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ASPHALT EMULSION TREATED AGGREGATES

Part I Laboratory Evaluation

Prepared by:

Dr. R.A. Jimenez, C.E. Dept.
Arizona Transportation & Traffic Institute
College of Engineering
The University of Arizona
Tucson, Arizona 85721

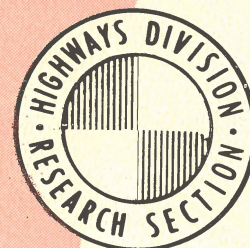
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Final Report - Phase I

ASPHALT EMULSION TREATED AGGREGATES

by

R. A. Jimenez

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Arizona Transportation and Traffic Institute
College of Engineering
The University of Arizona
Tucson, Arizona 85721

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IMPLEMENTATION STATEMENT

The objectives of the study were to review and evaluate procedures for the design of asphalt emulsion paving mixtures. The design procedure recommended in the report is considered to be viable and compatible with ADOT's equipment and procedures; thus it is planned to use the method concurrently with the present method for specially selected areas.

The need for information on the density and strength of emulsion treated bases is evident. In continuation of the development of the emulsion mixture design procedure, old construction and future ones will be sampled to fulfill this need. In this regard, special consideration will be given to detect and determine damage to these bases through the action of water and how this damage may be related to that caused by the laboratory soaking procedure.

B.W.O.

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Final Report - Phase I
ASPHALT EMULSION TREATED AGGREGATES

SYNOPSIS

This report is concerned with the development of a testing procedure for the laboratory evaluations of granular soils mixed with asphalt emulsions for use in pavements. The specific topics investigated or discussed for use in Arizona are aspects of mixing, compaction, and strength of testing of the asphalt-emulsion mixtures. Data are presented to show the effects of mixing water, emulsion content, and soaking of specimens on the density, R-value, stability, and cohesiometer value of aggregates compacted with the Triaxial Institute kneading compactor. The principal benefit or improvement from the use of the emulsion is shown to be on the cohesiometer value for mixtures prepared and tested at ambient temperature. Additional comparisons are made with specimens prepared and tested at other temperatures with the emulsion and also with the base asphalt cement of the emulsion. A procedure for the laboratory evaluation of emulsion-aggregate mixtures is presented.

INTRODUCTION

Arizona, as well as many other states, has been aware that the use of asphalt emulsions mixed with stone and sandy aggregates for road construction will increase significantly in the near future. The increased usage of asphalt emulsion mixtures would most likely be brought about because of limitations or restrictions placed on (a) the use of solvents for making cut-back asphalts, (b) the use of oil or gas required for the heating of aggregates in hot-mix plants, (c) the control of dust pollution in hot-mix plant operations, and also (d) the recognition that asphalt emulsion mixtures for road bases are more efficient than unbound aggregate bases.

Some of the problems that will arise with the anticipated increase in usage of emulsion treated aggregates are related to laboratory characterization of these mixtures and to the establishment of criteria for defining a suitable material. A specific mixture design procedure has been proposed by Chevron Asphalt Company since 1967 [1] and more recently in 1974 by the Asphalt Institute [2]; the two procedures are quite similar. If other design procedures existed prior to 1970, these were not found in the literature survey made for this study.

The primary question that may be posed in considering a design procedure for mixtures of emulsion and sand are concerned with three factors; (a) mixing procedure, (b) compaction method, and (c) test

method. The answer to these questions form the basis of the objectives of investigations executed in this work.

Prior to discussing the review of the related literature on emulsions and soil stabilization with asphalt emulsion we wish to emphasize that this recent work was concerned solely with sandy soils, that is, soils with less than 15 percent passing the #200 sieve and sand equivalent values greater than 25.

Emulsions

Asphalt emulsions are a mixture of asphalt droplets of very small size dispersed in water. The base asphalt is of penetration grade (high viscosity) and the micron-size asphalt droplets are kept in suspension with an emulsifying agent. Usages of asphalt emulsions in the early 1900's are reported by Traxler [3], Day and Herbert [4] and in Reference 5. At the present two types of emulsions are used principally in highway construction; these are called anionics and cationics.

Anionic Emulsions

This type of emulsion receives its name from the fact that the surface of an asphalt particle has a negative charge. The surface charge comes from the emulsifying agent which the jargon calls "soap". According to Traxler [3] extensive use has been made of sodium and potassium soaps and also soaps of high molecular weight organic acids. These emulsions are made to be alkaline in nature; a study of Arizona emulsions [6] showed the pH value to range from 7.6 to 11.3.

The binding effects of the high viscosity asphalt are obtained when the water phase of the emulsion is evaporated and the asphalt

droplets coalesce into a continuous film. It is apparent that until the asphalt droplets are exposed to air (dried), there will be no adhesion between the asphalt and a stone surface and so the emulsion can be washed away from its application site or surface.

Cationic Emulsions

According to Mertens and Wright [7] cationic emulsions were first used successfully for road construction in the United States during 1958. In this system the surface of the asphalt droplet carries a positive charge as opposed to the negative charge for anionic ones; additionally, the water phase of the cationic emulsion is acidic. For several Arizona cationic emulsions, Reference 6 showed pH values ranging from 3.2 to 5.3. The emulsifying agents are acid salts or organic amines or organic quarternary ammonium compounds [8].

According to the early literature, the cationic emulsions were to be preferred for use with silicious aggregates of negative surface charge since the difference in electrical charge would immediately attract the asphalt droplet to the stone's surface. The following is taken from a 1970 paper by Dybalski [9];

"The deposition of a cationic emulsion onto a surface is primarily an electrochemical phenomenon which, due to the inherent affinity or substantivity of the cationic agent, begins to take place at the moment of contact. Surface and atmospheric conditions have little effect, if any, on the adherent properties of the cationically treated asphalt, and the presence of moisture on a surface is no deterrent to adhesion".

Dybalski in Reference 10 presents an excellent and brief discussion on the composition of emulsion. In this reference he states that all aggregates including limestone have negative surface charge.

The foregoing paragraphs have given the general and basic definitions of the two main types of emulsions used for highway construction. Specific requirements for the various grades of these emulsions are given by ASTM and AASHTO.

Aggregates

Most of the reports originating in the 1930's and 1940's concerning soil-emulsion stabilization dealt with soils having the plasticity index (P.I.) ranging up to 40 and up to 30 percent of the particles being smaller than the #200 mesh sieve. More recently in the investigations of emulsion-aggregate mixtures the aggregate has been a granular material with less than 15 percent passing the #200 sieve and P.I. generally less than 6. A review of literature on emulsion-soil mixtures follows in the next section.

ASPHALT EMULSION-SOIL MIXTURES

The initial portions of this section are related to bituminous stabilization of fine grained soil rather than to the use of asphalt emulsion. The review of this early work is for the purpose of laying a foundation for an understanding of the work reported later.

In 1936 Rhodes and Havens [11] reported on field and laboratory studies of soil stabilization with coal tar. The laboratory studies showed a need and methods for establishing (a) the amount of moisture needed for mixing and also compaction, (b) the optimum amount of tar from the Hubbard-Field stability test, and (c) absorption of water by test specimens. The complete evaluation indicated that:

1. Sandy soils needed no waterproofing, but a high viscosity tar binder was required for stability,
2. Clayey soils needed no tar for stability as long as the water content remained below the plastic limit (P.L.), but a low viscosity tar was needed to waterproof the soil and keep it below the P.L. and,
3. A soil high in silt but low in clay needed tar for both stability and waterproofing.

Also in 1936 Reagel and Schappler [12] reported on the stabilization of soils with asphalts; however, in this case the work was related to gravel roads and the use of cutbacks and road oils.

The presentation discussed principally the forces existing in soil-water-oil systems and the relative wettability of soil particles by water or oil. It was suggested that preferential wetting behavior based on surface tension concept was not justified. The authors cited a wettability experiment on molecule orientation.

"This behavior, that of orientation is best illustrated by the following. A drop of molten fatty acid is put on a water surface. After solidification and removal from the water, this drop is easily wetted by water, only on the surface first in contact with the water, whereas the portion which originally solidified in air is easily wetted by oil. Apparently, while in the liquid state, the fatty acid molecules have arranged themselves so as to bring their hydrophilic heads into contact with the water and moved the more inert organic portion toward the air.

"Obviously, determination of surface tension of highly viscous or solid fatty acid systems toward water or oil will vary according to time allowed for orientation of the molecules. The same must be true of highly viscous asphaltic materials".

It is important to note that the above quotation is quite relevant to any discussion comparing the relative performance between anionic and cationic emulsion mixtures following the time required for "orientation of the molecules".

Muir, Hughes, and Browning [13] review the 1938 practice of design, construction and proportioning of bituminous stabilization for subgrades. Emphasis is placed on the differences in practice and results obtained by different states. The authors summarize the principles obtained from a questionnaire which showed objectives of waterproofing, improving stability, the need of premixing water (=P.L.) and compaction water (=optimum by Proctor), thorough mixing, and the need for good drainage of the subgrade.

Two of the 1940 papers reviewed were by McKesson [14] on soil-emulsion mixtures and by Winterkorn and Eckert [15] on the physico-

chemical factors important to bituminous (tars and SCs) soil stabilization. McKesson presents an interesting experiment with wet beach sand to establish the optimum film thickness of water for maximum stability. Then this same thickness of film was used to obtain the proper quantity of residual asphalt from the emulsion.

Benson and Becker [16] give an excellent discussion on the mechanisms affecting the stabilization of plastic soils with cutbacks. Benson et al define two ways by which soils are stabilized with bitumens. These are now known as the "intimate mixture" and the "plug mixture" theories. In the intimate mixture each particle is coated with bitumen and stabilization is obtained by the cohesive action of the binder. Sands and non-cohesive soils respond favorably to this theory. In the plug mixture small clods of soil at optimum moisture content are waterproofed with a cover of bitumen and capillaries are plugged to preserve the soil strength due to surface tension of the initial moisture. Clayey, cohesive soils are properly stabilized through this theory since their surface areas are too large to accommodate the intimate mixture theory.

Benson and Becker [16] recognized the need for a specific amount of premixing water and established this quantity to be that required to make the soil "fluff"; however, the fluff point is applicable only to heavy soils. Mixer effects were noted by these men and was considered in the work to be reported here.

One of the best reports on bitumen-soil is entitled, "Fundamental Research in Bituminous Soil Stabilization" by Endersby [17]. This paper discussed and amplified on the earlier work of Benson [16] and other researchers. Since most of the topics presented by Endersby have

already been presented only two new and pertinent ones will be reviewed. The first topic is concerned with the soaking of specimens for durability measurements. Endersby points out that the rate of soaking and duration of soaking have a great influence on response to loading. The longer the time taken to saturate, the less damage is done and the longer the duration of saturation the greater the amount of stripping (debonding) of the asphalt. It was stated that the curing and soaking procedure in the laboratory evaluation must be related to the environment of usage.

The second aspect to be shown is related to the use of additives for promoting asphalt adhesion to the aggregate surface. We believe this phase to be extremely important because of the analogy that can be made between the characteristics of mixtures made with anionic and cationic emulsions. The sketch of Figure 1 is taken from Endersby in which are shown two particles of soil coated with emulsion; one mixture is plain and the other is treated to improve adhesion.

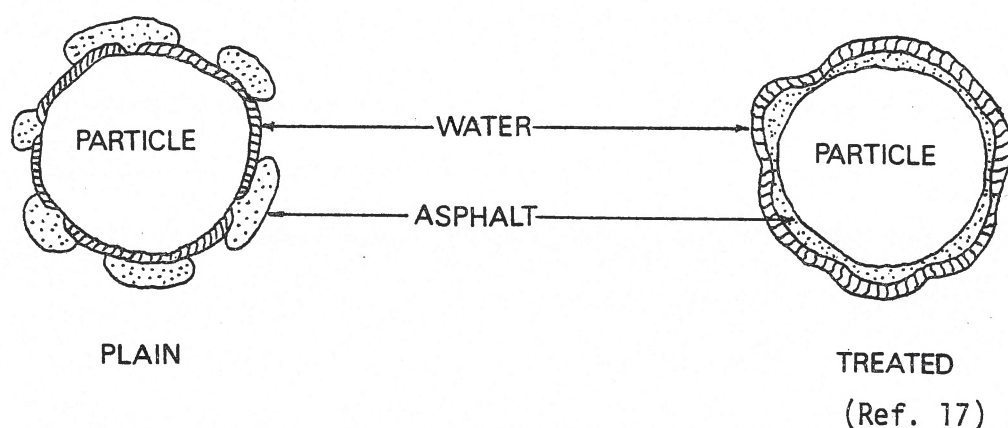


FIGURE 1 Distribution of Components in Plain and Additive-Treated Asphalt Emulsion-Soil Particles

Examination of the two particles should indicate the following:

1. The treated soil offers more resistance in mixing since the higher viscosity fluid is in direct contact with the particle.
2. The asphalt is absorbed into the particle more quickly for the treated mixture.
3. The treated mixture will cure more rapidly because the asphalt is under the water films instead of over them.

