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Study was conducted in cooperation with U. S. Department of Transportation, Federal Highway Administration

16. Abstract

The study is divided into two phases. Phase I investigates the use of Emulsified Asphalts for Prime Coats and Phase II investigates the use of Emulsified Asphalts as Binders for Open Graded Asphaltic Concretes.

During Phase I, several sets of aggregate based specimens were "primed" with various grades of Emulsified Asphalts with a device fabricated for the study. This provided sufficient data to make recommendations for the use of a CMS-2S grade Emulsified Asphalt as a suitable prime coat

In Phase II, attempts were made to determine the emulsion drainage properties and coatability of the Emulsified Asphalt and to determine the durability of mixtures comprised of Emulsified Asphalt and three types of aggregates, regraded to meet local specifications for open-graded asphaltic concrete finishing courses. The three aggregate types were a local natural aggregate, a synthetic aggregate and a volcanic cinder.

17. Key Words	18. Distribution Statement
Prime Coat, Asphaltic Concrete, Finishing Course, Emulsified Asphalt, Penetration Depth, Coatability, Drainage, Durability.	

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FINAL REPORT

METHODS AND PARAMETERS FOR THE USE OF EMULSIFIED ASPHALTS FOR PRIME COATS AND BINDERS FOR OPEN GRADED ASPHALTIC CONCRETE FINISHING COURSES

by

Boyd Smith

for

RESEARCH PROJECT - ARIZONA HPR-1-11(151)

Sponsored by

The Arizona Highway Department

in cooperation with

Department of Transportation,

Federal Highway Administration

ATL TESTING LABORATORIES
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INTRODUCTION

Agencies that are currently involved in the construction and maintenance of roadway pavement systems, are becoming increasingly concerned regarding the predicted shortage of Liquid Asphalts and the pollution inherent to the hot mixed asphaltic concrete production. Therefore, this Research has been undertaken to develop "Methods and Parameters for the use of Emulsified Asphalts for Prime Coats and Binders for Open Graded Asphaltic Concrete Finishing Courses."

Based upon cited research, it has been concluded that properly designed and constructed prime coats and asphaltic concrete finishing courses utilizing emulsified asphalts can and will provide products equal in performance to those constructed by conventional processes. Utilizing emulsified asphalts for the described purposes will offer the following benefications.

1. Eliminate the quantity of light distillates required to provide the low temperature viscosity required of the liquid asphalts, thus conserving the lighter distillates for fuel.

2. Reduce the quantity of pollutants that are generated during the placement and curing of the liquid asphalts and the pollutants generated during the hot mixed asphaltic concrete production.

In order to convey the intent of this research the following defintions are made to provide a common ground between the author and the readers.

1. Liquid Asphalt - An asphaltic material having a soft or fluid consistency that is beyond the range of measurement by the normal penetration test, the limit of which is 300 maximum. Liquid asphalts include the following.

   a. Cutback Asphalt - Asphalt cement which has been liquified by blending with petroleum solvents (diluents). Upon exposure to atmospheric conditions, the diluents evaporate leaving the asphalt cement to perform its function.

      1. Rapid Curing (RC) Asphalt - Liquid asphalt composed of asphalt cement and a naptha or gasoline-type diluent of high volatility.

      2. Medium Curing (MC) Asphalt - Liquid asphalt composed of asphalt cement and a kerosene-type diluent of medium volatility.

2. Emulsified Asphalt - An emulsion of asphalt and water which contains a small amount of an emulsifying agent, a heterageneous system containing two normally immiscible phases (asphalt and water) in which the water forms the continuous phase of of the emulsion, and the minute globules of asphalt form the discontinuous phase.

3. Prime Coat - A prime coat consists of an application of low viscosity liquid asphalt to an absorbent surface.

A prime is used to prepare an untreated base for a layer of asphaltic concrete or an emulsion and chip and seal coat. The prime penetrates into the base, sealing voids and provides a bond between the subsequent layers of asphaltic concrete or provides a portion of the surface of a bituminous surface treatment.

4. Open Graded Asphaltic Concrete Finishing Courses- A mixture of asphalt cement and an open graded aggregate usually 3/8-inch maximum size, that provides a seal and a wearing course for the underlying layers of asphaltic concrete.

This research has been divided into the following two phases; Phase I investigates the feasibility of utilizing emulsified asphalts for prime coats, and Phase II investigates the feasibility of utilizing emulsified asphalts as a binder for open graded asphaltic concrete finishing courses.

PHASE I

EMULSIFIED ASPHALT PRIME COATS

Conventionally, prime coats are comprised of a spray application of liquid asphalt in the amount of from 0.20 to 0.50 (0.9 ℓ/m^2 to 2.26 ℓ/m^2) gallons per square yard. The conventional prime coat must be placed under ideal conditions, (due to the temperature, viscosity relationship of the asphalt), to assure proper performance of the prime. This, at times, may require delays or even changes in the construction phasing to allow an adequate curing period for the conventional prime coat. Additionally, the diluents leaving the liquid asphalt during the curing period rise off as pollutants. Furthermore, the placement of an asphaltic concrete pavement upon an uncured prime coat may, and can be, detrimental to the performance of the new asphaltic concrete surfacing.

As a result of the numerous problems inherent in utilizing a liquid asphalt, the research was initiated.

A. Test Apparatus

1. Spray Apparatus

To simulate the field application process, a device had to be fabricated that would provide uniform application of the bituminous material at the desired temperatures. The device constructed to meet these criteria consists of a commercial spray paint apparatus and a track mounted device capable of variable speed travel. Also, constant temperature baths were required to maintain the elevated temperatures of the bituminous material during the application process.

Figure A-1 shows the spray apparatus during a calibration spray.

Figure A-1

2. <u>Molds for Aggregate Base Specimens</u>

The molds utilized to prepare the aggregate base test specimens consist of a six (6) inch nominal size Acrylonitreil-Butadiene-Styrene plastic pipe. The length of the molds are 7-inches (177.8 mm) and have an inside diameter of 5.75-inches (146.1 mm). This mold yields a compacted specimen having a surface area of 0.02 square yards (0.0167 m^2).

B. <u>Physical Testing</u>

1. <u>Aggregate Base Specimens</u>

The physical testing was conducted on aggregate base specimens, compacted to 100 percent of their maximum dry density determined in accordance with AASHO T-99-61 Method "C" and conforming to the gradation requirements of AB-la of the 1969 Edition of the Standard Specifications of the Arizona Highway Department. The specimens utilized consisted of three different gradations varying from coarse to fine, all within the specification grading band for AB-la.

The gradations of the aggregate base utilized are shown in Figure I-1 and are charted in Figure I-2.

U. S. Std. Sieve Size	Sieve Opening (mm)	Gradation Designation Type I*	Type II*	Type III*
1"	25.000	100	100	100
3/4"	19.000	93	95	99
1/2"	12.500	69	80	90
3/8"	9.500	57	72	84
1/4"	6.300	44	60	74
#4	4.750	40	56	69
#8	2.360	35	47	59
#10	2.000	33	45	56
#16	1.180	29	40	48
#30	0.600	22	30	38
#40	0.425	18	24	31
#50	0.300	14	18	23
#100	0.150	7	12	13
#200	0.750	5	6	8

*Expressed in accumulative percents passing.

Figure I-1
Gradations of Aggregate Base Specimens

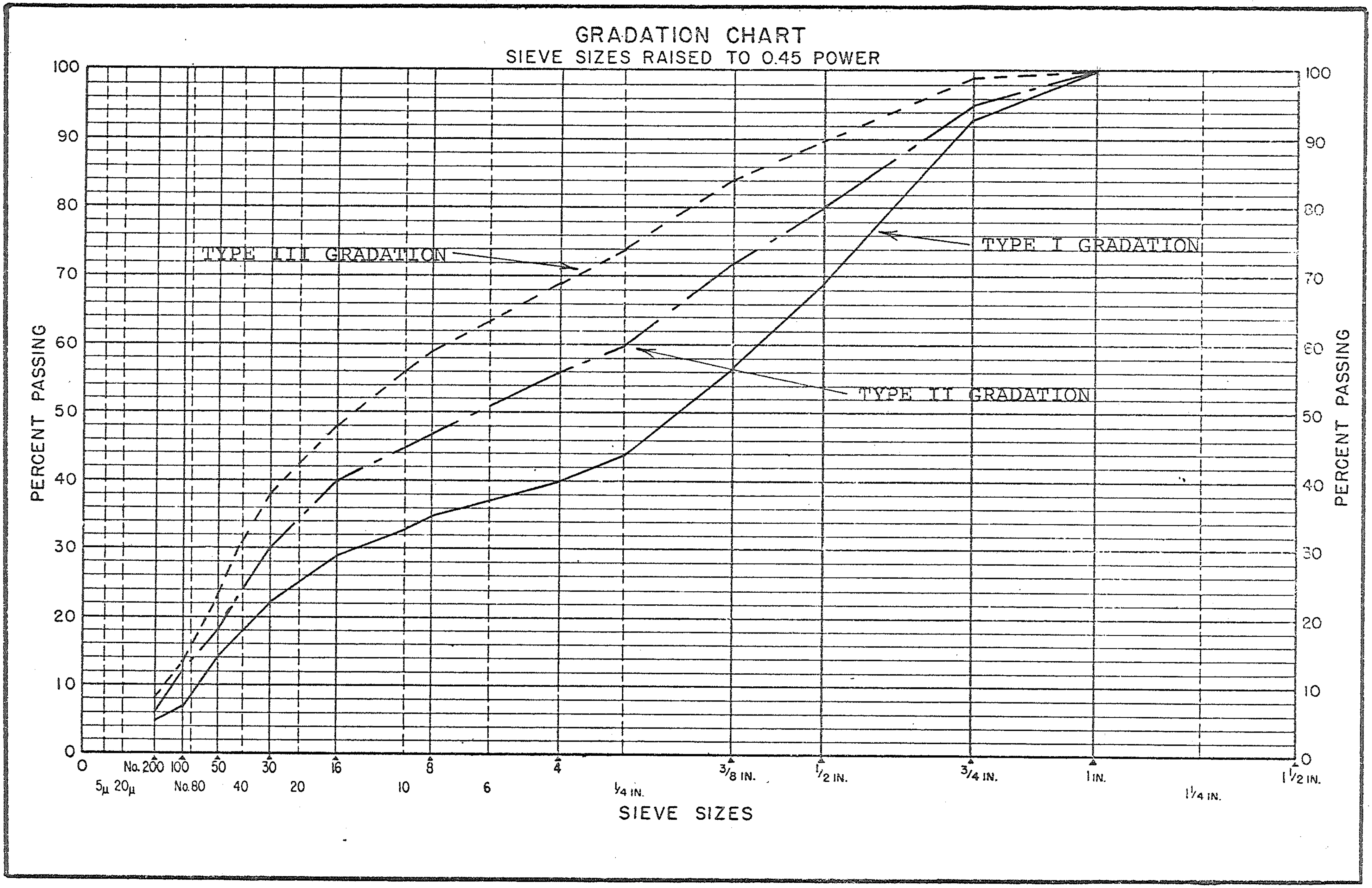
GRADATION CHART
SIEVE SIZES RAISED TO 0.45 POWER
PERCENT PASSING
PERCENT PASSING
0
10
20
30
40
50
60
70
80
90
100
TYPE III GRADATION
TYPE I GRADATION
TYPE II GRADATION
0
5μ 20μ
No.200
100
No.80
50
40
30
20
16
10
8
6
4
1/4 IN.
3/8 IN.
1/2 IN.
3/4 IN.
1 IN.
1 1/4 IN.
1 1/2 IN.
SIEVE SIZES

Figure I-2

Figure A-2 exhibits the compacted aggregate base specimens immediately prior to spraying.

