5}{D_2}\left(\frac{P_v}{P_h} - 1\right) + 1} + .05\,C_1$$

Where:

C_1 = Cohesiometer Value in grams per linear inch of specimen width. This is an index to the tensile strength of the specimen.

CALCULATION OF PERCENT AIR VOIDS IN COMPACTED SPECIMENS

14.1 Determine the maximum specific gravity of the uncompacted bituminous paving mixture in accordance with AASHTO T 209. Prepare the mixture in the laboratory at the estimated optimum asphalt content. Adjust the maximum specific gravity thus obtained for incremental changes in asphalt content by use of the attached nomograph (Figure No. 3).

14.2 Calculate the percent air voids in each compacted specimen using the following formula:

$$\text{Percent Voids} = 1 - \left(\frac{\text{Sp. Gr. of Specimen}}{\text{Max. Sp. Gr.}} \right) \times 100$$

REPORT

15.1 The following test result values for Bituminous Surfacing Design will be reported by computer print-out.

1. Percent bitumen, mix basis
2. Maximum specific gravity of the uncompacted mixture
3. Bulk specific gravities of the compacted specimens
4. Stability value of each specimen
5. Cohesiometer value of each specimen
6. R_t value of each specimen
7. Percent air voids in each specimen
8. Resilient Modulus (M_r) value of each specimen

SIGNIFICANCE OF VALUES REPORTED

16.1 Maximum Specific Gravity of Mixtures - The maximum specific gravity of the mixture as determined by AASHTO T 209, is a more realistic value than the maximum theoretical specific gravity which is calculated by using the specific gravity of the asphalt cement and apparent or bulk specific gravity of the aggregate. This is especially important for absorptive aggregates since the AASHTO method measures the actual volume occupied by the asphalt and coated aggregate, excluding any asphalt absorbed into the aggregate. The calculated theoretical maximum specific gravity will be higher than actual when using apparent specific gravity or lower than actual using bulk specific gravity unless the volume of asphalt absorbed is known and taken into account in the calculations.

16.2 Bulk Specific Gravity of the Compacted Specimens - The bulk specific gravity of the compacted specimens is used to calculate the percent air voids. When the recommended asphalt content falls between two contents at which specimens were actually made, the specific gravity of the compacted mix for the recommended asphalt content will be pro-rated accordingly. This reported value is the laboratory density referred to in Subsection 401.17 of the Standard Specifications to which field density tests are compared for compliance.

16.3 Stability Value of Bituminous Paving Mixtures - The stability value of bituminous paving mixtures as determined by the stabilometer test, reflects the ability of the mixture to resist lateral displacement when subjected to vertical pressure. This value may vary considerably depending upon the character of the sand or rock particles and especially with the amount and type of bitumen used. An arbitrary scale of "Stability" has been established in which the value of zero corresponds to a liquid having no measurable resistance to slowly applied vertical loads, and a value of 100 corresponds to a hypothetical solid that will transmit no measurable amount of lateral pressure upon application of a vertical load. A stability value of 35 or more is usually required for high type bituminous pavements. More information on the factors influencing mix stability will be found in Section 17.1.

16.4 Cohesiometer Value of Bituminous Paving Mixtures - The cohesiometer test measures the cohesive strength of the asphalt films and is accomplished by bending or breaking the same specimen that was used for the stabilometer test. Cohesiometer values have a linear relationship to Modulus of Rupture Values when applied to rigid or nonductile substances, which in turn may be related to the strength coefficients used in the structural design of the pavement system.

16.5 R_t, or Total Resistance Value of Bituminous Paving Mixtures - The R_t, or total resistance value is the result of the mathematical combination of the stability and cohesiometer values as described in Section 13.1. This is the actual value used to determine the strength coefficient of a bituminous mixture. When the frictional properties of a mix are such that a stability value of 35 cannot be obtained, an R_t value of 90+ will be considered satisfactory for high type pavements.