In 1946 when road construction resumed after the war years, the Highway Research Board published a paper on soil-bitumen roads [18]. A specific design procedure using sand and asphalt emulsions and evaluated with the Florida Bearing Test was presented. It was recommended that the mixture should have a modified Florida Bearing Value of 150 pounds per square inch (1034 kPa) when mixed with a quantity of emulsion equal to that calculated from the equation

$$P = \frac{0.43(0.05A + 0.10B + 0.50C)}{R}$$

where A = percentage of sand retained on the No. 10 sieve
 B = percentage between the No. 10 and No. 200 sieves
 C = percentage passing the No. 200 sieve
 R = percentage of asphalt in the emulsion
 P = percentage of emulsion based on the weight of sand.

The amount of premixing water was equal to P/2. The design equation is recognized to be based on the surface area concept developed in the western states.

Dunning and Turner [19] described a procedure for evaluating asphalt emulsion mixtures for road base materials. The procedure utilized the Triaxial Institute kneading compactor at 250 pounds per square inch (1724 kPa) pressure and the stabilometer to define strength. The authors found that the highest R values were not found at a liquid content at which maximum density occurred but at a value of one to three percentage points less than optimum moisture.

It was suggested that a simple 2^2 factorial of mixing water and emulsion was sufficient to establish the combination yielding the highest R value.

In order to assess the effect of water on stabilized specimens the authors developed a vacuum soaking procedure which reduced the soaking period required by other procedures.

In 1968 Terrel and Monismith [20] reported on a study performed to determine the effects of curing, loading conditions, and temperature on the response of a base course material treated with various types of asphalt. Specimens were made with a penetration grade asphalt, a cutback and an emulsion and tested under repeated load triaxial compression. Of particular significance, findings for the emulsion treated specimens showed that:

1. Resilient modulus increased with increasing age after compaction and then the value stabilized.
2. At older age the resilient modulus was quite independent of the confining pressure.

The implications of the above are that for pavement design the engineer

should recognize a low modulus at early age and a high modulus (as high as obtained for asphalt treatment) after the mixture has cured to a stable condition.

The 1973 paper of Dunn and Salem [21] showed results of triaxial tests performed on a fine sand (100 percent finer than 1.5 mm) stabilized with cationic emulsion. The specimens were formed with vibratory compaction with variable mixing and curing temperatures. The shear strength components of friction (ϕ) and cohesion (C) were increased with increases in both mixing and curing temperatures up to an optimum value at 45°C for mixing and at 60°C for curing and then both ϕ and C decreased with further increases in temperature. It was suggested that hot mixing be used for a surface course where a high value of C is needed.

Most of the prior citations have indicated that the strength test was one not used presently for routine testing of asphaltic mixtures. The next two references report on results obtained with the Hveem stabilometer or Marshall procedure for asphalt emulsion mixtures.

Yazdani [22] investigated three aggregate blends mixed with asphalt emulsions, SS-1h and CSS-1h, for Hveem strengths. Of particular interests are the results obtained with a sand and SS-1h mixture. Specimens were mixed cold and then aerated in a 140°F (60°C) forced draft oven to a prescribed fluid, water plus asphalt, content. Compaction was with the T.I. device using the standard 150 tamps at 500 psi (3,447 kPa) at ambient temperature. Following compaction, the specimens were left in the mold for three days at 77°F (25°C) and then measured for density and moisture content. Hveem stability and cohesiometer values were obtained at three different temperatures.

The curves of Figure 2 are for a sandy material and show the difference in density between using water only and water plus emulsion; all materials were compacted under T.I. procedures. It is noted that the density of the emulsion mixtures is less than for the water only mixture and optimum occurs at a higher fluid content. If the fluid content is reduced of the asphalt portion then the optimum moisture content for the emulsion samples varies from 0.8 to 1.9 percent less than the optimum for the water only mixture. It was noted by Yazdani that the specimens could not be compacted by T.I. procedure at a fluid content about 10 percent.

In Figure 3, strength values for the mixtures of Figure 2 are compared on the basis of compaction fluid content. The actual moisture contents at the time of testing were less than 2.5 percent. The graphs for stability show that an optimum compaction fluid content of 8 percent existed regardless of emulsion (or residual asphalt) content; increasing the mixing water resulted in a decrease in stability. Reducing the optimum compaction fluid content by the asphalt content results in moisture contents varying from 4.0 to 5.1 percent; which are from 2.6 to 3.7 percentage points less than the 7.7 percent moisture content for optimum density. It is also noted that the higher stabilities are associated with the lower emulsion contents.

The cohesiometer data for Figure 3 show that the tensile strength increased with increased compaction fluid and also emulsion content, but the values are too limited to indicate an optimum value.

The 1976 AAPT paper by Darter et al [23] was concerned with the testing of a 3/4-inch (12.8 mm) dense graded aggregate mixed with a soft base (340+ penetration) asphalt emulsion. The materials were

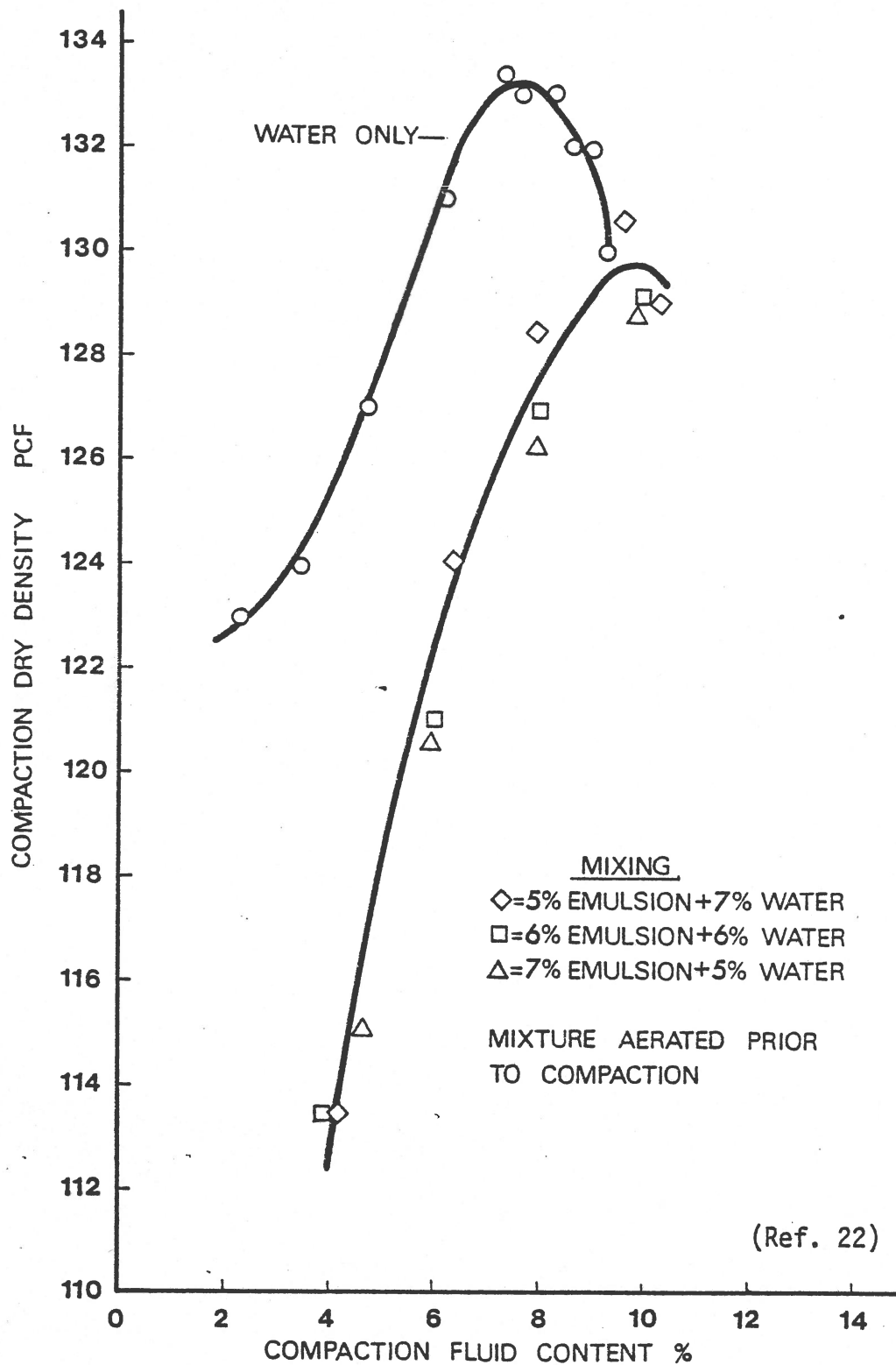


FIGURE 2 Effects of Compaction Fluid Contents on Density of Various Asphalt Emulsion-Sand Mixtures Under T.I. Compaction

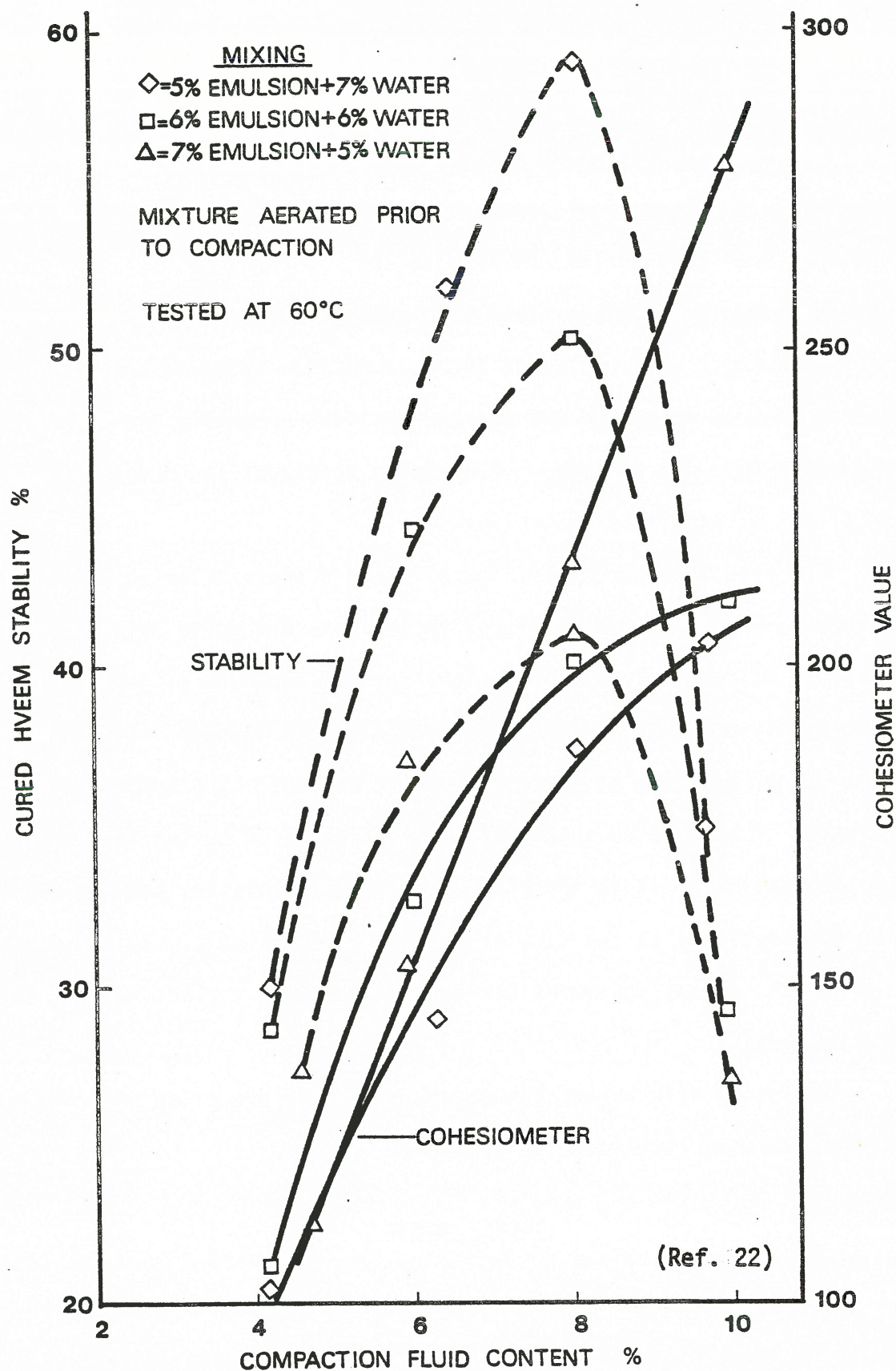


FIGURE 3 Effects of Compaction Fluid Content on Hveem Strengths of Various Asphalt Emulsion-Sand Mixtures Under T.I. Compaction

mixed at ambient temperature and then aerated at 77°F (25°C) to a predetermined moisture content and then compacted using the Marshall procedure using either 50 or 75 blows per face. Marshall stability and diametral resilient modulus were obtained at 77°F (25°C) for specimens that had been cured dried and also soaked.