Figure A-2

2. <u>Calibration of Spray Apparatus</u>

Two application rates were selected to evaluate the emulsified asphalt prime coat, compared to control specimens "primed" with MC-250 liquid asphalt. The application rates selected were 0.50 gallons per square yard (2.26 ℓ/m^2) and 0.3 gallons per square yard (1.36 ℓ/m^2).

It was necessary to establish exact application rates in terms of gallons per square yard (ℓ/m^2) corrected to $60^oF.(15.6^o C.)$ for the spray apparatus. This was accomplished by spraying a tared pan of the same cross-sectional area as the test specimens at varying speeds and at a nozzle adjustment that would provide full uniform coverage of the specimen.

Figure A-3 exhibits this process.

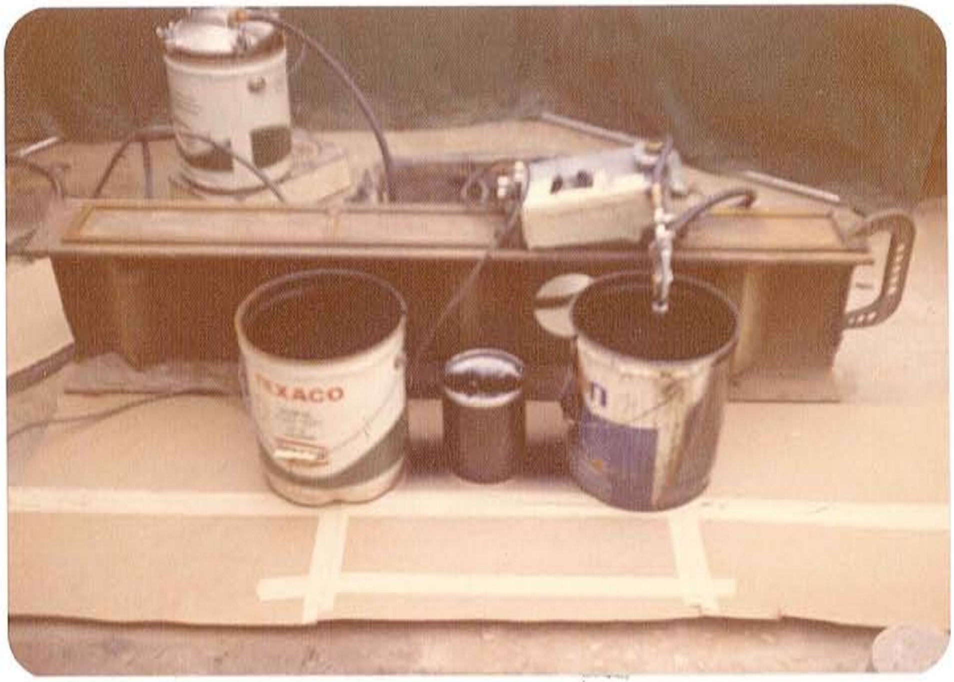

Figure A-3

The chart, Figure I-3, exhibits the relationship utilized to establish the required application rates, based upon the weight, in grams, of emulsified asphalt at 100° F. (37.8° C.) applied to the surface of the molded specimen.

3. Method of Test

The sealed aggregate base specimens were placed in the ambient atmospheric conditions for a period of 24 hours prior to the application of the asphalt. This measure was taken to allow the specimens to reach a condition as close as possible to the prevailing ambient atmospheric conditions. Figure A-4 depicts the actual process of applying the bituminous material to the test specimens.

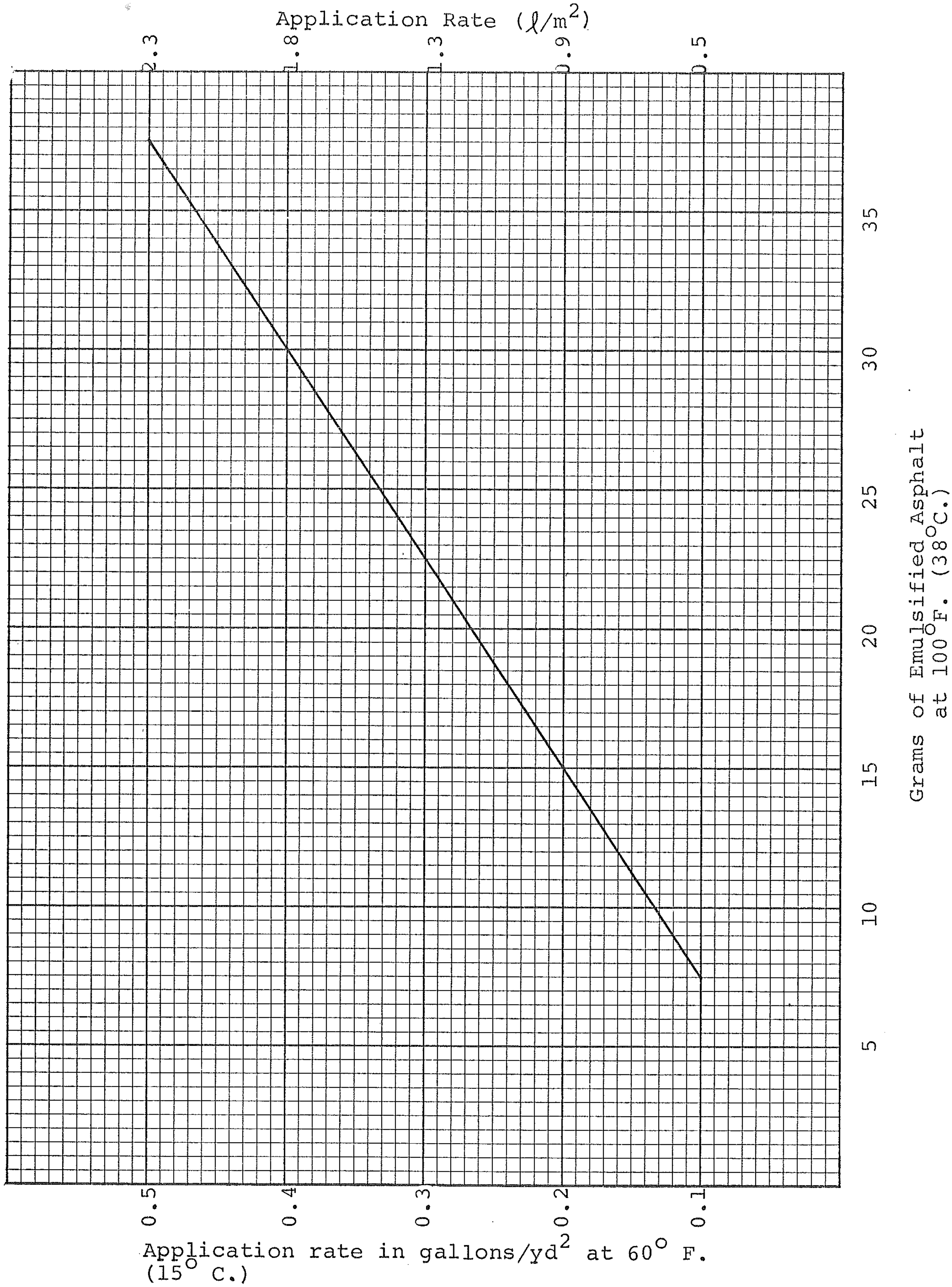
Application Rate (ℓ/m²)
2.3
1.8
1.3
0.9
0.5
35
30
25
20
15
10
5
Grams of Emulsified Asphalt
at 100°F. (38°C.)
0.5
0.4
0.3
0.2
0.1
Application rate in gallons/yd² at 60° F.
(15° C.)

Figure I-3

Figure A-4

After application of the bituminuous material, the specimens were allowed to cure for an additional 24 hour period, prior to the measurement of base penetration. The penetration was measured by cutting the specimen lengthwise and physically measuring the average depth of penetration.

C. Results of Testing Program

1. Control Specimens

   To provide a basis for evaluation, three (3) sets of specimens were "primed" with an MC-250 liquid asphalt. The graph, Figure I-4, exhibits the condition of the asphalt and specimens, and the average penetration of the prime coat.

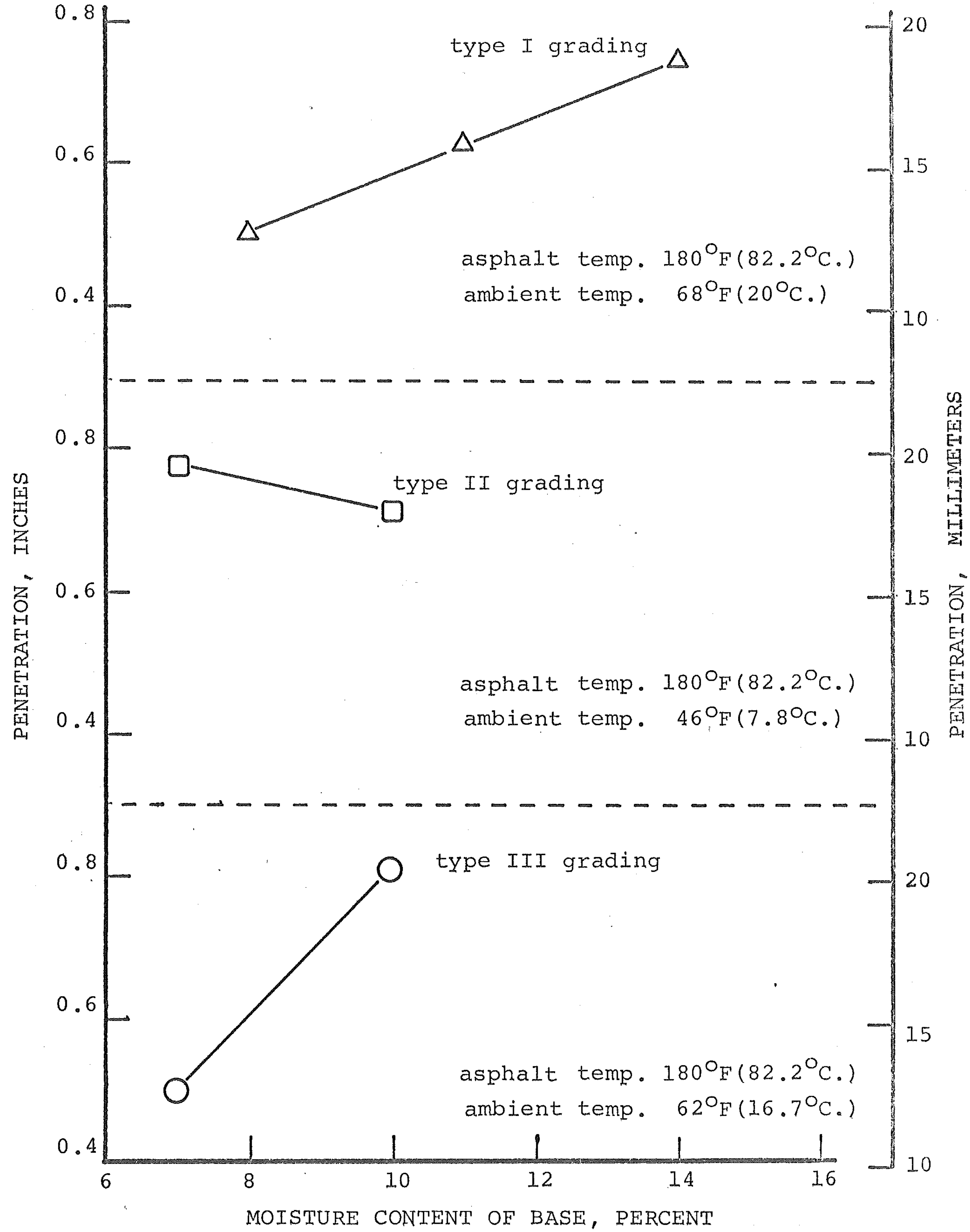

Figure I-4 Penetration of MC-250 liquid asphalt, application rate = 0.5 gals./sq.yd. (2.26 ℓ/m^2)

The graph indicates the MC-250 liquid asphalt to have a greater penetration depth with increasing moisture contents of the aggregate base specimens at temperatures higher than 60° F. (15.6° C.) independent of aggregate gradation.