16.6 Percent Air Voids in Compacted Laboratory Specimens - The percent air voids in compacted laboratory specimens, at the recommended asphalt content should normally be between two and five percent for high quality, dense graded mixtures. Theoretically, laboratory density is that density expected to develop in the pavement after traffic densification. At least two percent voids are required to allow for the expansion of the asphalt during hot weather without "bleeding" to the surface.

DETERMINATION OF OPTIMUM ASPHALT CONTENT

17.1 The optimum asphalt content is primarily based on the percent air voids in the compacted specimens and their stability values. In application, the general criteria is to select the highest asphalt content the mix will accommodate which will result in the air voids between two and five percent without a sharp drop in the Stability Value. Depending upon the availability of aggregate and economic factors, less than ideal value relationships may have to be settled for. For instance, a mix design may show that in order to achieve stability the percent voids would be above five percent. In this case, mineral filler could be used to reduce the voids and a new mix design made. In some mixtures with adequate stability, the asphalt content necessary to obtain air voids above two percent may be lower than desirable. In this case some adjustment in gradation could be made to open up the void spaces in the aggregate to permit additional asphalt. While almost any adjustments can be made in the laboratory, the practicality and economics of duplicating them on the construction project must be considered. The laboratory optimum asphalt content is selected considering the above criteria based on the judgement of the Flexible Pavement Design Engineer.

ADJUSTMENT OF OPTIMUM ASPHALT CONTENT FOR TRAFFIC AND ENVIRONMENTAL CONDITIONS

18.1 The above laboratory design procedure does not consider the effects of (1) the season of the year at which construction will actually take place, (2) the density of traffic, or (3) the climatic conditions at the construction project. Bituminous pavements constructed in the early spring or fall can tolerate a higher asphalt content than those constructed during the summer months. More asphalt can be used at higher altitudes. Also, pavements subject to low traffic density can accommodate more asphalt than those under heavy traffic.

18.2 The optimum asphalt content, selected from laboratory design test values, is adjusted for the above considerations by use of the nomograph (Figure 4) to obtain the final recommended asphalt content for the project. This adjustment should be made in the field at the time of construction.