The curves of Figure 4 show the effects of residual asphalt content on the strength and modulus of both soaked and dry specimens. It is interesting to note that the soaked specimens generally had higher strengths than the dry ones. The soaked specimens had been subjected to 5 days of capillary absorption.

The stability curves of Figures 5 and 6 are similar to those of Figure 4; however, the effects of curing time are quite noticeable in that at low residual asphalt content the dry strength is increased appreciably over the curing periods of 1, 3 and 14 days. This improvement is not achieved at the high asphalt content. The improvement in strength of the soaked specimens with increases in curing time is not as well defined. It is important to note that moisture content for the dry specimens at the time of testing varied from 0.2 to 2.2 percent and for the soaked specimens the moisture content varied from 2.5 to 3.7 percent.

These specific values for moisture content are cited here for comparison with results to be presented later.

Survey Summary

In summary of the literature review the most salient points in regards to asphalt emulsion stabilization or treatment of soils are listed

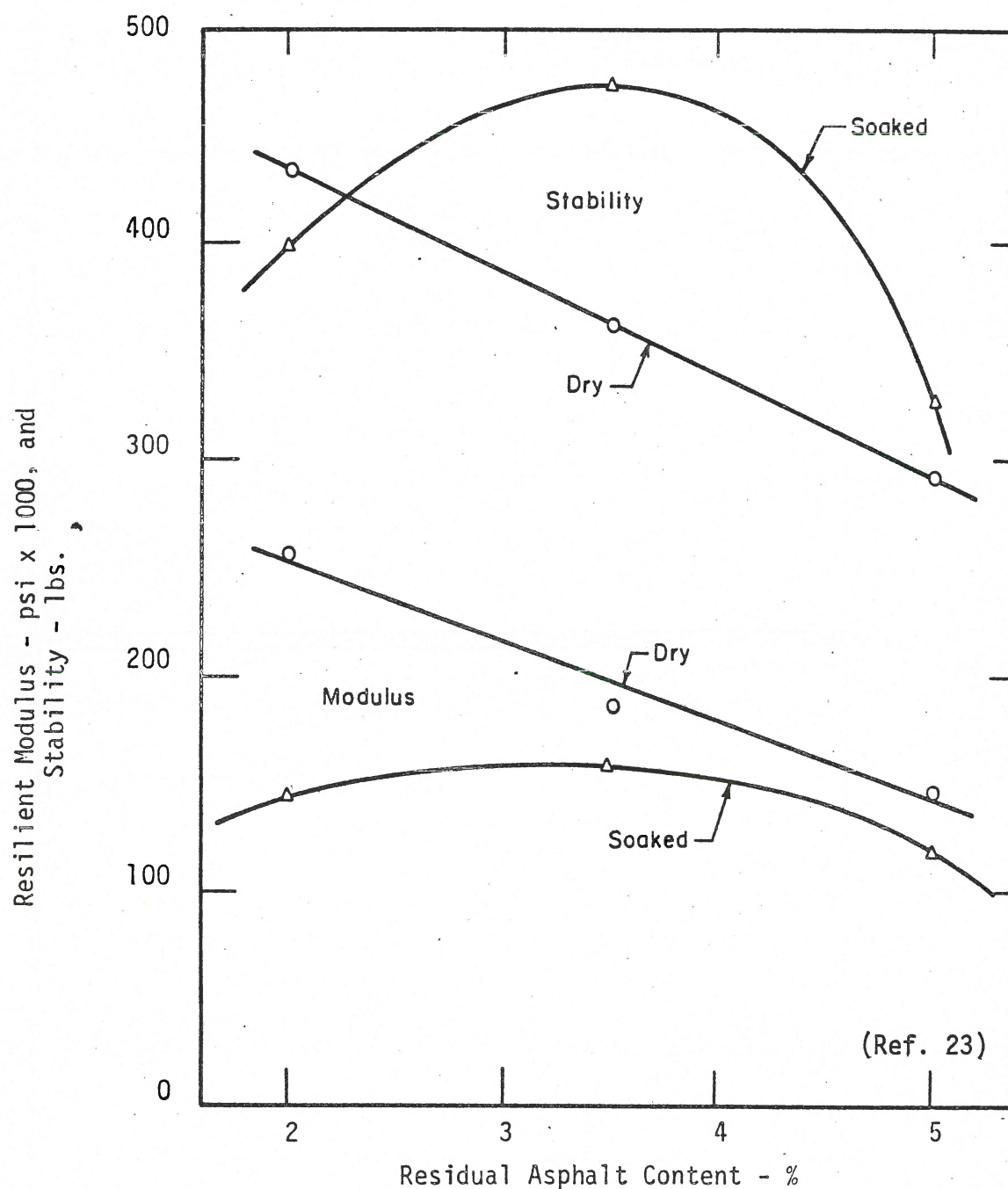


FIGURE 4 Relationship Between Resilient Modulus and Stability and Residual Asphalt Content for Both Dry and Soaked EAM Specimens

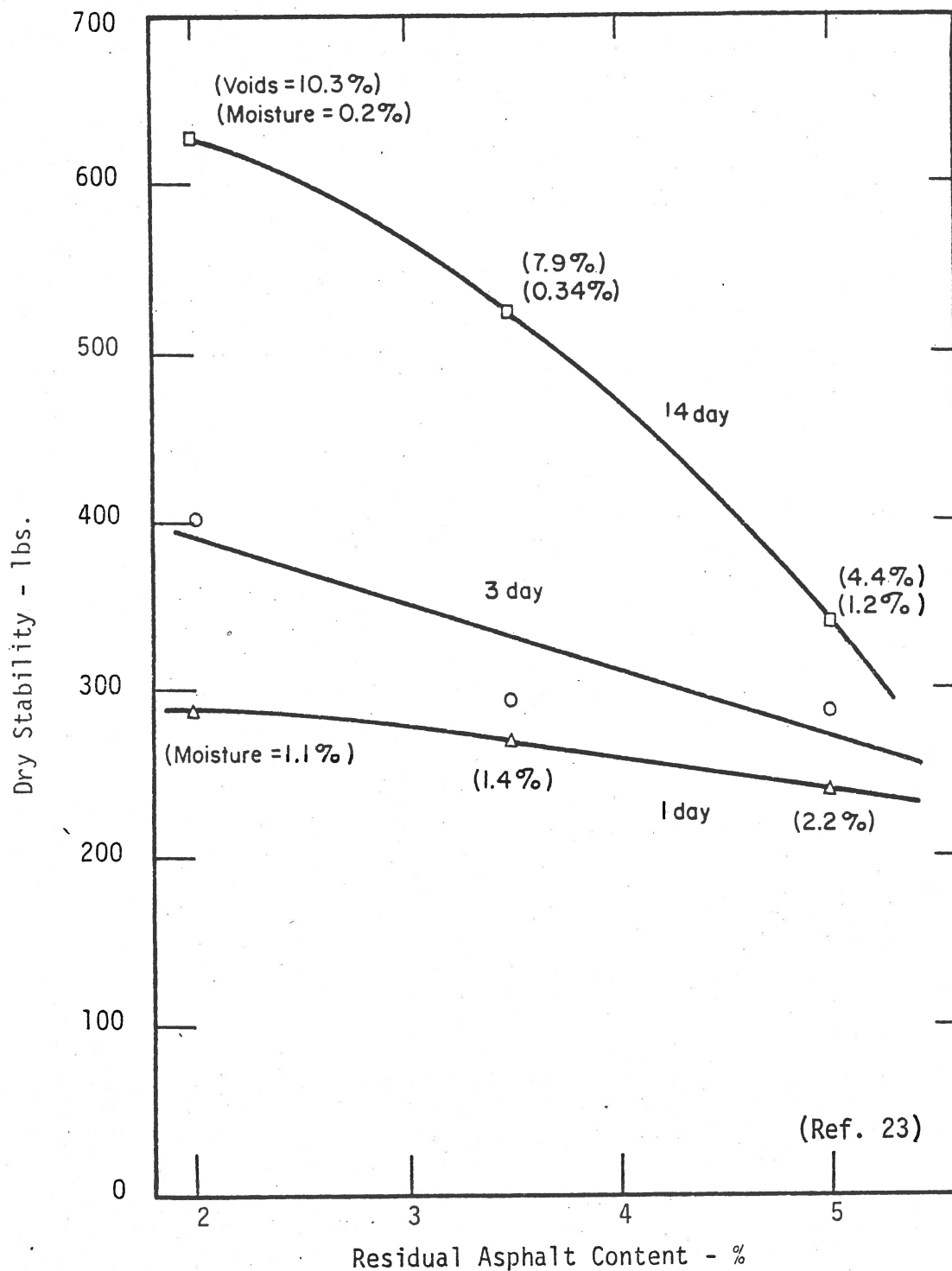


FIGURE 5 Effect of Residual Asphalt Content on Dry Stability of EAM Specimens at 1, 3, and 14 Days Curing (Moisture Content at Testing and Total Voids Shown in Parentheses)

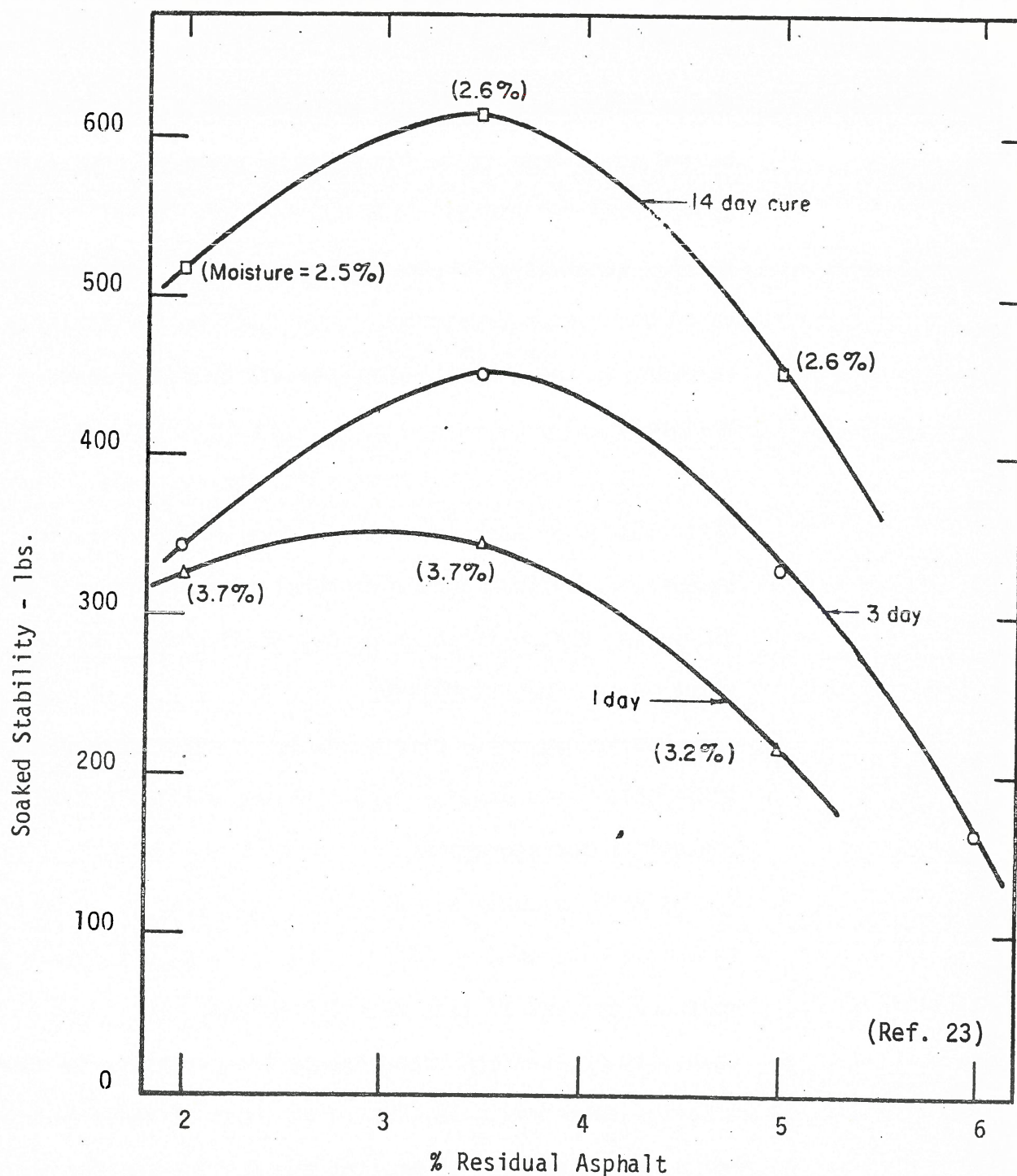


FIGURE 6 Effect of Residual Asphalt Content on Dry Stability of EAM Specimens at 1, 3, and 14 Days Curing (Moisture Content at Testing Shown in Parentheses)

below; however, the emphasis will be placed on the treatment for sandy soils:

1. The mechanism of stabilization is quite different for cohesive soils than it is for sandy or granular ones. As a consequence for highway base courses, the use of "fluff point", aeration prior to compaction, and relationships based on Proctor Compaction, should not be particularly relevant to the evaluation of asphalt emulsion-sand mixtures.
2. Premixing moisture is necessary for the even and efficient distribution of asphalt emulsion in a mixing operation; however, an optimum amount of total moisture content at compaction exists for maximum dry density and a different value for maximum stability.
3. Laboratory compactive effort should be consistent with achievable field density, and with the available void content of the aggregate.
4. It has been commonly accepted that specimens be cured in the compaction mold at 77°F (25°C) for 3 days to yield a moisture content of less than 2.5 percent.
5. Stability or strength measurements are necessary to characterize these mixtures. Up to now most of these measurements have been made at ambient temperature and suitable for high rates of production.

6. It is recognized that there is a need to determine the effects of water on the strength of these mixtures but there is no agreement on the rate and duration of saturation to be used.
7. There is a need to set minimum design requirements for these mixtures and also to characterize them in terms applicable for pavement design.

WORK PROGRAM

The objectives of this study were to establish an emulsion-aggregate mixture design procedure for usage in the State of Arizona. The procedure was to be developed through a survey of the literature and laboratory measurements with consideration of the available laboratory equipment. The laboratory work was to delve into three phases of mixture preparation, specimen compaction, and specimen testing. The following sections go into detail of specific materials, procedures, and equipment used in this phase of the study.

Materials

The initial proposal for the study listed three graded aggregates and one type of emulsion of the SS-1 grade. The thought on the selection of aggregates was to use material generally available from dry washes and creeks which are quite numerous in the southern part of the state. As will be noted, more than three aggregates were used in certain parts of the study.

The selection of only one grade of emulsion was based on the thought that the long-term performance of an asphalt emulsion-aggregate mixture would be principally affected by the characteristics of the residual asphalt. Additionally, in order to minimize changes in the emulsion due to storage, a limited amount of the SS-1 was made periodically and at our request by the Materials Section of the Highway Division of ADOT.

Emulsion

The choice of the SS-1 emulsion was based on its use in mixing operation as opposed to spraying and also to having a medium high viscosity base asphalt. Table 1A in Appendix A shows that the viscosity of the emulsion was relatively low (SSF of 21) and that the aging index of the base asphalt was relatively high with reference to ADOT's specifications [24]. Except, where noted, the emulsion was always at ambient temperature when it was poured into the mixing bowl.

Aggregate

Table 2A in the Appendix A lists the general physical characteristics of the aggregates used in the study. As mentioned earlier, all of the aggregates were not evaluated completely by all tests. The river sand was really a terrace sand since there are no rivers in southern Arizona. The 3/8-inch blend was made up from a combination of the river sand and 3/8-inch chip seal aggregate.

Figure 7 is the graphical presentation of the particle distribution for the main aggregates tested.

Mixing Procedure

The mixing procedure used was essentially that described by the Asphalt Institute in Reference 2; however, slight modifications were made.

Estimate of Premixing Water

The purpose of wetting the soil prior to mixing with emulsion is to prevent balling-up of fine grained mixtures and to promote uniform

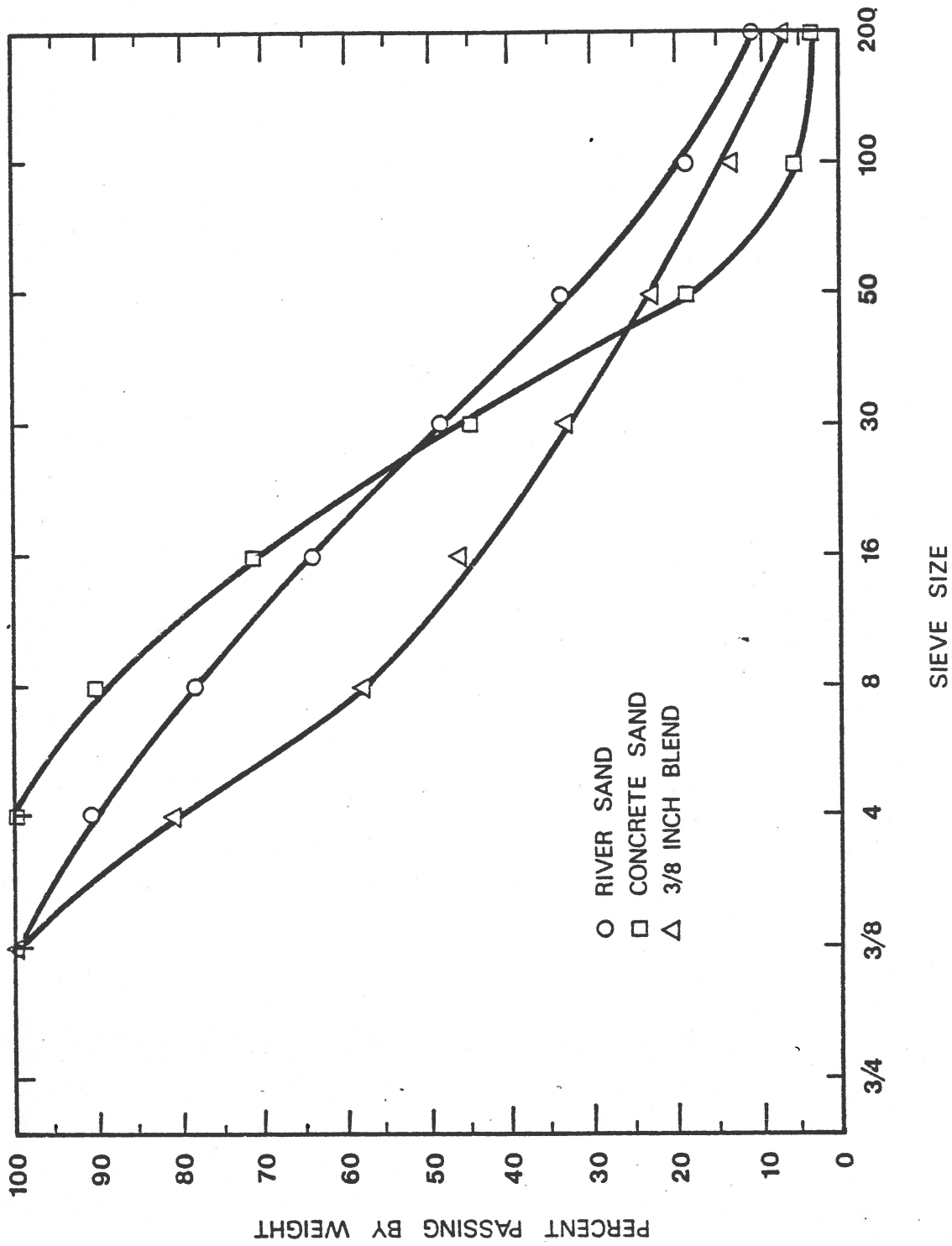


FIGURE 7 Gradation of the Three Principal Aggregates Tested

coating of the aggregate. It would seem that the minimum amount of premixing water to give a uniformly coated emulsion mixture would be desirable in order to minimize the drying time. Initial experimentation in the use of premixing water and the subsequent mixing with emulsion indicated that the primary functions of the premixing water are to keep the emulsion from coming in contact with the dry aggregate and to fill the surface voids of the aggregate and thus serve as a lubricant in facilitating the spreading of the emulsion over the aggregate surface. It was found that the amount of water that caused just darkening of the color of the aggregate was sufficient to satisfy its functions. The amount of water to cause darkening was a function of mixer speed and the amount of the aggregate charge. The procedure for determining the amount of water for darkening was set in the following manner. The mixer was a Hobart C-10 model and the speed setting of 2 gave a maximum tangential speed of 8.39 feet per second (2.56 m/s) for the wire whip (type D) undergoing planetary rotation. The amount of air-dry aggregate to be used was set at 1000 grams. Water was added to the aggregate while it was being agitated and the soil was first checked for darkening as soon as the dust was settled. In all cases agitation was resumed and water was added until the prescribed condition was met. The water was added to the soil through a plastic squeeze bottle and the amount used was found by weight difference. The photograph of Figure 8 shows the mixer, 10-quart bowl, and wire whip used to mix the aggregate with water or emulsion; also shown are a water bottle and a beaker of emulsion.



FIGURE 8 Photograph of the Hobart Mixing Equipment
Used for Blend Soil, Water, and Emulsion

Mixing Asphalt Emulsion and Soil

Air dried aggregate was weighed and placed in the 10-quart ($9.46 \times 10^{-3} \text{ m}^3$) Hobart mixing bowl. The amount of aggregate was such to have enough mixture to make 3 standard sized specimens and have at least 100 grams left over for moisture content determination. The specimen was of 4 inches (101.6 mm) in diameter and intended to be 2-1/2 inches (63.5 mm) high.

The mixer, wire whip beater, and speed were the same for mixing the emulsion as used for determining the "darkening" water. While the dry aggregate was being agitated the predetermined amount of premixing water was introduced through the use of the plastic squeeze bottle. Then while the aggregate was still being mixed, the cold emulsion was poured into the mixing bowl from a graduated beaker until the proper amount was introduced as determined from weight differences. The mixing was continued until a uniformly colored mass was obtained; this period of mixing rarely exceeded two minutes.

The above procedure was termed ambient or cold mixing. For the 140°F (60°C) mixing, essentially the same procedure was used except that the aggregate, water, and emulsion were heated in an oven at 140°F (60°C) prior to mixing. The beaker of emulsion was sealed with aluminum foil to prevent evaporation of water during the heating period.

Mixing Asphalt Cement and Soil

The three principal aggregates were mixed with the base asphalt used for making the emulsion. The aggregate and asphalt were heated to 285°F (141°C), the proper amount of asphalt was added to the hot aggregate and then they were mixed in a manner similar to the one used for the emulsion blends.

Compaction Procedure

The majority of the specimens were compacted using the Triaxial Institute (T.I.) compactor and the procedure described by ADOT's test number ARIZ 803 [25], except for the temperature requirements. It may appear that the compaction energy from the T.I. compactor at 150 tamps of 500 psi (3,447 kPa) is unduly high for a mixture to be used as a base course in a road; also, it would appear that these laboratory densities would not be reached in the field. The compaction effort was used since it was the one recommended by the Chevron Asphalt Company [1] and the Asphalt Institute [2]. A limited number of density measurements made on cores from emulsion treated bases indicated values in excess of 130 pcf (2078 k/m^3)*.

Specimens evaluated by the Marshall method were compacted using 50 blows per face according to the Asphalt Institute's publication MISC-74-2 [2]; again exceptions were related to temperature requirements.

Specimen Conditioning

Standard Curing

After either T.I. or Marshall compaction the specimens were left in their mold and stored in a horizontal position so that both faces were open to the atmosphere. The storage or curing of the specimen was for a period varying from 67 to 72 hours at a temperature of $77 \pm 2^\circ\text{F}$ ($25 \pm 1^\circ\text{C}$). Longer periods of curing under the stated conditions would not reduce the moisture content appreciably nor consistently.

*More data on emulsion treated bases have been made available recently and these are presented in Table 5 of Appendix D to confirm the high values of field density.

At the end of the curing period the specimen was measured for height and weight in the mold. Density calculations were made from these measurements.