As has been stated, the penetration values in Figure I-4 are average penetration depths at the indicated conditions. However, the penetration was found to vary from a minimum of 0.01 inches (0.25 mm) to a maximum of 1.25 inches (31.7 mm). Also, it was difficult to determine the penetration depths of the specimens prepared from the Type I (coarse) Gradation due to the asphalt draining through the voids at a rapid rate. Therefore, these laboratory values may not be consistent with field results due to the different compacting force and a possible difference in surface texture.

2. <u>SS-1h Emulsified Asphalt</u>

The first emulsified asphalt investigated for use as a prime coat was the SS-1h type. The properties of this emulsified asphalt may be found on page A-1 of Appendix A.

The SS-1h emulsified asphalt is in popular use and is readily available to users. Since these facts exist, it was felt to be a matter of course to investigate the SS-1h emulsified asphalts applicability as a prime coat.

Aggregate base specimens were prepared in the moisture percentages shown in Figure I-5, and sprayed with the selected application rates at varying asphalt and ambient temperatures. The graphs, Figure I-5, indicate the average penetration depths to not be appreciably effected by varying conditions, except for the Type I Gradation, where once again, the draining effect was observed. Furthermore, the penetration depths in the Type I Gradation specimens were erratic. Therefore, on the basis of this experience, and that with the MC-250 Liquid Asphalt, a decision was made to eliminate any further testing with the Type I (coarse) Gradation of the aggregate base.

As is indicated by Figure I-5, the penetration depths for all specimens are very low. No penetration was observed in the aggregate base specimen of Type III (fine) Gradation primed with 0.5 gallons per square yard (2.26 ℓ/m^2) The maximum depth of penetration was observed in the aggregate base specimen of Type I (coarse) Gradation primed with 0.5 gallons per square yard (2.26 ℓ/m^2). This maximum depth was 0.3 inches (7.6 mm).

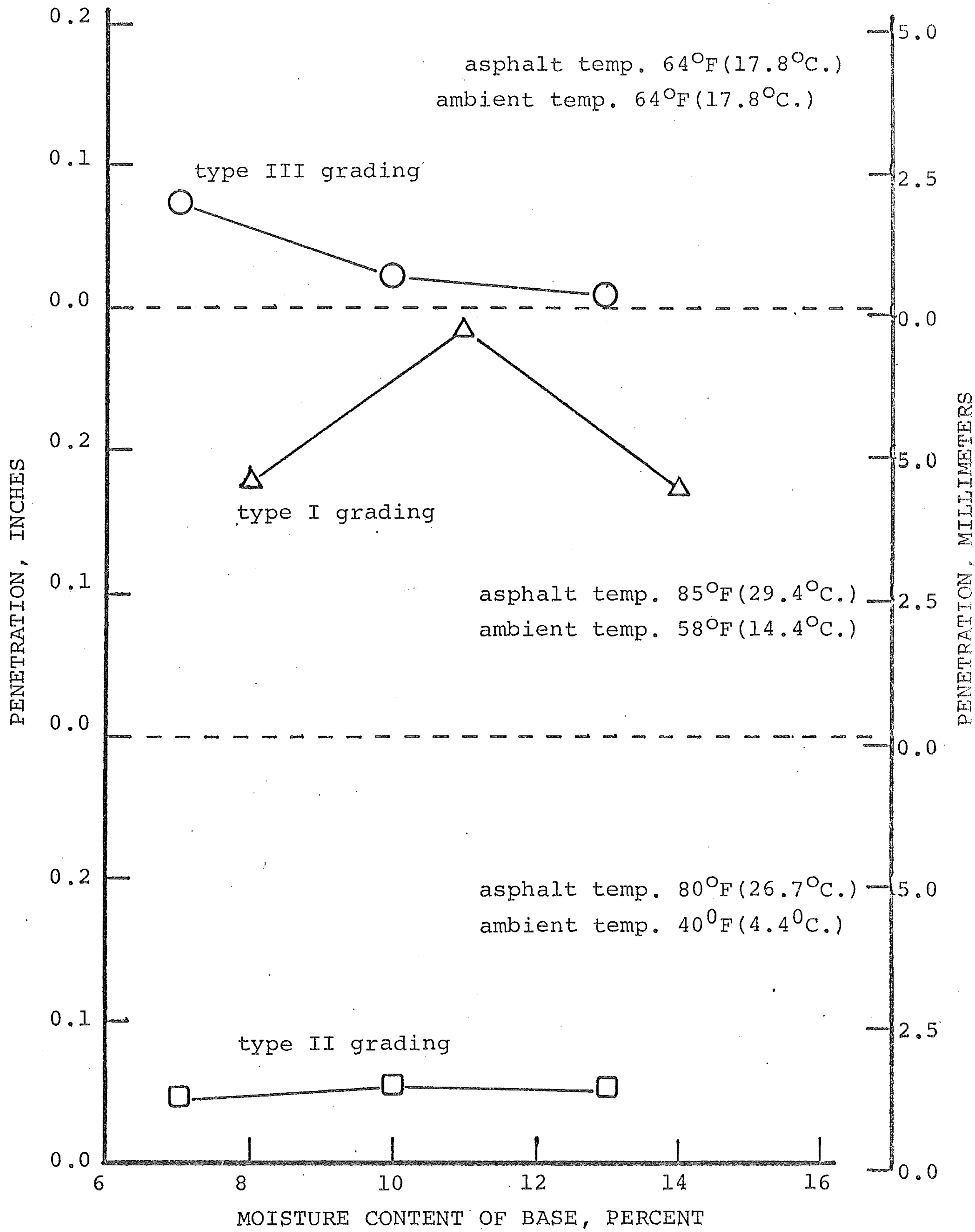

Figure I-5 Penetration of SS-1h emulsion, application rate = 0.5 gals./sq.yd. (2.26 ℓ/m^2)

As may be suspected with the low penetration rates, the emulsified asphalt broke leaving a film of free asphaltic cement on the surface of the aggregate base specimens. This situation was considered to be detrimental to the pavement system since it may provide a weak zone with respect to shear thus allowing the surface course to "shove". The condition of these specimens is exhibited in Figure A-5.

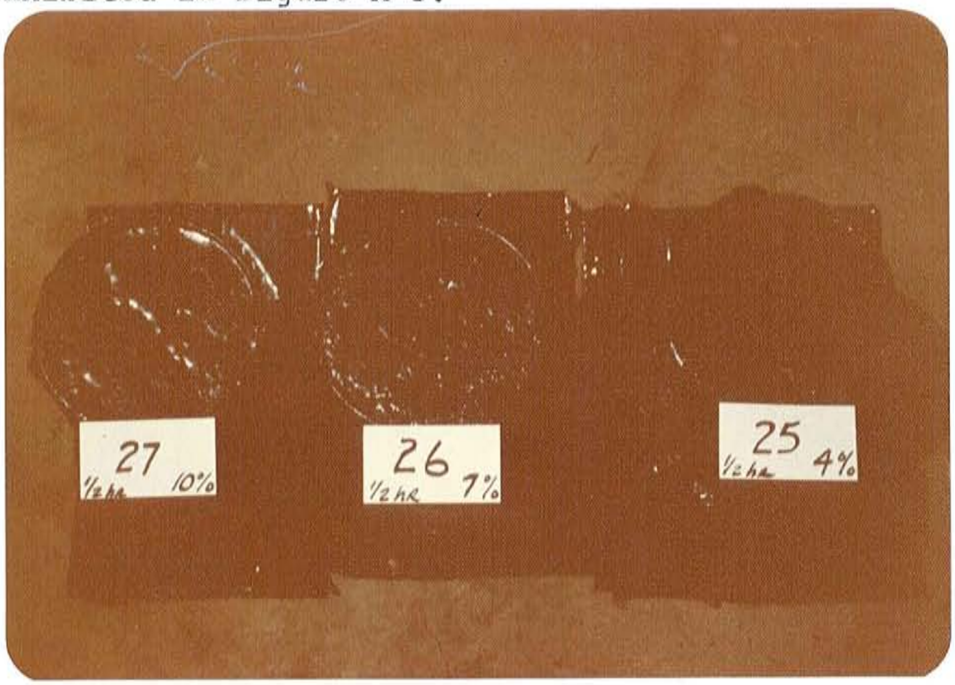

Figure A-5

Attempts were made to overcome the low penetration depths of the SS-1h emulsified asphalt in order to eliminate the film of free asphalt on the surface of the specimens.

a. Priming at Higher Ambient Temperatures

An additional aggregate base specimen was prepared of the Type (medium) II Gradation and molded at a 7 percent moisture content.

The ambient temperature at the time this specimen was primed was 72° F. (22.3° C.) The results of these conditions were virtually the same as those obtained at the lower ambient temperature with no decrease in the free asphalt film.

b. The Use of a Wetting Agent

A surface-active type wetting agent was utilized in an attempt to decrease the tension between the SS-1h emulsified asphalt and the aggregate base so that the penetration depths may be increased.

The following methods were utilized to introduce the wetting agent:

1. Varying amounts of the wetting agent were mixed with water that was utilized to effect the compaction of the aggregate base.

2. The wetting agent was mixed with the SS-1h emulsified asphalt in the amount of 0.74 cc wetting agent to five (5) gallons (19.9) of emulsified asphalt. The mixture was then applied to aggregate base specimens molded at various moisture contents.

The Graphs, Figure I-6, exhibits the result of the above described conditions. As can be seen, the average penetration depths

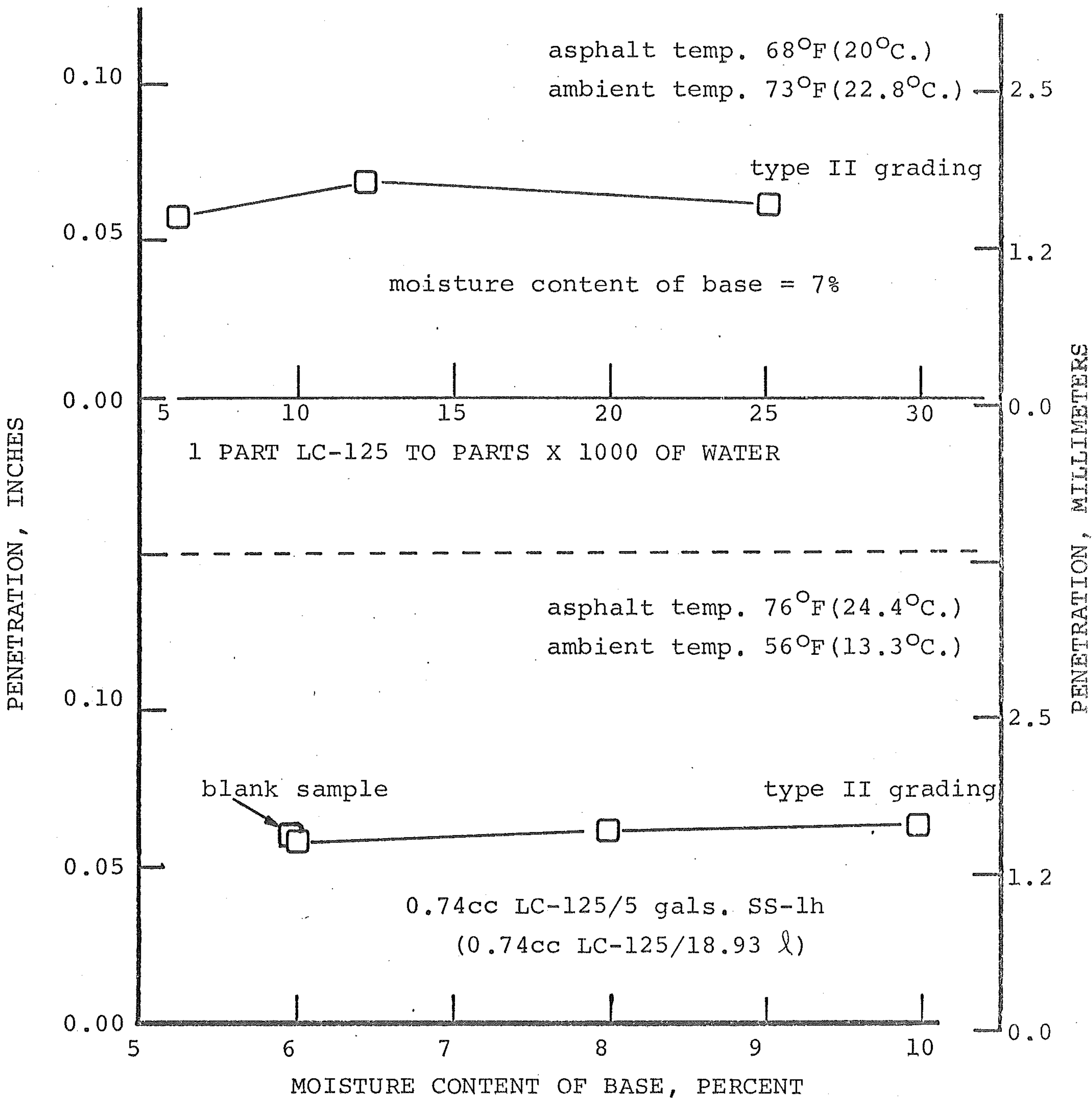

Figure I-6 Penetration of SS-1h emulsion with the addition of penetration aid LC-125. application rate = 0.5 gals./sq.yd. (2.26 ℓ/m^2)