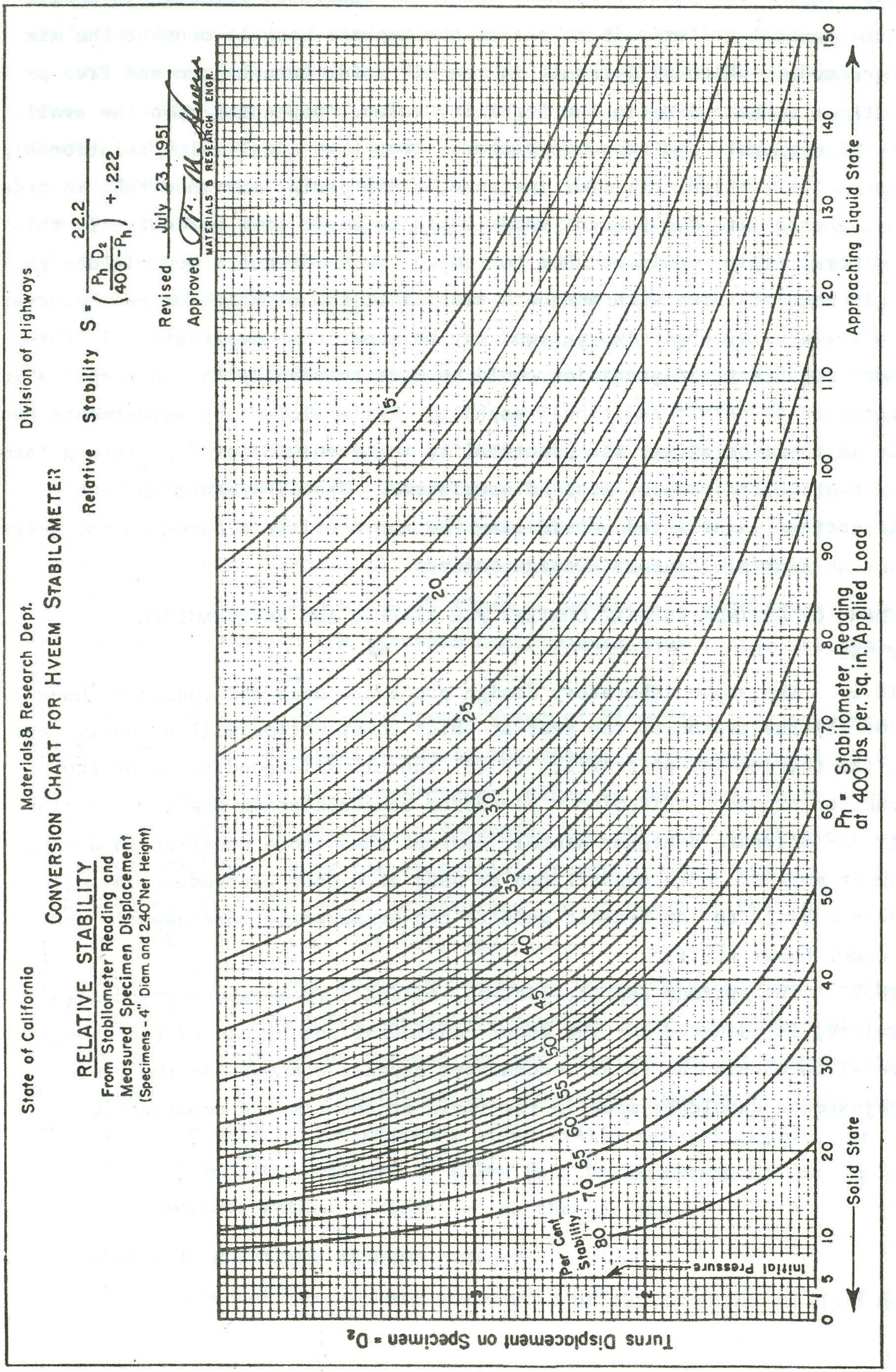

State of California
Division of Highways
Materials & Research Dept.
CONVERSION CHART FOR HVEEM STABILOMETER
RELATIVE STABILITY
From Stabilometer Reading and Measured Specimen Displacement
(Specimens - 4" Diam. and 2.40" Net Height)
Relative Stability S = 22.2 / (Ph D2 / (400 - Ph)) + .222
Revised July 23, 1951
Approved
MATERIALS & RESEARCH ENGR.
Turns Displacement on Specimen = D2
Ph = Stabilometer Reading at 400 lbs. per sq. in. Applied Load
Solid State
Approaching Liquid State
Initial Pressure
Per Cent Stability
80
70
65
60
55
50
45
40
35
30
25
20
15
0
5
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
FIGURE I

CHART FOR CORRECTING STABILOMETER VALUES TO SPECIMEN HEIGHT OF 2.50

Height correction should be made using the table and chart below.

Example: Overall height of 2.74", select correction curve "B". Stabilometer value uncorrected = 35 Stabilometer value corrected = 38.

Overall Specimen Ht.	Correction Curve
2.80" to 3.00"	A
2.60" to 2.79"	B
2.40" to 2.59"	C
2.20" to 2.39"	D
2.00" to 2.19"	E