Specimen Soaking

In order to examine the effects of water on some properties of the compacted specimens, they were subjected to vacuum while submerged in water and then tested. Following the standard curing procedure, the specimens were left in the mold and then placed under a bell jar device. The device shown in the photograph of Figure 9 allowed for the introduction of water to cover the specimens and for the reduction of air pressure. The common procedure was to introduce sufficient water to cover the top of the specimens by at least one inch (25.4 mm) and then apply a vacuum of 4 inches (101.6 mm) of mercury which was held for one hour and then released. Further soaking at atmospheric pressure was continued for an additional hour. Modifications to the soaking procedure were related to the amount of vacuum (15 inches or 381.0 mm) and to the time period (15 + 15 minutes). All soaking was done at ambient temperature.

The reader is reminded that the soaking vacuum was not as high as used by Dunning [19], or the Asphalt Institute [2]. Chevron [1] had recommended the vapor moisture susceptibility (VMS) test of California for water absorption; it is a slow procedure which takes 75 hours. Noting Endersby's [17] comments on saturation, we believe we are using a compromise on rate and duration of saturation.

Strength Tests

The Hveem strength tests for R value, stability value, and cohesiometer value were performed according to procedures of ARIZ 803 [25].

The Marshall stability and flow values were obtained as described by the Asphalt Institute [2]. Exceptions to test temperatures were made for all the strength tests.

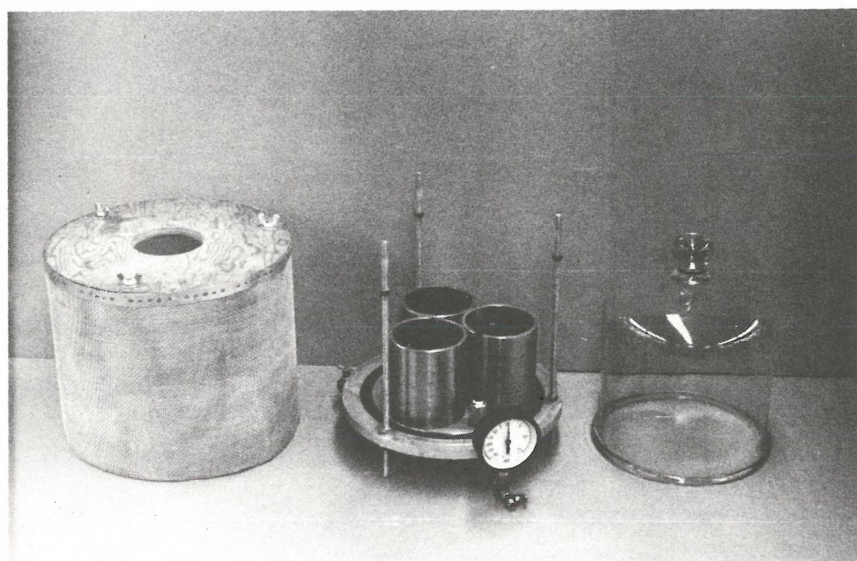


FIGURE 9 Apparatus for Soaking Specimens
Under Vacuum

RESULTS OF TESTING PROGRAM

Moisture-density relationships for soils are usually established using compaction procedures defined by ASTM or AASHTO. Since the emulsion-soil mixtures were compacted by ARIZ 803 procedure, it was deemed necessary to compact the soils with the same procedure for determining moisture-density relationship and also strength characteristics at optimum moisture.

Soil and Water Only

Compaction and Strength

The data obtained from compaction and strength tests for the soils are listed in Table 1B in Appendix B. The strength tests were performed in order to compare with results obtained for asphalt emulsion mixtures. The table shows only one test value beyond the optimum moisture; this was so because the soil could not withstand the 500 psi (3,447 kPa) pressure. Compaction at these higher moisture contents by a double plunger method at 40,000 pounds (177.9 kN) produced densities that were too high to fit extrapolation of the original moisture-density curve.

It should be pointed out that the strength measurements were made on soil specimens compacted at near optimum moisture; however, we would expect that strengths at optimum moisture content would not vary much from the values shown.

Darkening Moisture

Examination of the data in Table 2A Appendix A related specifically to darkening moisture content, surface area, CKE oil ratio, and the amount of -#200 sieve material, shows no reasonable relation between darkening moisture and the other properties of the aggregates. The data show that darkening moisture content increases as either surface area or the amount of -#200 sieve decreases; although these comparisons are fairly linear, they are not as expected at first hand. As implied earlier, we believe that the darkening moisture content is related principally to the surface texture of the aggregate. Visual and touch examinations of the materials showed the concrete sand to have the roughest surface texture followed by the Fica sand and the dune sand to have the smoothest surface. Of course, this evaluation was not a very scientific one but we believe it yielded the proper relative values in this case.

Soil and Asphalt Emulsion Mixtures - Cold Mixing

Prior to discussing test results for density and strength measurements, a particular finding of interest will be presented. The finding is related to the degree the emulsion broke during the T.I. compaction. The photograph of Figure 10 shows split specimens of dune sand and emulsion compacted cold and hot. The top two-toned specimen was compacted cold and shows the upper portion of the specimen, that portion receiving the tamping foot, to be darker and better coated with asphalt than the bottom portion. This behavior was noted in the other mixtures but to a lesser degree.

It would seem that the tamping pressures of the T.I. compactor are too severe since this visual degree of non-homogeneity was not observed for specimens compacted by the Marshall method nor by V.K. compaction.

The tables shown in Appendix B list all test values obtained. These values are the average of triplicate specimens. The various properties will be discussed separately.

Density of Emulsion Mixtures

The effects of compaction fluid content on dry density of three soils are obtained from Tables 2B, 3B, and 4B and are presented graphically in the next three figures. The fluid content includes both water and asphalt and is expressed as a percent of the weight of dry aggregate. The water content can be established since the asphalt residue content of the emulsion is known to be 62 percent by weight of emulsion.

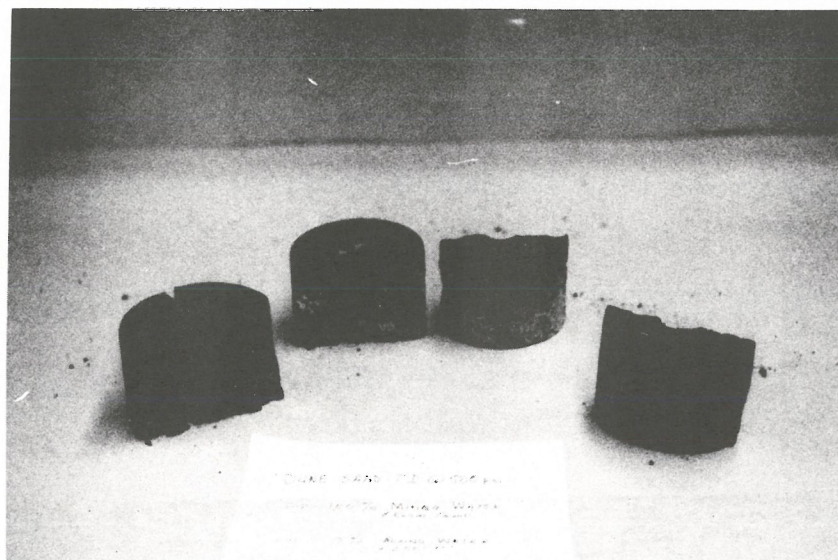


FIGURE 10 Dune Sand-Asphalt Emulsion Specimens
Showing Differences in Homogeneity.
The Top Specimen was Compacted Cold
and the Bottom One was Compacted
Hot with the T.I. Compactor

Mixing water and emulsion content are expressed as percent by weight of dry aggregate.

The test dry density is the weight of aggregate only and obtained from knowing the moisture content at the time of testing for strength and using the height of specimen while in the mold right after curing.

River Sand. The curves of Figure 11 show the comparison between the dry weight of the sand when compacted with water only and with various amounts of emulsion. The main differences between the two curves show that higher densities were achieved with water only and because of this higher fluid contents were possible for the emulsion mixtures. The data do not readily differentiate between the cured and soaked specimens. The reason for the difference in densities seems to be based on the difference in viscosity between the water and emulsion.

If the fluid content at maximum density is assumed to be 8 percent for the 4.9 percent emulsion mixture, then the optimum moisture content is about 5.0 percent which is less than the 6.0 percent indicated for the sand.

Although the points for the emulsion mixtures in Figure 11 do not clearly show a difference in dry density between the cured and soaked specimens, the data in Table 2B do show a consistent 2 pounds per cubic foot (320 kg/m^3) difference for the wet test densities.

Concrete Sand. The density data for the concrete sand are plotted in Figure 12 and show quite a different effect caused by the asphalt emulsion. The maximum density for the emulsion mixtures is as high as for the case when water only was used; however, the optimum water

RIVER SAND

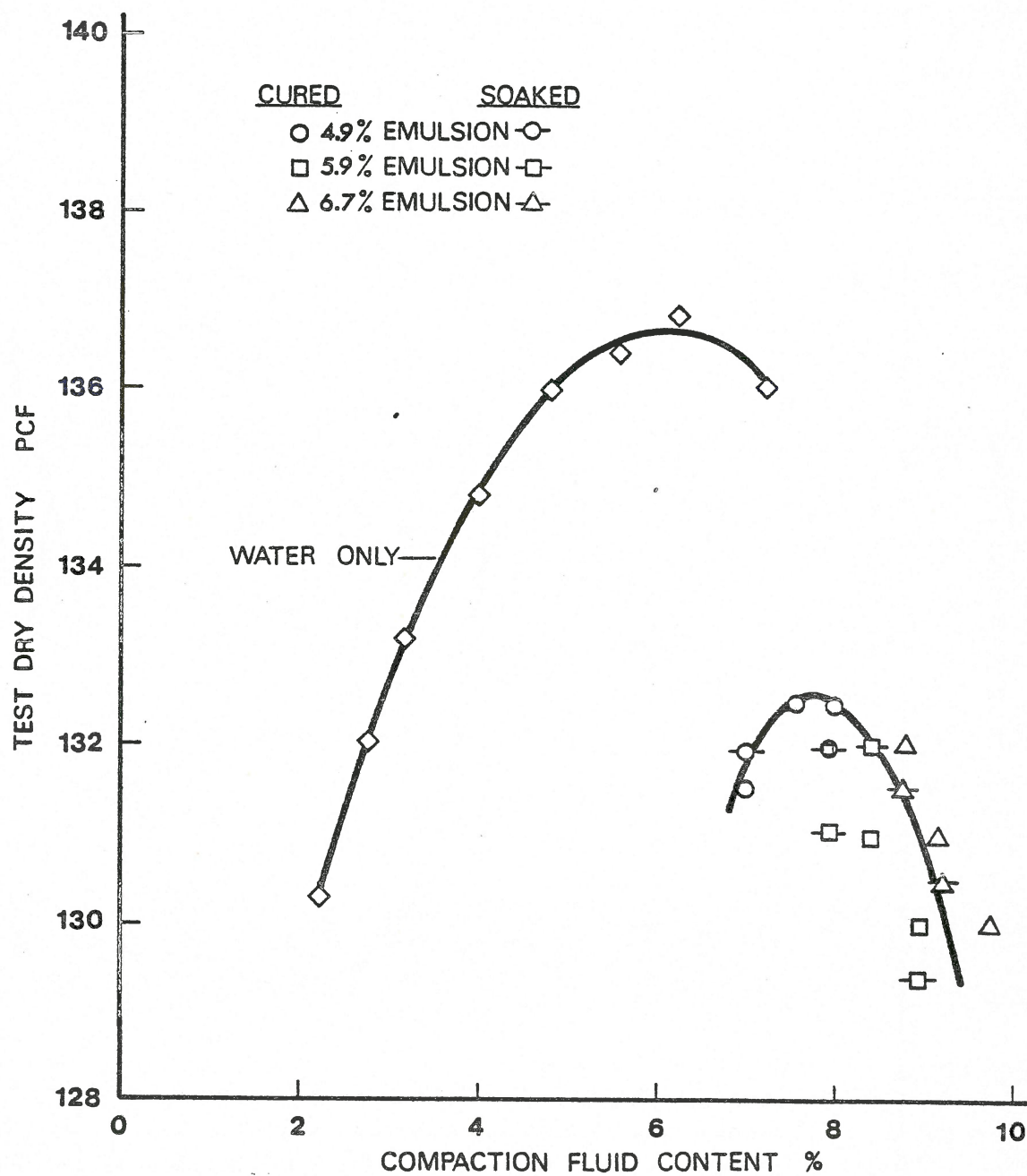


FIGURE 11

Effects of Compaction Fluid Content on the Dry Density of River Sand. Compaction by T.I., 150 Tamps at 500 psi.