were virtually the same and the film of free asphaltic cement remained upon the surface of the specimens.

C. Priming at Higher Temperatures of Bituminous Material and Higher Ambient Temperatures.

As a further attempt to increase the penetration depth of the SS-1h emulsified asphalt the following measures were taken:

1. The SS-1h emulsified asphalt was applied at an application temperature of 130° F. (54.4° C.) to a specimen conditioned to 84° F. (28.9° C.).
2. The SS-1h emulsified asphalt was diluted with 40% water by total weight of the emulsified asphalt and applied at an application temperature of 120° F. (48.9° C.) to a specimen conditioned to 82° F. (27.8° C).
3. A CSS-1h emulsified asphalt was applied at a spraying temperature of 96° F. (35.6° C.) to a specimen conditioned to 84° F. (28.9° C.). This measure was taken to determine if the positively charged emulsion would have any appreciable effect on penetration depth.

The aggregate base specimens for the above situations consisted of the Type III (Fine) Gradation aggregate base and the bituminous material was applied at the rate of 0.5 gallons per square yard ($2.26\ \ell/m^2$).

Figure I-7 exhibits the results of the above described tests. Furthermore, Figure I-7 indicates the penetration depths to be less than desirable. Also, the SS-1h and the CSS-1h emulsified asphalt

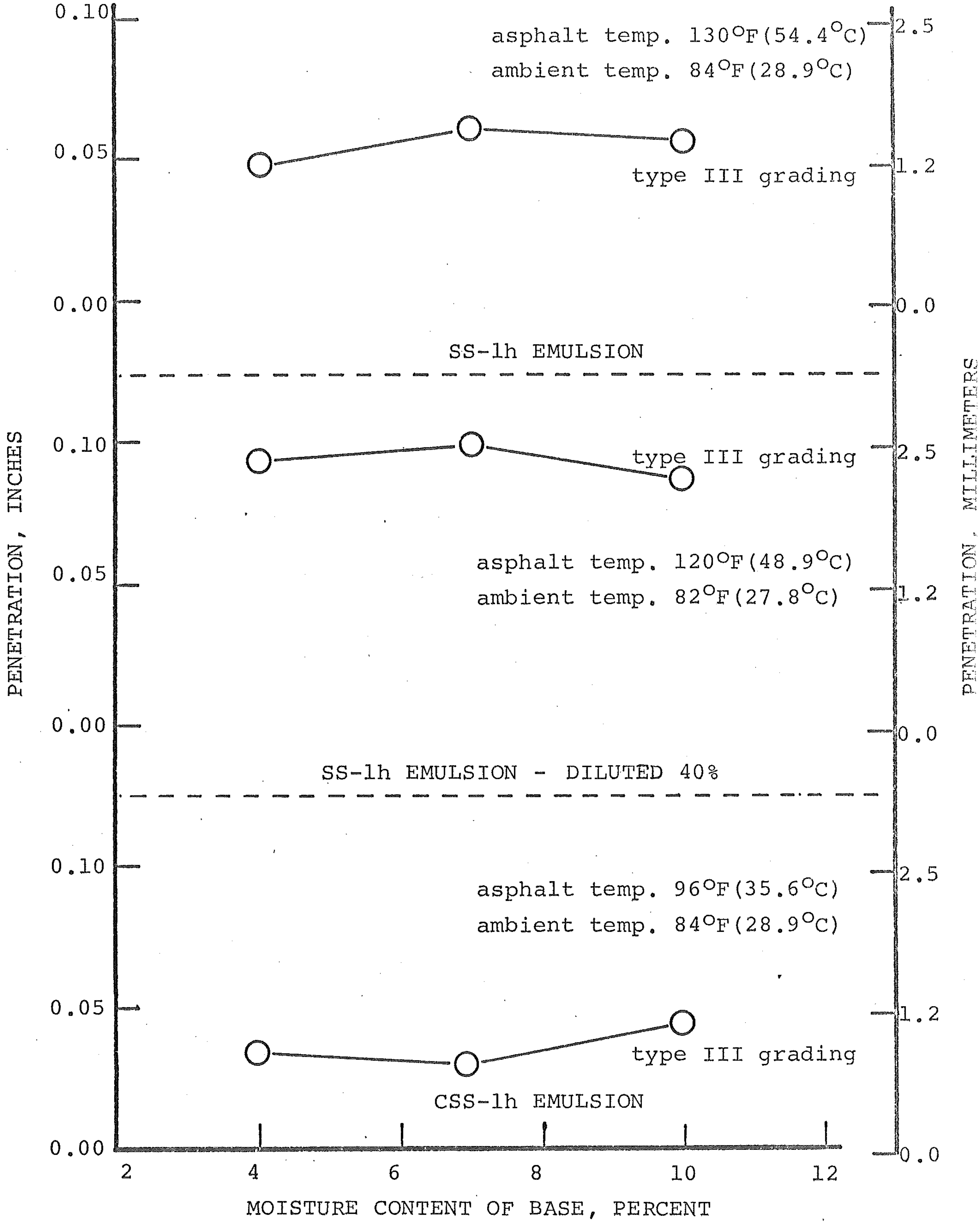

Figure I-7 Penetration of emulsions, application rate = 0.5 gals./sq.yd. (2.26 ℓ/m^2)

specimens, once again, had a film of free asphalt on the surface of the specimen. However, the diluted SS-1h specimens had a greater depth of penetration with a lesser film of free asphalt, but this condition was still considered to be less than satisfactory.

3. CMS-2S Emulsified Asphalt

After the attempts of utilizing the SS-1h and the CSS-1h emulsified asphalts failed, a decision was made to investigate the use of a CMS-2S emulsified asphalt as the bituminous material for a prime coat. The chemical and physical properties of the CMS-2S emulsified asphalt may be found on page A-1 of Appendix A.

One Type III (Fine) Gradation aggregate base specimen, molded with four (4) percent moisture and conditioned to 87° F. (30.6° C.) was sprayed with 0.5 gallons per square yard (2.26 ℓ/m^2) of CMS-2S emulsified asphalt at 100° F. (37.8° C.). The penetration depths into this specimen varied from a minimum of 0.063 inches (1.6 mm) to a maximum of 0.13 inches (03.3 mm). Also, within 15 minutes after application of the CMS-2S emulsified asphalt, it had completely penetrated into the aggregate base specimen without leaving a film of free asphalt on the surface of the specimen.

After a review of others experiences with a similar application of the CMS-2S emulsified asphalt, a decision was made to mix naptha with the emulsion on a volume basis and then dilute the mixture with 40 percent water, by weight of the emulsion and naptha mixture.

Figures I-8, I-9, and I-10 exhibit the results of attempts of utilizing various mixtures of the CMS-2S emulsified asphalt.

In all CMS-2S applications, it was found that the emulsified asphalt mixture penetrated and set at a much more rapid rate than did the MC-250 liquid asphalt. Furthermore, the most favorable results were obtained from utilizing a mixture, consisting of CMS-2S emulsified asphalt and nine (9) percent naptha, diluted with 40 percent water, and applied to aggregate base specimens whose surface had been allowed to air dry to a depth of 0.75 inches (19 mm).

As indicated by the graphs of Figures I-8, I-9, and I-10, the depth of penetration is not as great as the depths achieved by utilizing the MC-250 liquid asphalt. However, the surface condition was in a much tighter and more favorable condition. Also, it becomes a highly debatable question as to the required depth of a prime coat to penetrate before it will perform satisfactorily.