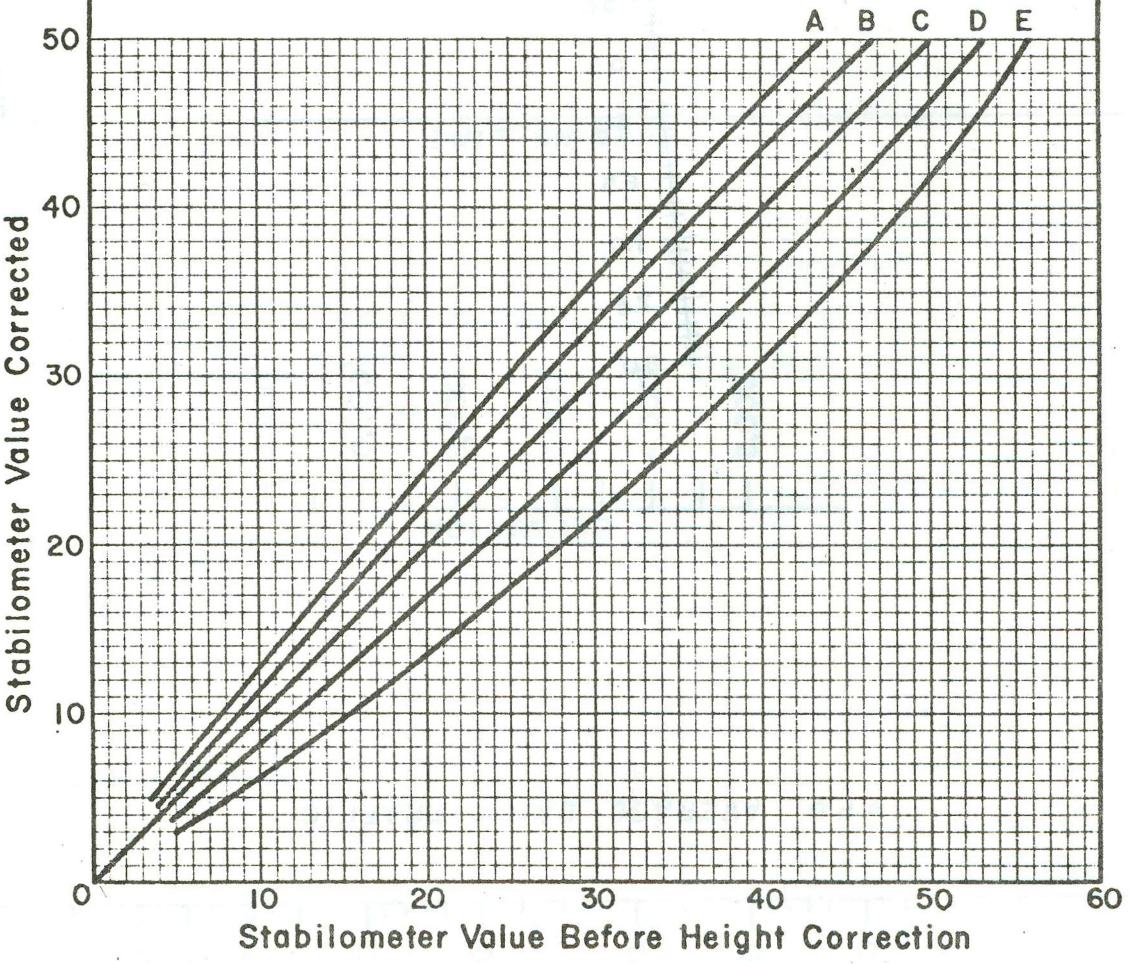


FIGURE 2

NOMOGRAPH for