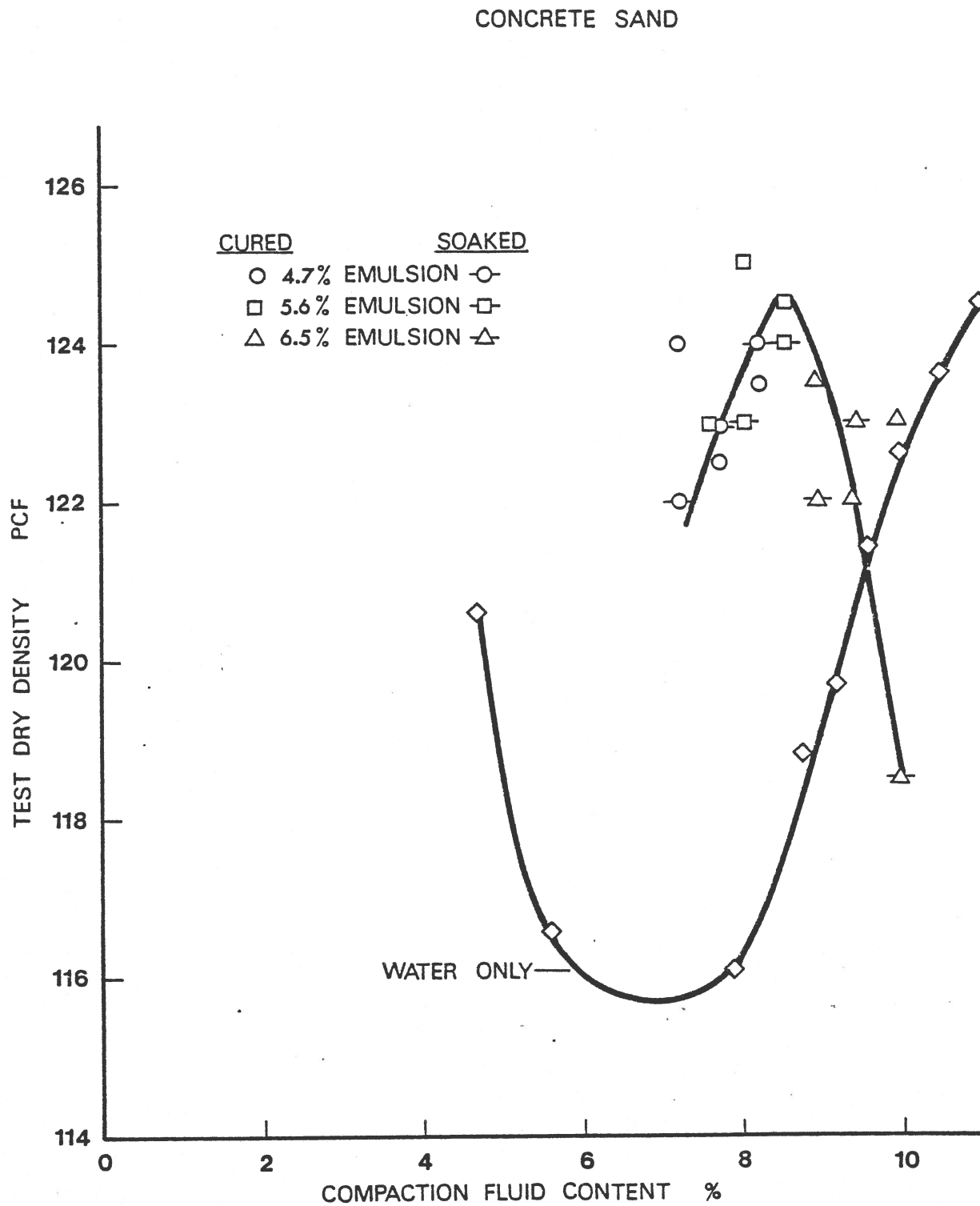


FIGURE 12

Effects of Compaction Fluid Content on the Dry Density of Concrete Sand. Compaction by T.I., 150 Tamps at 500 psi.

content for the emulsion mixture is calculated to be about 5.2 percent which is much less than the 10.5 percent found for the optimum moisture for the concrete sand.

The difference in density effects caused by the emulsion in comparison with the river sand is considered to be due to the greater amount of premixing water used in the concrete sand and also to the more open gradation of the concrete sand.

The density data shown in Table 3B of Appendix B show that the differences between the wet test densities for cured and soaked specimens were not of a consistent value but ranged from 0.5 to 4.0 pounds per cubic foot (0.8 to 64.0 kg/m³) when compacted by the T.I. procedure. Compaction by the Marshall method resulted in lower densities and as a consequence the differences between cured and soaked wet densities were larger and averaged about 5.0 pounds per cubic foot (80.0 kg/m³).

3/8-Inch Blend. The plot of Figure 13 and the data of Table 4B show that the effects of compaction fluid on the density of these blends were quite similar to those effects caused on the river sand. This is so since the 3/8-inch blend was made from a mixture of river sand and 3/8-inch chip seal aggregate.

The review of the literature indicated an abiding desire to establish the optimum moisture content for emulsion mixtures; also the review indicated that this amount was equal to that found for soil and water only mixtures. The data presented here show that optimum moisture for the emulsion mixtures was less, from 1 to 5 percentage points, than that for the soil and water only.

3/8 INCH BLEND

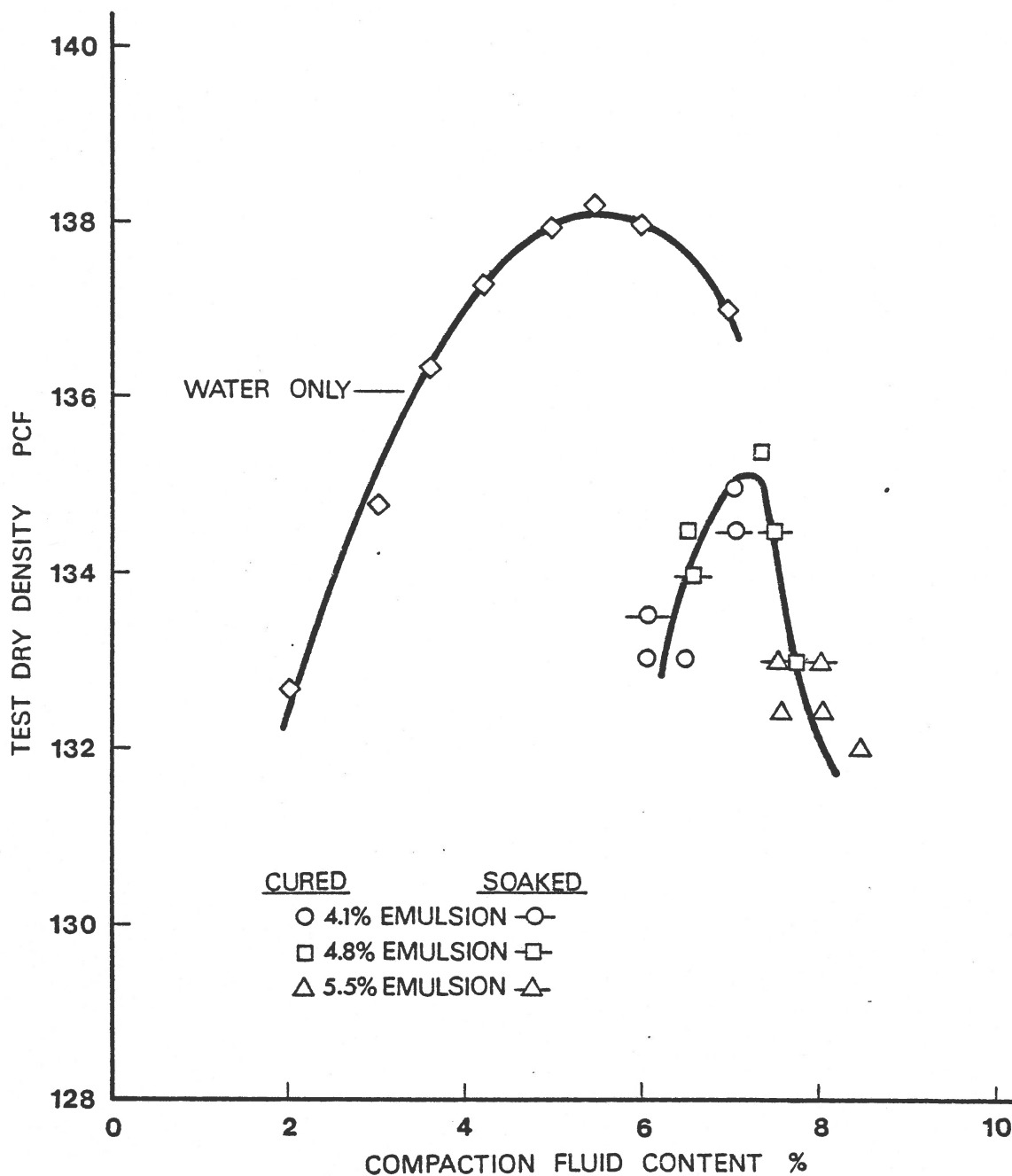


FIGURE 13 Effects of Compaction Fluid Content on the Dry Density of 3/8-Inch Blend. Compaction by T.I., 150 Tamps at 500 psi.

Strength of Emulsion Mixture

Strengths of the asphalt emulsion specimens were determined at ambient temperature and by the Hveem procedure for R and S values, cohesiometer value, and by the Marshall method. The Hveem strengths were obtained on the same specimen. The "final displacement" measurement used in obtaining the R-value was made after applying 5,000 pounds (22.2 kN) to the test specimens. This procedure was justified on the basis of the work reported by Jimenez and Gallaway [27]. Tables 2B, 3B and 4B in Appendix B show the strength values obtained for the three aggregates.

A close examination of the strength results will show the unpredictable effects of compaction fluid content on the Hveem values for strength. It is assumed that this variability is due to the contributing effects of both premixing water and emulsion contents on density.

The curves of Figures 14, 15 and 16 show the effects of compaction fluid content and residual asphalt content on the Hveem strengths for the river sand. Parts a of the figures demonstrate the variability associated with compaction fluid content. In parts b of the figures the corresponding three points of part a were averaged and plotted. The three figures, 14 to 16, show that R, S, and C values decreased with increased residual asphalt content. A review of the density curve shown in Figure 11 for the river sand will show that the majority of the test specimens were on the wet side of optimum compaction fluid content, which may account for the loss of strength with increased residual asphalt content.