D. Field Test Section

Through the cooperation of the Maricopa County Highway

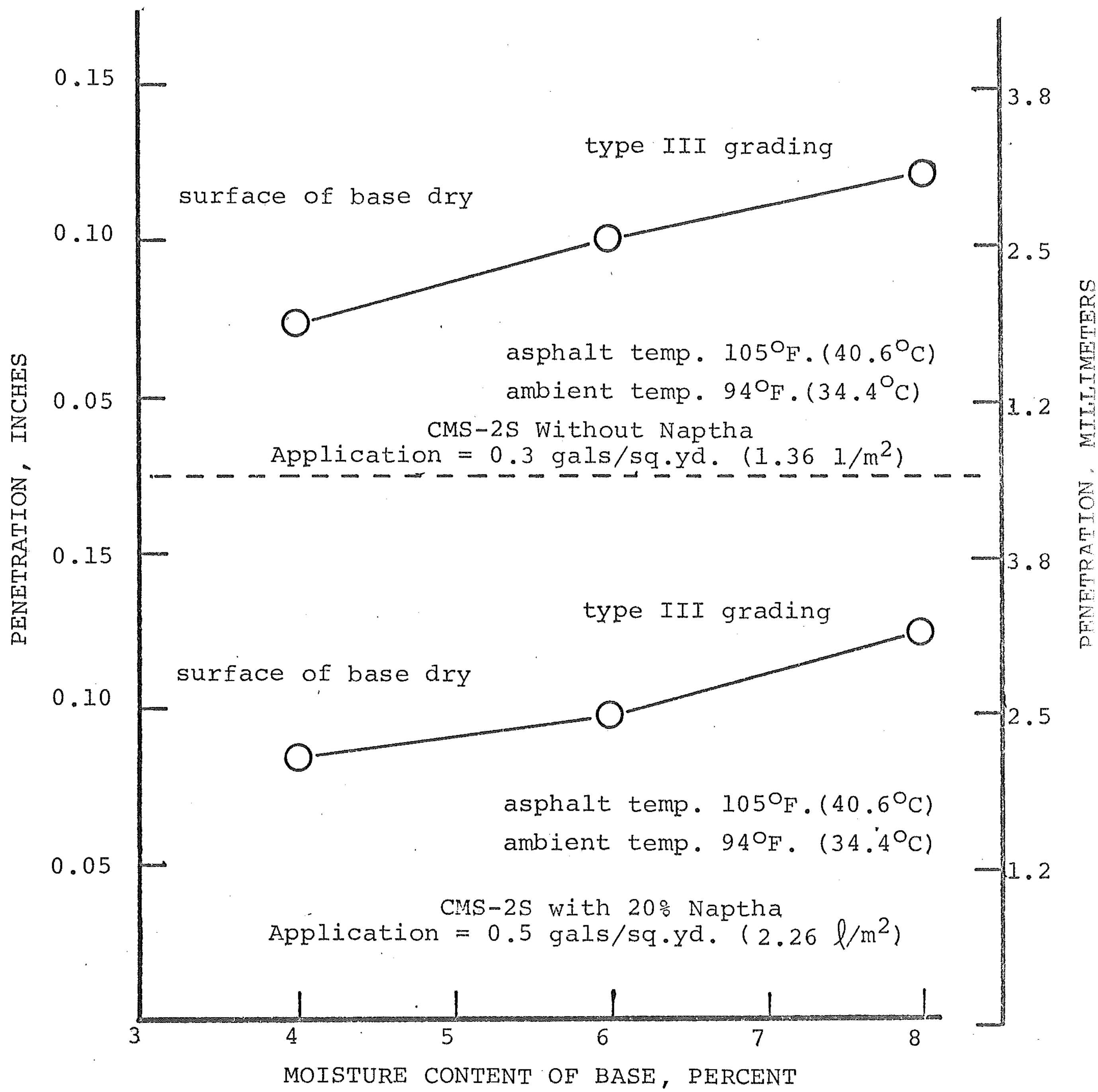

Figure I-8 Penetration of CMS-2S emulsions diluted with 40% water

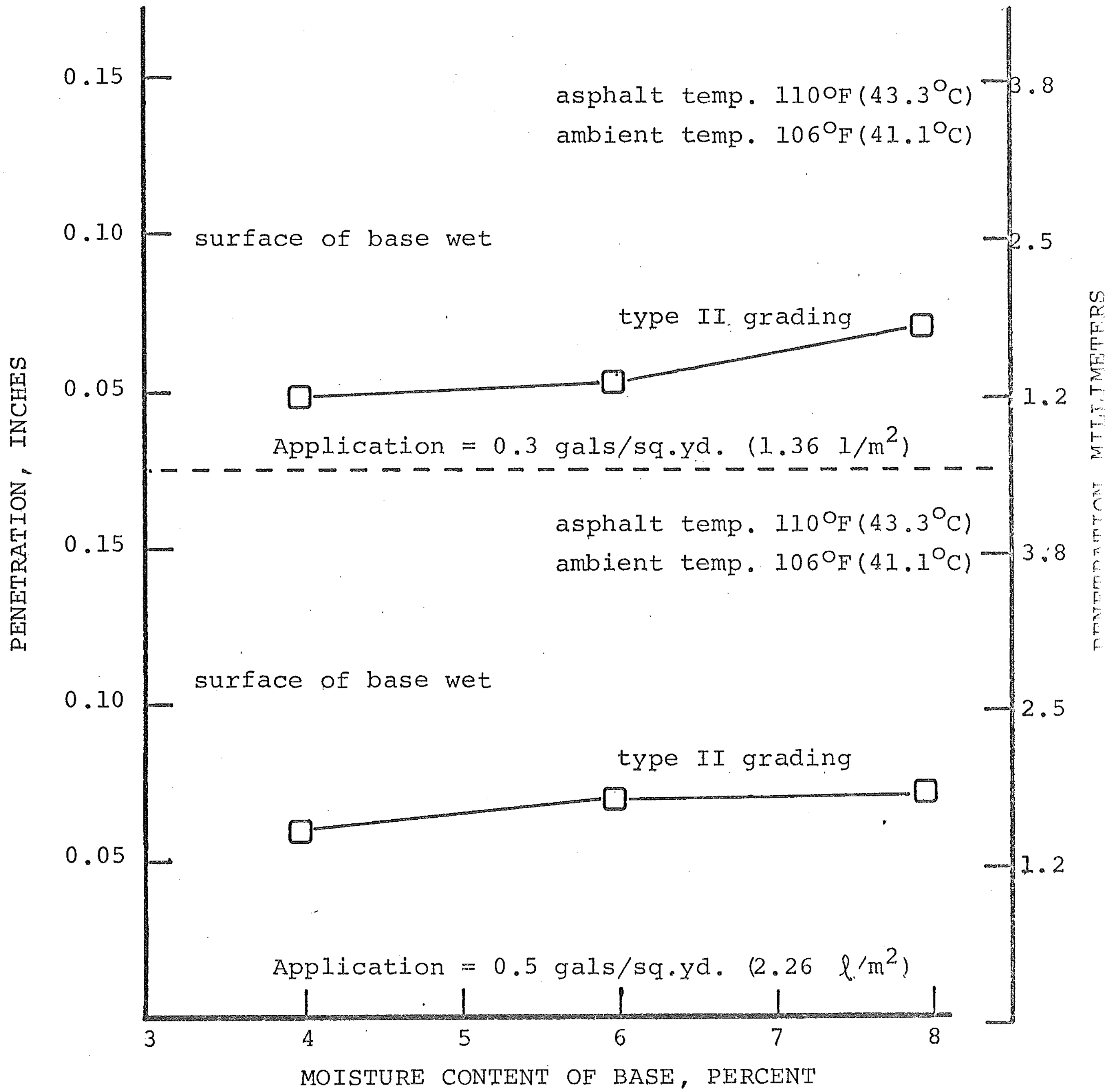

Figure I-9 Penetration of CMS-2S emulsion with 9% Naptha and diluted with 40% water

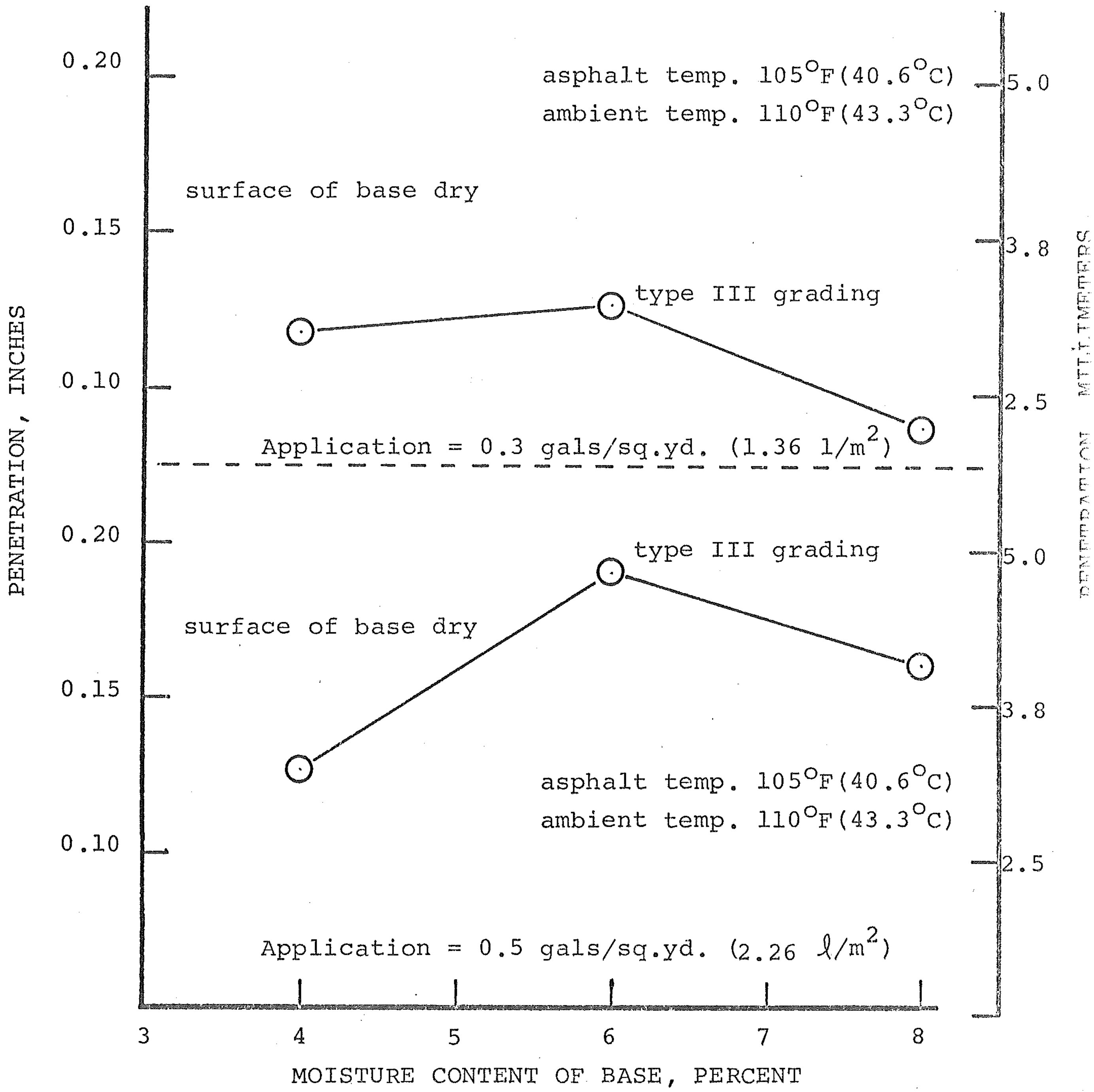

Figure J-10 Penetration of CMS-2S emulsion with 9% Naptha and diluted with 40% water

Department, a section of 28 feet (8.53 m) wide County Highway was selected as a field test section. The total length of this section is approximately 1/2 mile (0.80 km). This section of roadway was programmed to receive a base course consisting of 4 inches (101.6 mm) of aggregate base and a bituminous surface treatment consisting of a prime coat and a RS-2 emulsified asphalt and chip seal coat.

The conditions of the test were to apply alternate sections of prime coat consisting of 0.5 gallons per square yard (2.26 ℓ/m^2) of MC-250 liquid asphalt and CMS-2S emulsified asphalt mixture in such a manner so that at any point the prime coat for the adjacent lanes would consist either of the CMS-2S emulsified asphalt or the MC-250 liquid asphalt. The CMS-2S emulsified asphalt had added to it, 9 percent naptha, as a percentage, by volume, of the original volume of the emulsified asphalt, and the mixture was further diluted with 40 percent water, as a percentage, by weight, of the weight of the emulsion and naptha mixture.

The surface of the aggregate base course was found to be in a tight condition due to some silt that had been pulled onto the surface of the aggregate base during the trimming and shaping operation. Figure A-7 exhibits the condition of the test section immediately prior to the application of the prime coats.

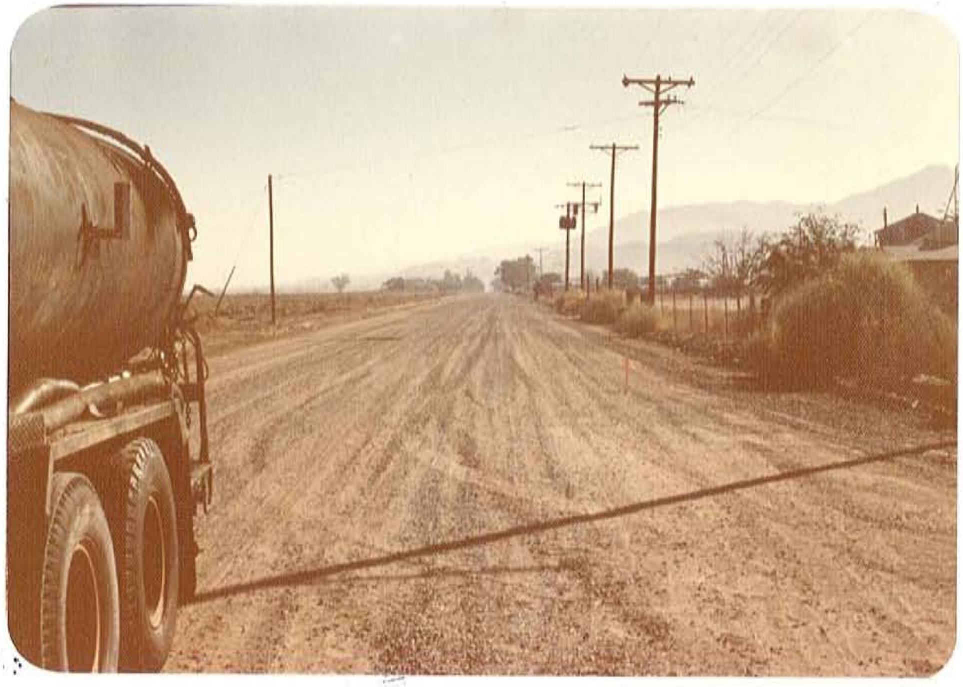

Figure A-7

The surface of the aggregate base course was moistened with a fog spray of water immediately prior to the application of the bituminous material. The bitumen was applied under the following conditions at the rate of 0.5 gallons per square yard (2.26 ℓ/m^2).