DETERMINING SPECIFIC GRAVITY of LOOSE BITUMINOUS MIXTURE

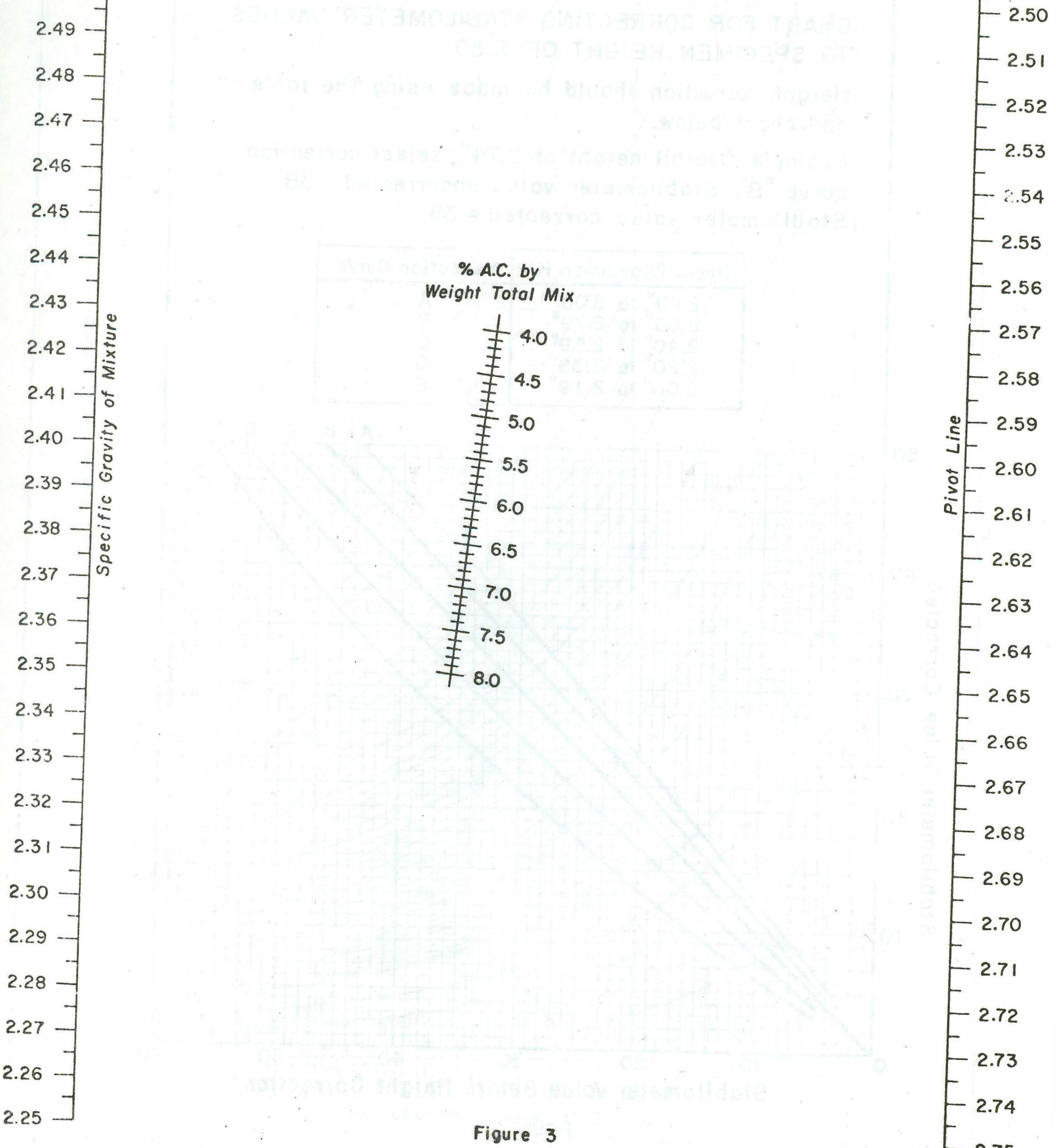
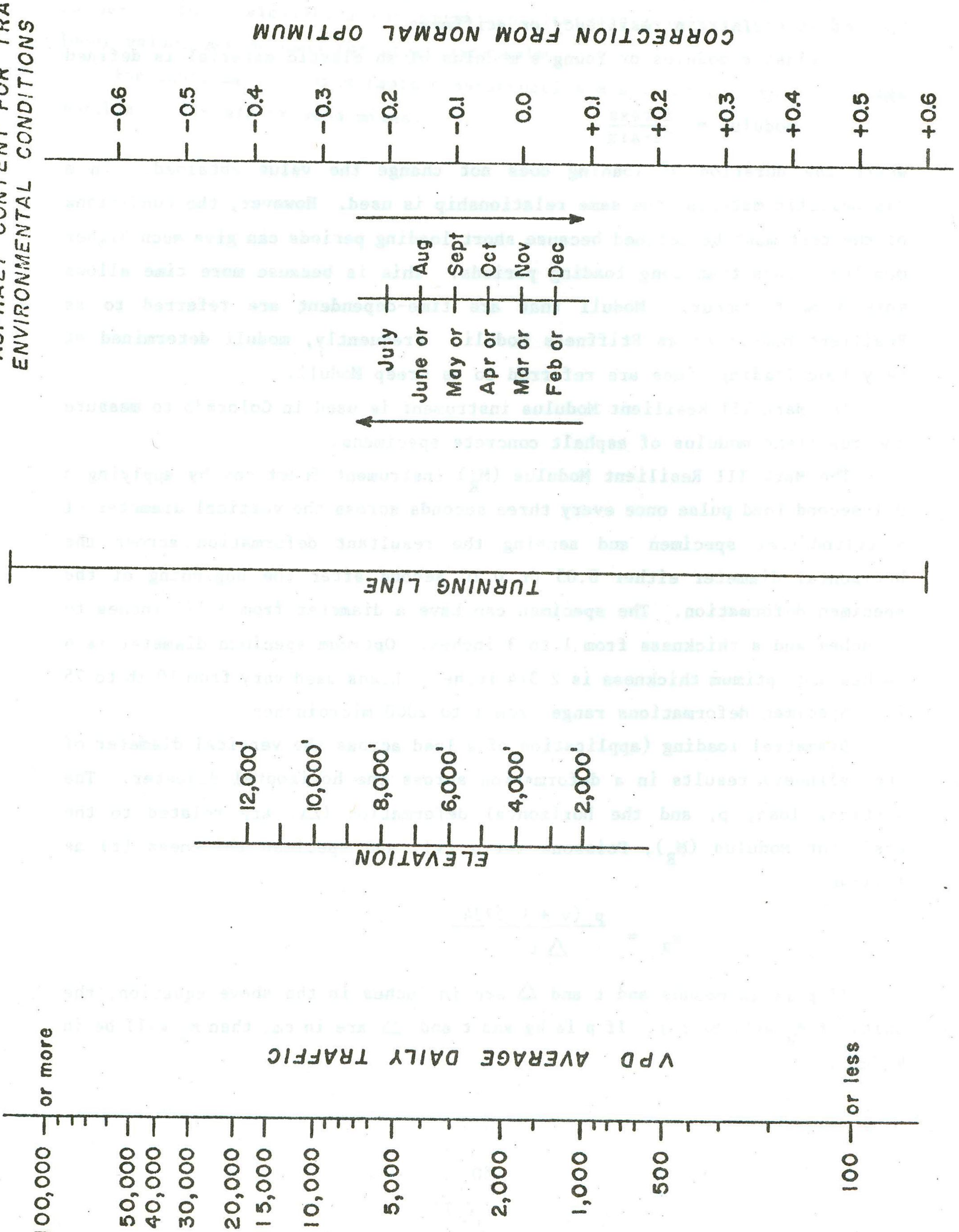