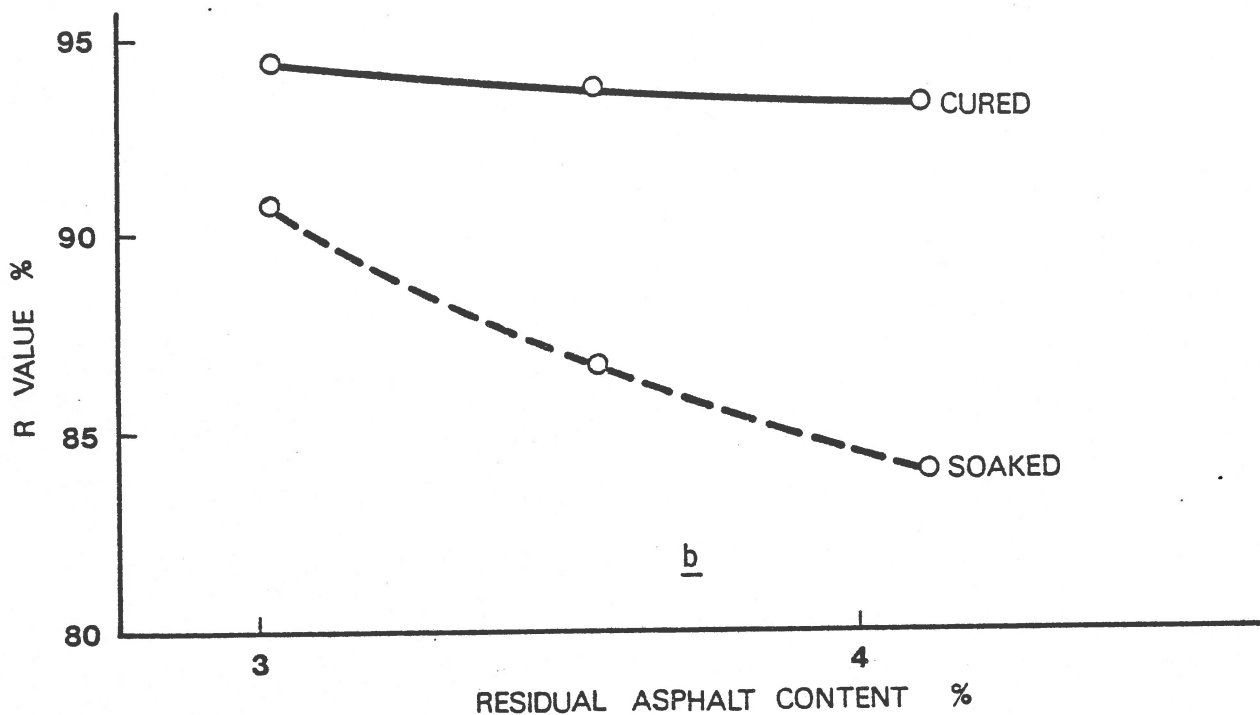
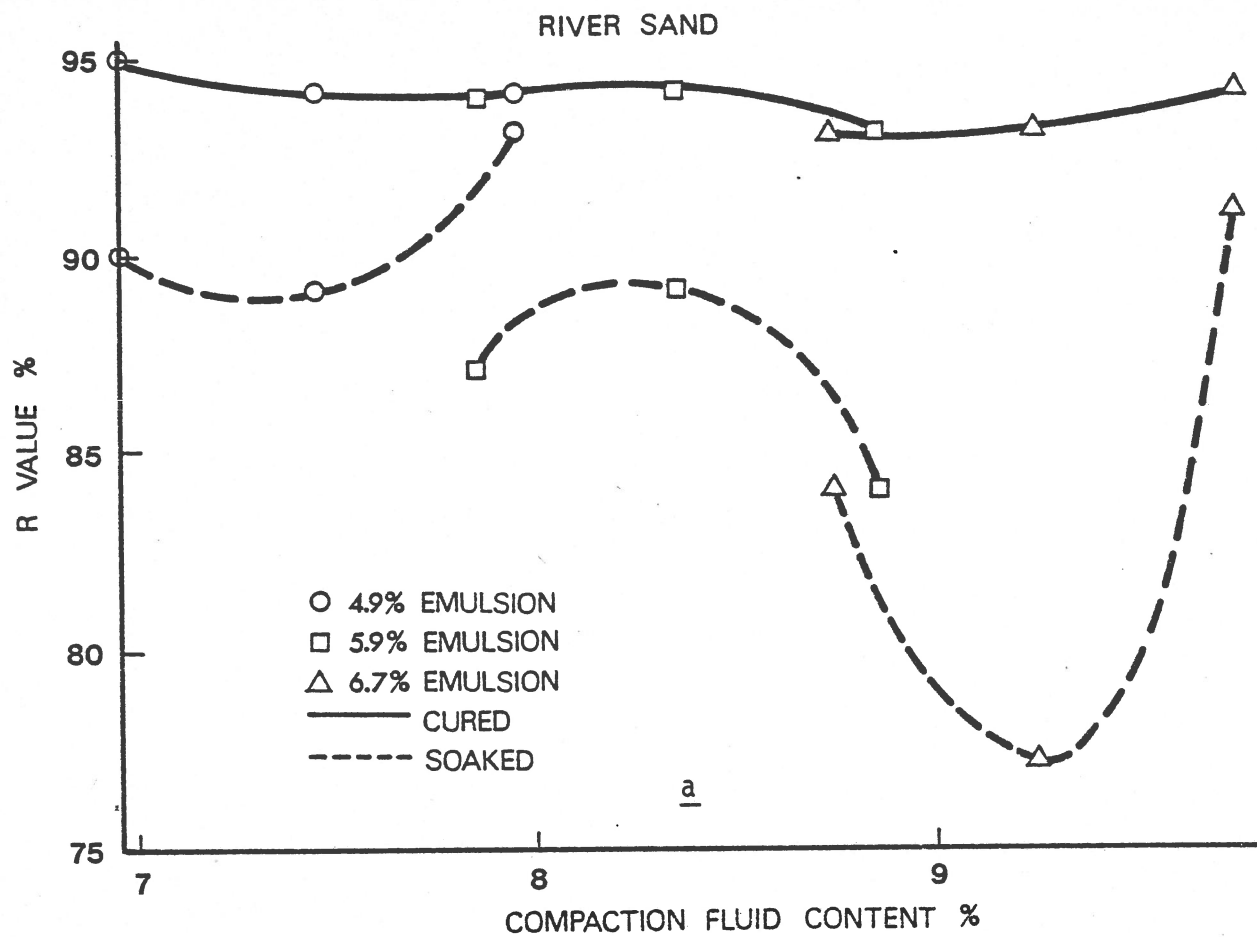


FIGURE 14. Effects of Compaction Fluid Content and Residual Asphalt Content on R-Value for the River Sand

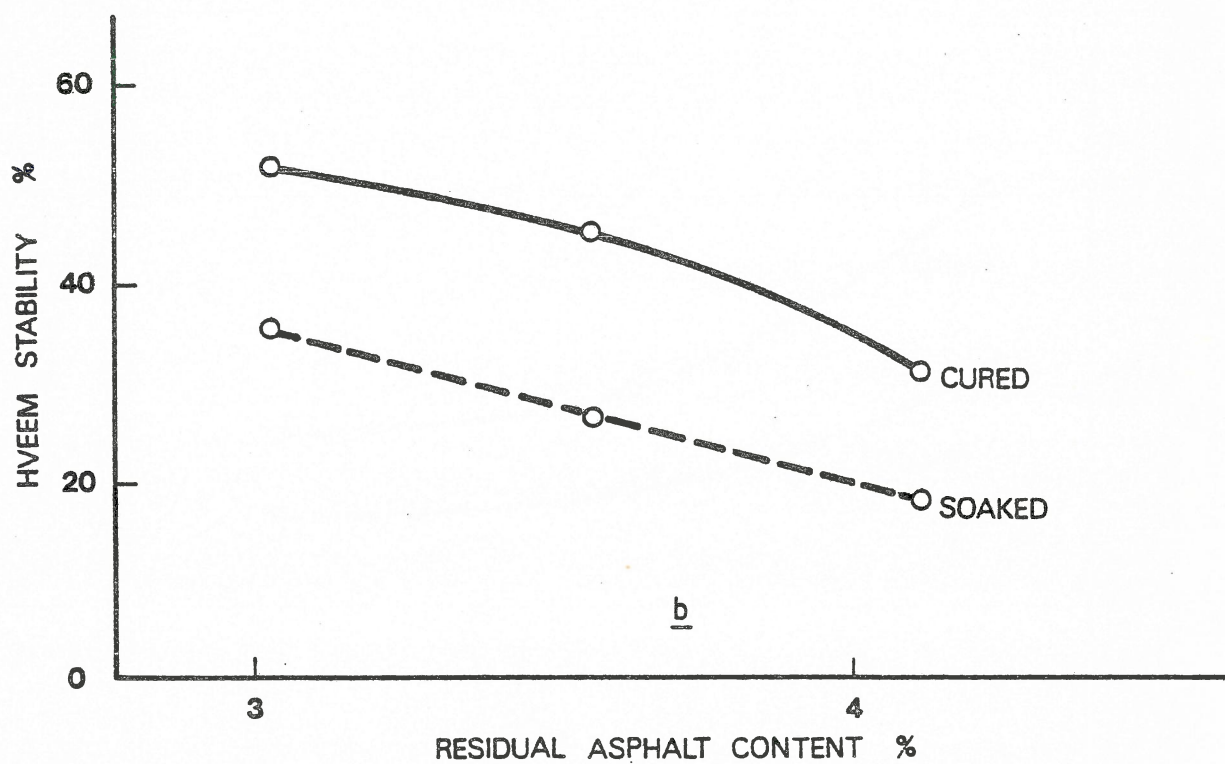
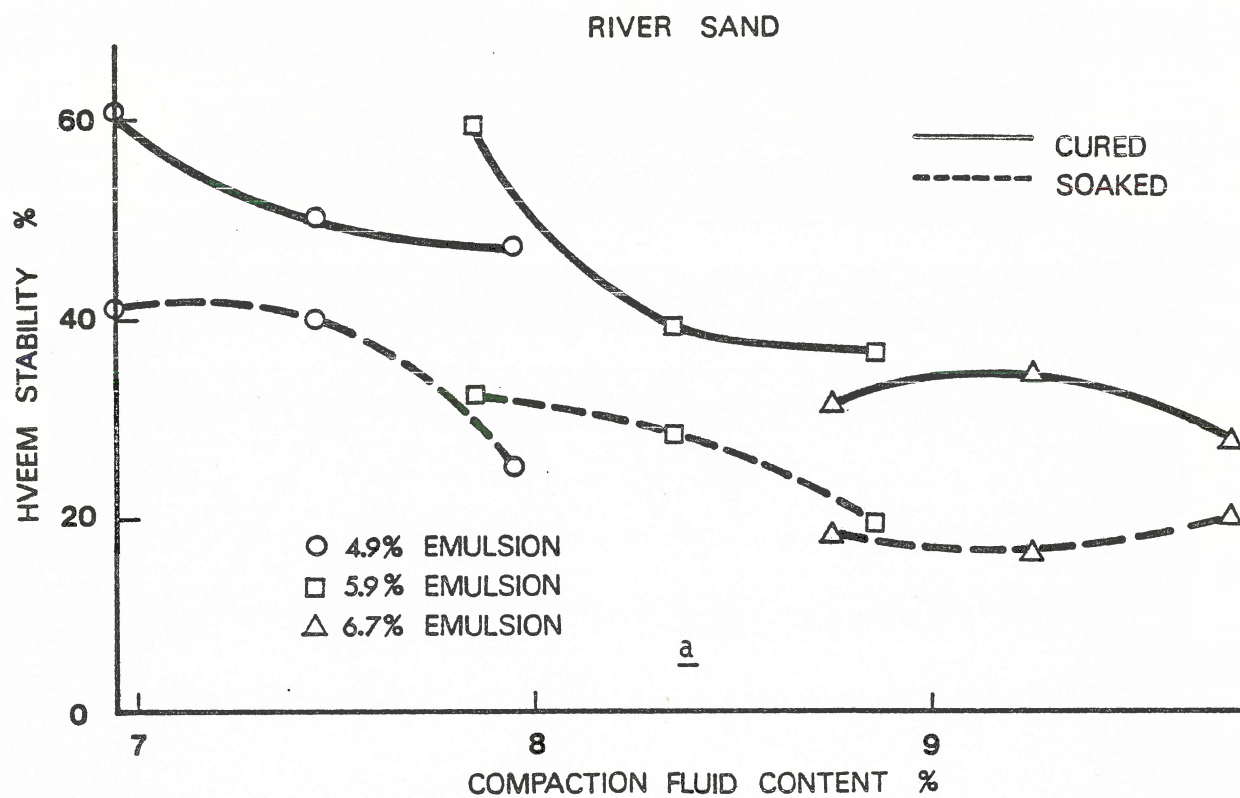


FIGURE 15. Effects of Compaction Fluid Content and Residual Asphalt on Hveem Stability for the River Sand