Bitumen	Temperature of Bitumen
MC-250 Liquid Asphalt	250° F. (121° C.)
CMS-2S Mixture	140° F. (60° C.)

The ambient temperature at the beginning of the test was 80° F. (27° C.) and was 90° F. (32° C.) at the end of the test application.

Figure A-8 depicts the average condition of the two different applications. The CMS-2S is shown on the right side of the roadway, and the MC-250 is shown on the opposite side of the roadway. The photograph, Figure A-8, was taken approximately twenty (20) minutes after the application of CMS-2S mixture and approximately 2½ hours after the application of the MC-250 liquid asphalt.

Figure A-8

1. <u>Observations from Field Test Section</u>

The setting time for the CMS-2S mixture was found to be between 15 minutes and 1 hour after application. The MC-250 liquid asphalt had not completely set until the day following the application.

The depth of penetration of the CMS-2S mixture was found to vary from a minimum of 0.125 inches (3.2 mm) to a maximum of 0.25 inches (6.4 mm). However, the MC-250 liquid asphalt penetrated from a minimum of 0.25 inches (6.4 mm) to a maximum of 0.75 inches (19.1 mm).

One week after the seal coat had been applied, the test section was inspected. The inspection revealed that both products had produced a firm wearing surface and at that time appeared to be performing equally as well.

After the test section had been in service for a period of 26 days, specimens were removed from the pavement. The specimens were removed by hand chiseling and were found to vary in total thickness from a minimum of 0.50 inches (12.7 mm) to a maximum of 1.0 inches (25.4 mm). Also, specimens from both products were found to be resilient. Figure A-9 and A-10 exhibit the above mentioned conditions.

Figure A-9

MC-250 Liquid Asphalt

Figure A-10

CMS-2S Mixture

E. Conclusions and Recommendations

It is the opinion of the author and not necessarily the opinion of the Arizona Highway Department or the Federal Highway Administration that emulsified asphalts, especially the CMS-2S mixture, can be utilized for prime coats. The benefications of such an application have been discussed and the testing, both laboratory and field, have born out the applicability of the use of emulsified asphalts for prime coats.

1. Recommendations for Use

The following recommendations are made for the use of the CMS-2S emulsified asphalt as a prime coat.

a. This research indicated that the CMS-2S mixture, consisting of the CMS-2S emulsified asphalt with 9 percent naptha and diluted with 40 percent water, provided the best prime coat. However, due to the time allowed for the project and the scope of the research statement, attempts were not made to optimize the percentage of naptha required for the most suitable performance. Therefore, it is left to the user to develop the optimum naptha content. It is however, the opinion of the author that the optimum naptha content is approximately 9 percent.

Based upon a mixture with 9 percent naptha, the best results were obtained by following the application techniques that are given below.

b. The application temperature of the CMS-2S mixture should be 140° F. ± 20° F. (60° C. ± 11° C.).

c. The ambient temperature should be 50° F. (10° C.) and rising with a surface temperature above 32° F. (0° C.).

d. The surface that is to be primed should be in a relatively dry condition but should also be free from excessive amounts of fine loose material (dust).

It is further recommended that additional field tests be conducted not only to establish an optimum percentage of naptha, but to clearly define the potential application problems and the long term performance of the mixture, under varying conditions.

PHASE II

EMULSIFIED ASPHALTS

AS

BINDERS

FOR

OPEN GRADED

ASPHALTIC CONCRETE FINISHING COURSES

Asphaltic concrete finishing courses are conventionally produced by mixing the mineral aggregate with an asphaltic cement of the AR-2000 type in a hot mix plant. The mixture is subsequently placed upon a layer of dense graded asphaltic concrete to provide a wearing course and a seal for the underlying asphaltic concrete. This product, as used by the Arizona Highway Department, is usually placed in an average thickness of 1/2 inch (12.7 mm) and the aggregate component has a maximum size of 1/4 inch (6.4 mm) and tends to be virtually one sized.

This phase of the research will investigate the feasibility of utilizing an emulsified asphalt as the binder phase of asphaltic concrete finishing courses. The testing will be performed upon three different types of aggregate material. These three types are as follows:

1. Natural aggregates from the Salt River: The rock constituent is predominately ultra-basic and the fines (sands) are predominately silica and potash feldspars.
2. Natural light weight aggregates from West Sunset Mountain: These aggregates are composed of volcanic cinders.
3. Synthetic light weight aggregates: These aggregates consist of an expanded montmorilinite clay from Southern California.

The various physical properties of the above aggregates may be found on page A-2 of Appendix A.

The synthetic aggregate and the cinder aggregate were found to be deficient in fines (-#4 fraction). Therefore, it was necessary to blend sand from the Salt River source with these aggregates to meet the specification for "MA-6" as specified in the Table 703-1 of the 1973 Supplemental Specifications of the Arizona Highway Department. Figure II-1 illustrates the specification and the aggregate gradation utilized for the test specimens.

Sieve Size U. S. Std.	mm	Gradation of Test Specimens*	MA-6 Specifications*
3/8"	9.53	100	100
#4	4.75	46	30-60
#8	2.36	11	7-15
#200	0.075	1	0-4

*The gradation of the test specimens and the specification are expressed in accumulative percents passing.

As was directed by the Research Section of the Arizona Highway Department, the basic criteria in determining a suitable percentage of emulsified asphalt was one that would result in just sufficient emulsified asphalt to provide enough mass viscosity to allow for compaction, thus providing for a subsequent flush coat of emulsified asphalt.

A. Methods of Tests

1. Mixing Tests

Samples of the three different aggregate types were mixed with varying amounts of different grades of emulsified asphalts and at varying moisture conditions of the aggregates. The mixtures were then placed upon a concrete pad and allowed to cure under ambient conditions. After placement of the specimens, observations were made to ascertain the coatability of the emulsified asphalt, the drainage characteristics, and the setting times of the aggregate-emulsified asphalt mixtures.

Setting time is defined as the increment of time between the addition of the emulsified asphalt to the time the mixture obtains sufficient tenacity to allow mechanical laboratory compaction.

2. Durability Test

In order to assimilate in service wearing conditions, a test apparatus had to be fabricated. The apparatus constructed to meet these conditions is illustrated in Figure B-1.

Figure B-1

As can be seen, this apparatus consists of two 4.00 x 8 smooth implement tires mounted on a small steel channel. The channel is rotated about its center at 19.05 rpm (1.99 rad/s) by a gear reduction electric motor, thus scribing a circle with the two smooth tires. The tires are inflated to 20 psi (140 kPa) and are loaded due to the weight of the apparatus to 216.6 pounds (98.2 kg) which provides a contact pressure of 54.2 psi (374 kPa).

The specimens are prepared in the four (4) pans for the wearing test. These pans form an annular area whose inner radius is 2½ feet (726 mm) and whose outer radius is 3½ feet (1.07 m). The pans are also 1 inch (25.4 mm) in depth which allows adequate space for the sample and any stripping agent, such as water. The use of the four (4) pans allows for the testing of four different specimens during one test.

B. Testing Program

1. Mixing Tests

The three (3) types of aggregates were mixed with three (3) different grades of emulsified asphalt. Those emulsions were SS-1h, CSS-1h and CMS-2S. This mixing was accomplished at varying aggregate moisture contents and varying emulsion contents in order to determine what grade of emulsified asphalt would provide the most favorable results at the lowest possible percentage of emulsified asphalt. From this series of tests the CSS-1h emulsified asphalt was found to provide the most favorable results, within the constraints of this research.

The next consideration was to optimize the percentage of CSS-1h emulsified asphalt and the percentage of mixing water. This again, required a series of mixing tests similar to the first. However, after the mixing of each batch, it was spread over a concrete pad at an approximate thickness of 1/2 inch (12.7 mm). Observations were then made with respect to setting time, coatability, and the presence or absence of the emulsified asphalt draining to the lower portion of the specimen. Figure B-2 exhibits the placement of the mixture.

Figure B-2

The results of these tests for the three (3) aggregate types are presented in Figures II-2, II-3, and II-4. The lines separating the different mixtures in terms of asphalt drainage and tenacity have been established by subjective observations. The mixtures plotted on the plus (+) side of tenacity line indicates favorable results while those falling on the minus (-) side indicate unfavorable results. With respect to the drainage line, the converse of this is true; therefore, those mixtures falling on the plus (+) side of the tenacity line and the minus (-) side of the drainage line are those samples that most fit the prescribed criteria.

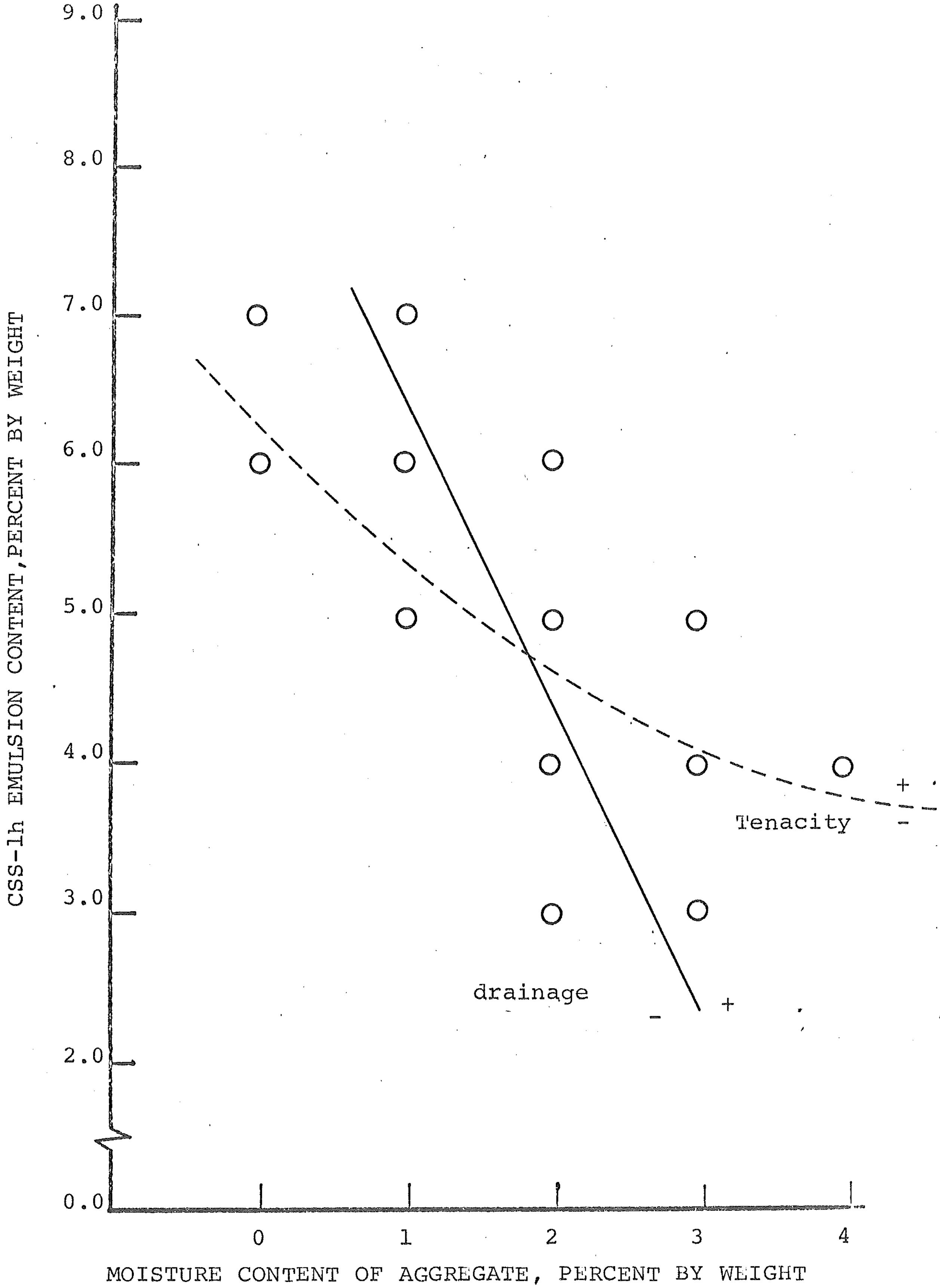

FIGURE II-2 Plot of emulsified asphalt mixing test samples using Salt River aggregates