Figure 3

FIGURE 4

NOMOGRAPH FOR ADJUSTING OPTIMUM ASPHALT CONTENT FOR TRAFFIC AND ENVIRONMENTAL CONDITIONS



APPENDIX D

RESILIENT MODULUS MEASUREMENT

The Resilient Modulus is the value obtained by determining the time related stress/strain resiliency or stiffness.

An elastic modulus or Young's modulus of an elastic material is defined as:

$$\text{Modulus} = \frac{\text{Stress}}{\text{Strain}}$$

where the duration of loading does not change the value obtained. In a viscoelastic material the same relationship is used. However, the conditions of the test must be defined because short loading periods can give much higher modulus values than long loading periods. This is because more time allows more flow to occur. Moduli that are time-dependent are referred to as Resilient Moduli or as Stiffness Moduli. Frequently, moduli determined at very long loading times are referred to as Creep Moduli.

The Mark III Resilient Modulus instrument is used in Colorado to measure the resilient modulus of asphalt concrete specimens.

The Mark III Resilient Modulus (M_R) instrument functions by applying a 0.1-second load pulse once every three seconds across the vertical diameter of a cylindrical specimen and sensing the resultant deformation across the horizontal diameter either 0.05 or 0.10 second after the beginning of the specimen deformation. The specimen can have a diameter from 3 1/2 inches to 4-inches and a thickness from 1 to 3 inches. Optimum specimen diameter is 4 inches and optimum thickness is 2 3/4 inches. Loads used vary from 10 lb to 75 lb. Specimen deformations range from 1 to 2000 microinches.

Diametral loading (application of a load across the vertical diameter of the cylinder) results in a deformation across the horizontal diameter. The vertical load, p, and the horizontal deformation (Δ) are related to the Resilient Modulus (M_R), Poissons ratio (v), and specimen thickness (t) as follows:

$$M_R = \frac{p\,(v + 0.2734)}{\Delta\, t}$$

If p is in pounds and t and Δ are in inches in the above equation, the units of M_R will be psi. If p is kg and t and Δ are in cm, then M_R will be in kg/cm^2.

Thus, by measuring the thickness of the specimen and deformation resulting from a known pulsating load, the Resilient Modulus, or M_R can be calculated. A Poissons ratio of 0.35 has been shown to be a reasonable value to use in this calculation for sound asphalt-treated materials. Higher or lower values may be used for other materials.

The instrument permits rapid nondestructive measurement of the resilient modulus of asphalt-treated mixes.

PUBLICATIONS

Department of Highways-State of Colorado
Division of Transportation Planning

66-1	Final Report - Denver SE Pavement Study I 25-3(20)
66-2	Interim Reports on the Experimental Base Project At Ordway, Colorado #1
66-3	Interim Report on the Clifton-Highline Canal Experimental Project I 70-1(14)33 #1
66-4	Final Report on Statistical Research Project - Quality Control Study on Asphalt Pavement
66-5	Final Report on the Automatic "Icy Road" Sign Study
66-6	Interim Report on Crawford-South Experimental Project S 0125(9) #1
66-7	Final Report on the Strasburg E & W Pavement Study I 70-4(30)
66-8	ASCE Report on High Altitude Multiple Vehicle Emission Tests
66-9	Final Report on Photo and Engineering Geology Along Interstate Route 70 from Dotsero to Rifle, Colorado
66-10	Interim Report on the Reflective Traffic Bead Study #1
66-11	Rock Slope Stability in the Precambrian Metamorphic Rocks of the Front Range, Colorado
67-1	Interim Report on Experimental Base Project at Ordway, Colorado #2
67-2	Second Interim Report on Crawford-South Experimental Project S 0125(9)
67-3	Interim Report on Clifton-Highline Canal Experimental Project I 70-1(14)33 #2
67-4	Reflective Traffic Bead Study #2
67-5	Density-Temperature-Roller Data from Asphalt Paving Projects in Colorado
67-6	Skid Resistance in Colorado
67-7	Swelling Soils Study at Cedar Point, Colorado
67-8	Lime Shaft and Lime Till Stabilization of Subgrades on Colorado Highways
67-9	Embankment Construction Without Moisture-Density Control
67-10	Study of Preformed Open Cell Neoprene Joint Sealer
67-11	Dielectric Measurements of Asphalt Content
67-12	Revision of Colorado CHLOE Profilometer
67-13	Performance of Box Beam Guard Rail Having Vertical Post Mounted in Sand
67-14	Scaling on Concrete Bridge Decks
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68-2	Equilibrium Moisture and Density Study of Subgrades in Colorado
68-3	Grooving of Concrete Pavement Surfaces in Colorado to Prevent Hydroplaning
68-4	A Statistical Study of Rock Slopes in Jointed Gneiss with Reference to Highway Rock Slope Design
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68-6	Use of a Microwave Oven for Rapid Drying of Aggregate Samples
68-7	Means for Measuring Surface Smoothness
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68-9	Colorado's Reflective Bead Study
68-10	Dielectric Measurements of Asphalt Content - Final Report

PUBLICATIONS

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69-3 Evaluation of Dielectric Measurement Apparatus for Determining Pavement Density
69-4 Pavement Marking Materials Tested in Colorado
69-5 Study of Preformed Open Cell Neoprene Joint Sealer for Use in Transverse Weakened Plane Sawed Joints - Final Report
69-6 Use of Microwave Oven for Rapid Drying of Aggregate Samples - Final Report
69-7 Follow Up Report, Colorado's Reflective Bead Study
69-8 Rock Rippability Study - Final Report
69-9 Ordway Experimental Project, Post Construction Field Measurements - Interim Report

70-1 State-of-the-Art - Automatic Controls on Construction Equipment
70-2 Action Program to Promote Highway Safety
70-3 Reflective Traffic Bead Study - Final Report
70-4 Asphalt Membrane Project at Elk Springs - First Interim Report
70-5 Evaluation of Colorado's Flexible Pavement Base Design Methods - Final Report
70-6 The Effect of Vibration on the Durability of Concrete Pavement - First Interim Report
70-7 Crawford - South Experimental Project S 0125(9) - Third Interim Report
70-8 The Whitewater Experimental Project: An Instrumented Roadway Test Section to Study Hydrogenesis - Final Report
70-9 Clifton-Highline Canal Experimental Project - Third Interim Report

71-1 The Effect of Good Vibration on the Durability of Concrete Pavement #2
71-2 Effect of Vibration on Durability of Concrete
71-3 Lighted Deer Crossing Signs and Vehicular Speed

72-1 Reflection Cracking in Bituminous Overlays - Interim Report
72-2 Evaluation of Dielectric Measurement Apparatus for Determining Pavement Density
72-3 Skid Testing in Colorado
72-4 Development of Dwarf Ground Cover for Erosion Control in Colorado
72-5 Corrugated Metal Arch Barrier, Phase 1, Scale Model Study
72-6 Styrofoam Highway Insulation on Colorado Mountain Passes
72-7 Colorado Tunnel Ventilation Study - Interim Report
72-8 Effectiveness of Absorptive Form Liner for Horizontal Surfaces
72-9 Partially Beaded Centerline Markings
72-10 Field Study of Erosion Control Agents in Colorado
72-11 Soil Modification Highway Projects in Colorado
72-12 Calibration of Colorado's Texturemeter - Final Report
72-13 Air Pollution at High Altitude Construction Sites

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73-2	The Ordway Colorado Experimental Base Project
73-3	Noise Levels Associated with Plant Mix Seals
73-4	Accelerated Concrete Strength Study
73-5	Colorado Tunnel Ventilation Study
73-6	Clifton-Highline Canal Experimental Report
73-7	Seibert Experimental Project
74-1	Implementation Package for Swelling Soils in Colorado
74-2	Embankments With and Without Moisture Density Control
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75-2	The Effects of Vibration on Durability of Concrete Pavement
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75-4	Asphalt Membrane Project at Elk Springs, Colorado
75-5	Treatment of Swelling Soils - West of Agate, Colorado, Project I 70-4(48)347
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77-7	Performance of Culvert Materials in Various Colorado Environments
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77-9	Crack Reduction Procedures
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78-2	Squeegee Seals in Colorado
78-3	Automatic Speed Measurements and Axle Classification on State Highways in Colorado 1978
78-4	Rate of Progressive Deterioration on Colorado Highways
78-5	Colorado Photologging Program
78-6	Ordway Experimental Project Progress Report
78-7	Evaluation of the Outflow Meter in Colorado
78-8	Hold-Gro Erosion Control System

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78-10	Correlation of Subgrade Moduli and Stabilometer "R" Values
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