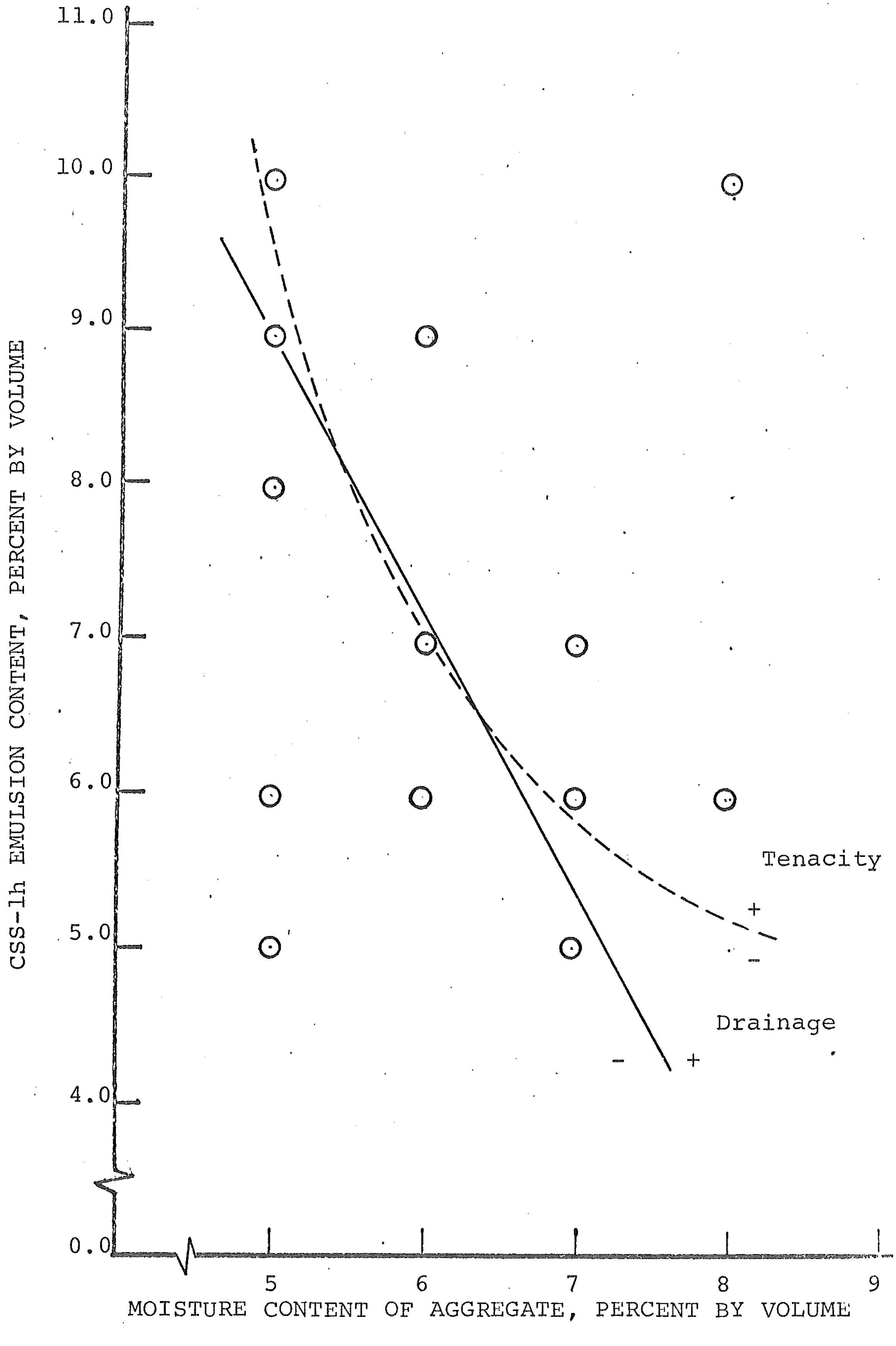

FIGURE II-3 Plot of emulsified asphalt mixing test samples using synthetic aggregates

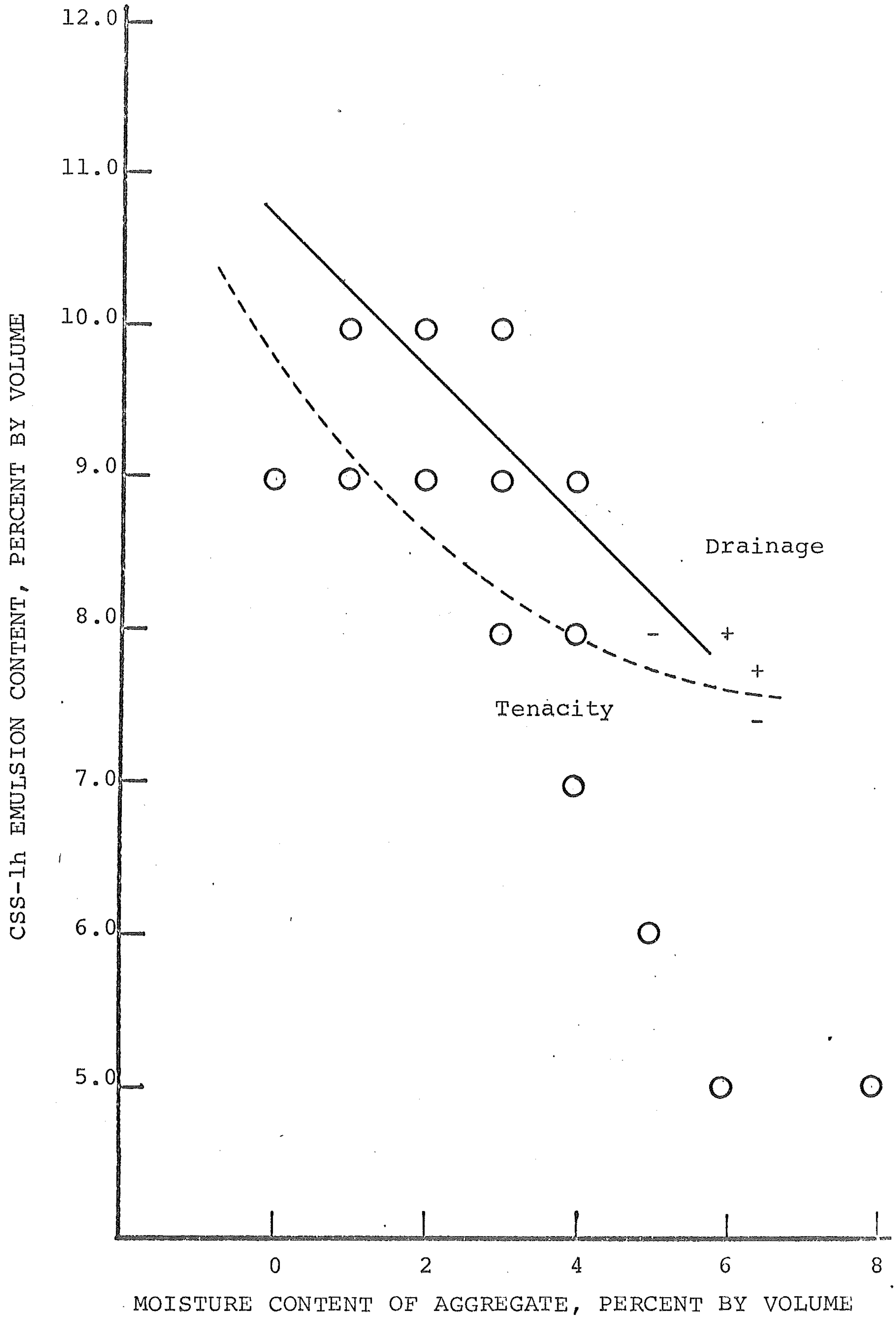

FIGURE II-4 Plot of emulsified asphalt mixing test samples using volcanic cinder aggregates

2. Durability Tests

Based upon the results of the mixing tests, specimens were prepared to be subjected to the durability test. The first series of these specimens consist of the following:

a. A control specimen, consisting of Salt River aggregate and six (6) percent, by weight of the total mix, of AR-2000 grade asphaltic cement. This mixture was placed in the test trays at 275° F. (135° C.).

b. A specimen consisting of Salt River aggregate with two (2) percent by weight of the dry aggregate, of mixing water and six (6) percent, by weight of the dry aggregate, of CSS-1h emulsified asphalt. This specimen was mixed with an emulsion temperature of 140° F. (60° C.) and an aggregate temperature of 78° F. (26° C.)

c. A specimen consisting of the synthetic aggregate with six (6) percent of CSS-1h emulsified asphalt and seven (7) percent mixing water, both as a percentage of the bulk volume of the aggregate. The mixture was prepared with an emulsion temperature of 140° F. (60° C.) and an aggregate temperature of 78° F. (26° C.).

d. A specimen consisting of the volcanic cinder aggregate and eight (8) percent CSS-1h emulsified asphalt and four (4) percent mixing water, both as a percentage of the bulk volume of the aggregate. The mixture was prepared with an emulsion temperature of 140° F. (60° C.) and an aggregate temperature of 78° F. (26° C.).

The mixtures were placed in the test pans, (Figure B-3) of the Durability Testing device. The initial compaction of each of the four (4) specimens was achieved with a solid steel cylinder weighing ten (10) pounds (4.56 kg). A further attempt at obtaining the optimum particle orientation of the mixtures was to further roll the mixture with an 4.00 x 8 smooth implement tire load to provide a contact pressure of approximately 60 psi (420 kPa).

Figure B-3

These attempts at obtaining compaction and particle orientation were considered to be less than satisfactory.

The first set of specimens prepared with the emulsified asphalt did not develop enough tenacity, within a 48 hour period, to even hold together. Therefore, an exact duplicate set of specimens were prepared utilizing a new batch of emulsified asphalt. These specimens were subject to the same initial compactive effort as were the first and were allowed to cure at ambient conditions varying from 80° F. (27° C.) to 102° F. (39° C.). These specimens had an initial set within 1½ hours and final compaction was achieved within 4 hours from the time of placement.

The second set of specimens prepared with the CSS-1h emulsified asphalt and the one prepared with the AR-2000 grade of asphaltic cement were subjected to 229 revolutions of the durability test track (Figure B-4 illustrates the in-test conditions).

Figure B-4

As can be seen, the device tended to shove the material and greatly densify the material in the wheel path. At this point it was believed that this condition was due to the low residual asphalt content of the emulsion mixtures. Also, the described situation, without a great deal of "shoving", occured in the specimen of the AR-2000 grade asphaltic cement.

An additional set of emulsified asphalt and aggregate specimens were prepared at higher emulsion contents. These percentages of emulsified asphalt are as follows:

a. Salt River aggregate - 7 percent CSS-1h emulsified asphalt

b. Synthetic aggregate - 9 percent CSS-1h emulsified asphalt

c. Volcanic Cinder aggregate - 10 percent emulsified asphalt.

This set of samples, after curing over night, were subjected to 420 revolutions of the test track with the same results in-so-far as densification in the wheel path and "shoving".

An additional set of specimens at the higher emulsion content were prepared and cured. As an attempt to eliminate the shoving situation it was decided to flush the prepared specimens with a sufficient quantity of CSS-1h emulsified asphalt to increase the residual asphalt content by two (2) percent. The flush was applied at 140° F. (60° C.) with a commercial spray paint apparatus. The penetration of the flush coat was minimal, 0.125 inches (3.18 mm). This was attributed to the necessity of having to make several passes with the spray apparatus in lieu of one. Figure B-5 illustrates the flush coat application.

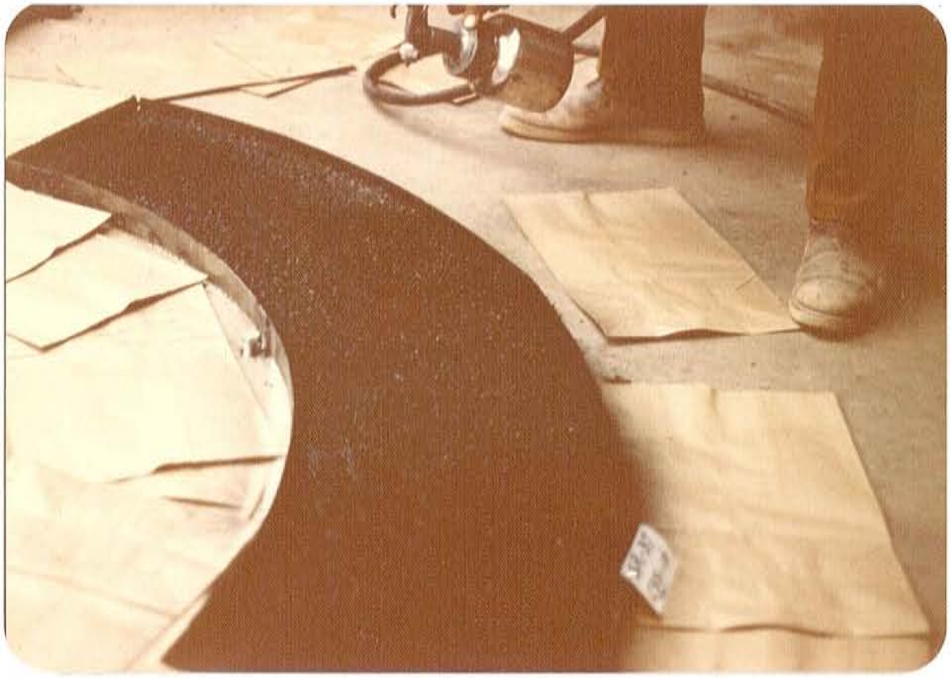

Figure B-5

The samples were allowed to cure over night prior to being subjected to 1143 revolutions of the test track. Once again, the situation developed of the material being shoved by the wheels of the test track; however, at a lesser severity than had been previously experienced.

The failure of developing a mixture that performs well in the durability test is attributed to the impossibility of being able to provide proper compaction and optimum particle orientation in the laboratory, rather than the competency of the prepared specimens.

C. Conclusions & Recommendations

It is the opinion of the author that the mixtures of the open-graded aggregate and CSS-1h emulsified asphalt can provide an asphaltic concrete finishing course that will perform satisfactorily. However, the mixture will need to be mixed at an emulsion content low enough to avoid excessive drainage of the emulsified asphalt during transportation to lay-down and then be flushed with a sufficient quantity of emulsified asphalt that will provide the durability required of a wearing course. Also, it is recommended that field test sections be established and observed for a sufficiently long period to determine the performance quality of the product.

COMMENTS

Phase I of this research has established the feasibility of utilizing an emulsified asphalt for a prime coat. Also, the methods employed to accomplish this investigation may be employed to design application rates for prime coats on a project basis. However, it is felt that an investigation need be made into the actual benefication of providing a prime coat in a pavement system. Therefore, it is suggested that a study be implemented to ascertain the structural value of a prime coat and to ascertain its value as a landing interface between a base course and the overlying layer(s) of asphaltic concrete pavement.

The investigation of Phase II has provided a basis to extend the research into a practical field test application. However, further attempts should be made to duplicate field placement techniques in the laboratory. This would, then, allow for a definitive durability test method to be established. Also, definite correlation should be established between field specimens and laboratory prepared specimens. Furthermore, this durability testing appears to be a rational method of designing the open-graded mixtures that have been investigated.

ACKNOWLEDGEMENT

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1. Chevron Asphalt Company
2. Arizona Refining Company
3. Lightweight Processing Company

APPENDIX A

"UNIFORM PACIFIC COAST SPECIFICATIONS FOR EMULSIFIED ASPHALT"

Grade	SS-1h		CMS-2S		CSS-1h	
	Min.	Max.	Min.	Max.	Min.	Max.
Tests on Emulsions:						
Viscosity SSF @ 77°F.	20	100	--	--	20	100
Viscosity SSF @ 122°F.	--	---	50	450	--	---
Settlement 5 days, %	--	5	--	5	--	5
Storage Stability 1 day	--	1	--	1	--	1
Cement Mixing Test, %	--	2.0	--	---	--	2.0
Sieve Test, %	--	0.10	--	.10	--	.10
Residue by distillation, %	57	---	--	---	--	---
Tests on Residue from Distillation Test:						
Penetration, 77°F.	40	90	100	250	40	90
Ductility, 77°F., 5 cm/min.cm.	40	--	40	----	40	--
Solubility in trichloretylene, %	97.5	--	97.5	---	97.5	--

AGGREGATE PROPERTIES

	Salt River Aggregate	Synthetic Aggregate	Volcanic Cinder Aggregate
Specific Gravity (O.D.)			
Coarse (+#4)	2.63	1.26	2.02
Fine (-#4)	2.62	1.41	
Absorption (water)			
Coarse (+#4)	1.30%	14.7% (1 hr.)	8.36%
Fine (-#4)	1.26%	15.7% (1 hr.)	
Abrasion			
L.A.,% loss @ 500 rev.)	16%		23%
Soundness			
(Na_2SO_4)			
Coarse (+#4)		1.62%	
Fine (-#4)		1.76%	

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SUPPLEMENT I

SUPPLEMENT I

A. EMULSIFIED ASPHALTS WITH A LOW-TEMPERATURE BUTADIENE-STYRENE POLYMER AS A BINDER FOR OPEN GRADED ASPHALTIC CONCRETE FINISHING COURSES

1. Scope

The purpose of the additional work was to determine if, and by what methods a low temperature butadiene-styrene polymer could be introduced into an open graded asphaltic concrete mixture. Also, a determination was to be made as to the amount of the polymer that could be successfully added to the mixture.

The polymer utilized was an emulsion with a monomer ratio of 70 percent butadiene to 30 percent styrene.

The emulsified asphalt used in this investigation was an SS-1h type.

2. Testing

A program of testing similar to the mixing test conducted in Phase II was implemented. However, the emulsified polymer was pre-mixed with the emulsified asphalt in the amounts of 3 and 5 percent, as a percentage of the weight of the emulsion prior to mixing with the "MA-6" mineral aggregate.

In preparing the first series of the emulsified asphalt-emulsified polymer mixtures, it was found that the emulsified polymer would break, slowly, upon mixing with the SS-1h emulsified asphalt. This demonstrates inconsistent properties of the emulsified asphalts that are not controlled by specifications.

The results of the series of mixing tests are illustrated in Table SI-A1.

Emulsion Content	Moisture Content of AGG	Emulsified Polymer Content	Rubber Content	Emulsion Temperature	Mix Properties
5.5%	2.5%	5.0%	----	130°F. (54.4°C.)	Aggregate Would Not Coat. Asphalt balled in mixer
7.0%	0%	5.0%	----	130°F. (54.4°C.)	Same as Above
7.0%	0%	5.0%	----	130°F. (54.4°C.)	Same as Above (Fresh Emulsion)
7.0%	0%	----	----	130°F. (54.4°C.)	Good Coating Some Drainage of Emulsion-Control Specimen
7.0%	0%	5.0%	----	130°F. (54.4°C.)	Fair Coverage Some Balling of Asphalt
7.0%	0%	5.0%	----	130°F. (54.4°C.)	Same As Above
7.0%	0%	5.0%	----	140°F. (60.0°C.)	Aggregate & Latex Heated to 140°F.(60.0°C.) Mixture "Gummy"
7.0%	0%	3.0%	----	70°F. (21.1°C.)	Mix did not Coat
7.0%	0%	3.0%	----	70°F. (21.1°C.)	Broke Rapidly Coated Well (Hand Mixed)
7.0%	0%	5.0%	----	70°F. (21.1°C.)	Mix Did Not Coat Hand Mixed

Table SI-A1

Since difficulties were encountered in the mixing test, a decision was made to attempt to apply the emulsified polymer by spray methods. The spray mixture consisted of 5 percent emulsified polymer and 95 percent SS-1h emulsified asphalt diluted with 50 percent water, as a percentage of the volume of the mixture. The mixture was applied to the specimens at a rate such that the resultant residual would be 0.75 percent, as a percentage of the dry weight of the aggregate. The flush coat flowed through the specimen and after curing left the specimen in a very flexible condition.

3. Conclusions

Based upon the results of the testing program, it is the opinion of the authors that the most feasible method of introducing the low-temperature butadiene-styrene into the open graded asphaltic concrete mixture is by a spray application to the surface of the finishing course. Furthermore, it is suggested a field test section should be constructed prior to the major use of these described processes.

B. EMULSIFIED ASPHALTS AS A BINDER FOR OPEN-GRADED ASPHALTIC CONCRETE FINISHING COURSES WITH A GROUND VULCANIZED RUBBER FILLER

1. Scope

This investigation concerned the introduction of ground vulcanized automobile tire rubber into the open-graded asphaltic concrete finish course mixture. The rubber had been ground to an approximate maximum size equivalent to a number 40 U. S. Standard Sieve.

2. Testing

Once again, a mixing test similar to the one utilized in Phase II was employed for this investigation. However, the ground rubber was added to the dry aggregate as a percentage of the dry aggregate. Also, attempts were made to develop a mixture with the emulsified polymer-emulsified asphalt blend as a binder.

The results of the mixing tests are illustrated in Table SI-B1.

Emulsion Content	Moisture Content of AGG	Emulsified Polymer Content	Rubber Content	Emulsion Temperature	Mix Properties
7.0%	0%	----	----	130°F. (54.4°C.)	Mix Spread on Slab as Control Specimen
7.0%	0%	----	1.0%	130°F. (54.4°C.)	Mix Coated Well Could be rolled within 15 min.
7.0%	0%	----	2.0%	130°F. (54.4°C.)	Mix Well Coated But Set Rapidly
7.0%	0%	5.0%	1.0%	130°F. (54.4°C.)	Aggregate would Not Coat - Mix was Gummy
9.0%	0%	5.0%	1.0%	130°F. (54.4°C.)	Aggregate Coating better but mixture balling up.

Table SI-B1

3. Conclusion

Based upon the mixing tests, the optimum amount of ground vulcanized rubber is 1.0 percent, as a percentage of the dry aggregate weight. Furthermore, it is believed that the rubber may be introduced into the pugmill through a separate bin, in advance of adding the emulsified asphalt to the aggregate.

It should be noted, that the mixture containing 1.0 percent ground rubber exhibited satisfactory properties in regard to drainage and tenacity. However, due to the rapid setting time, this mixture would only lend itself to a traveling plant type operation.