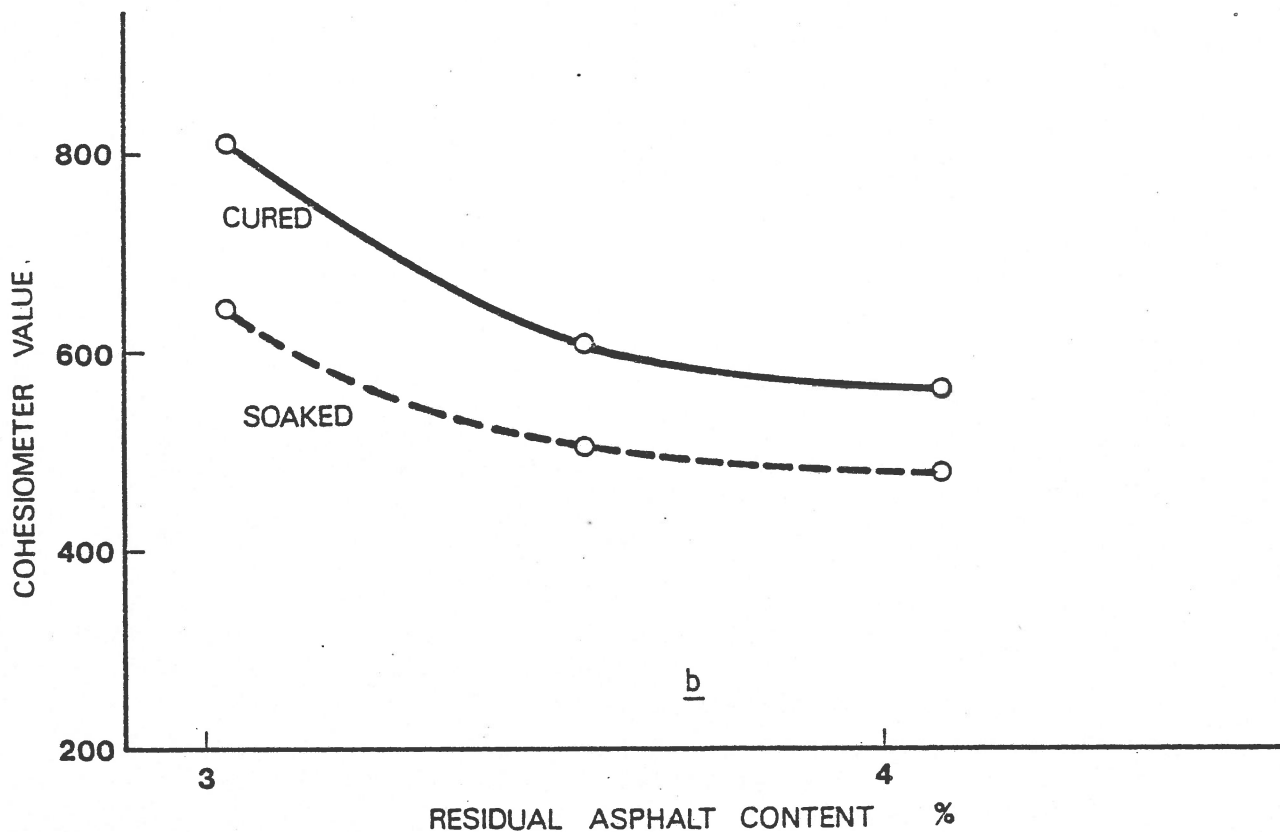
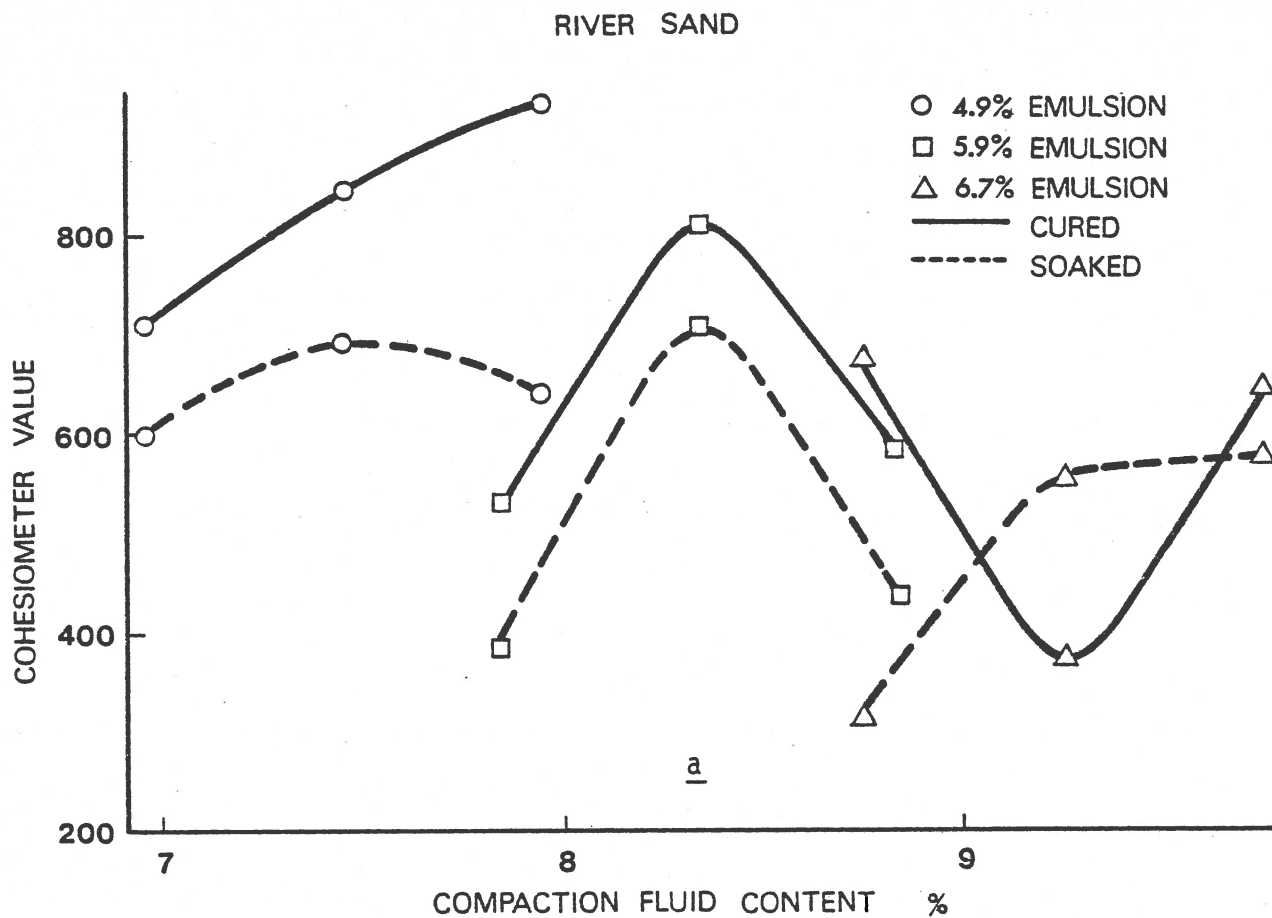


FIGURE 16. Effects of Compaction Fluid Content and Residual Asphalt Content on Cohesimeter Value for the River Sand

Marshall stability curves for the river sand mixtures are shown in Figure 17. It is noted here that the strength values are increasing with increases of residual asphalt content.

The strength data for the concrete sand indicate the same variability of effects from the compaction fluid content. However, the effect of residual asphalt content was to increase strength as it increased in amount. The curve of Figure 12 shows that most of the test specimen densities were on the dry side of optimum compaction fluid content.

As expected from the earlier comparison of test data between the river sand and the 3/8-inch blend, the strength test results for the 3/8-inch blend are comparable to those for the river sand.

A comparison of the soaked strength versus the cured strength shows that for the river sand and concrete sand, the Marshall test was the most severe in that the soaked strengths were about 30-40 percent of the cured values. In the Hveem tests, the cohesiometer showed the greatest loss for the soaked specimens of about 70 percent and the least loss due to soaking appears in the R-value test. The soaked R-values were generally greater than 90 percent of the cured value.

Asphalt Emulsion and Cement Mixtures - Hot Mixing

The Hveem procedure was used to investigate the effects of mixing and compacting at 140°F (60°C) on the strengths of the aggregates. Additionally, the original base asphalt of the emulsion was used for regular hot-mixing and testing with the Hveem method. Testing was

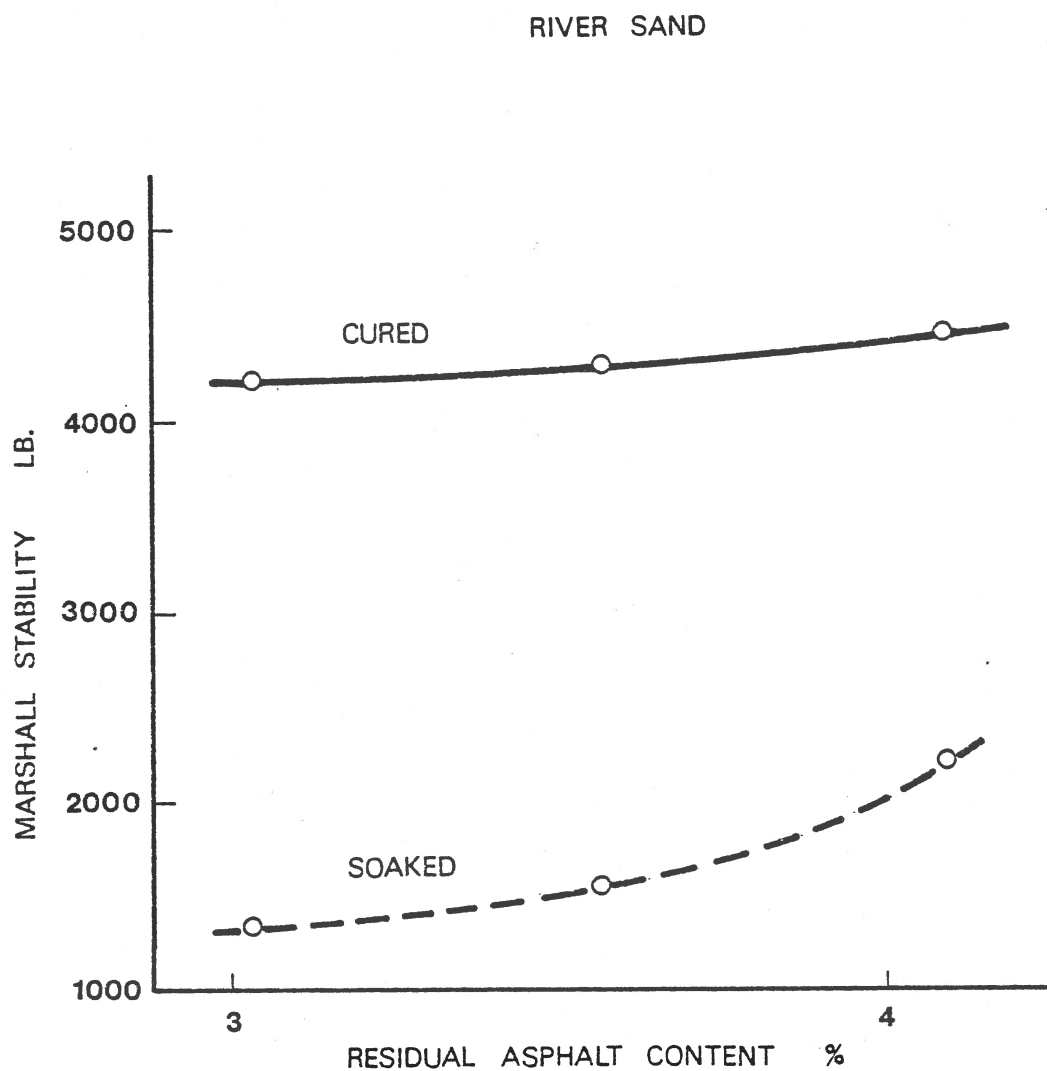


FIGURE 17. Effects of Residual Asphalt Content on the Marshall Stability for the River Sand

performed at ambient temperature for the emulsion mixtures and at ambient and 140°F (60°C) for the asphalt cement mixtures.

Asphalt Emulsion Mixtures

A previous section mentioned that for this phase all components were heated to 140°F (60°C) prior to mixing and then stored in sealed cans at this temperature prior to compaction. The procedures for compaction and testing were as outlined except that soaking was effected using a vacuum of -15 inches (381.0 mm) of mercury for a period of 15 minutes. The data obtained in this testing appear in Tables 5B, 6B, and 7B of Appendix B. Comparison of these data with cold mixing results show the following.

River Sand. The primary and significant differences obtained from the heated mixing and compaction, and the soaking procedure were, increased soaked moisture content (about 1 percentage point) and increased cohesiometer value of an average of 55 percent for the cured specimens and an average of 45 percent for the soaked ones.

Concrete Sand. The effect of the higher vacuum used in the soaking procedure resulted in higher soaked moisture content; increases ranging from 2.3 to 3.8 percentage points which correspond to an increase averaging about 80 percent. There was not much change in the cured cohesiometer value but there was a slight reduction in the soaked value.

3/8-Inch Blend. The comparison of data obtained for the cold mixing and the heated mixing shows no significant differences in strength values.

Asphalt Cement Mixtures

The aggregates and asphalt cement were heated to 285°F (140°C) prior to mixing and then stored at 250°F (121.1°C) prior to compaction. The asphalt contents used corresponded to the amounts of residual asphalt contents in the emulsion mixtures. The compacted specimens were cured in the same manner as for emulsion mixtures and density was calculated from measured specimen height while in the mold. These specimens were not soaked. The R, S, and C values for the river sand and the 3/8-inch blend appear in Tables 8B and 9B in Appendix B. As noted on that page the concrete sand mixtures could not be compacted using the standard procedure. A generalized comparison of the physical properties of these specimens with the emulsion specimens mixed at ambient temperature is as follows.

River Sand. The test densities of the asphalt cement specimens were less than for the cold-mix emulsion ones. This was probably due to the higher binder viscosity at compaction of the asphalt cement specimens. The only difference in R values resulted when the asphalt cement specimens were tested at 140°F (60°C). The stability values were appreciably higher for the asphalt cement specimens tested at ambient temperature. Both R and S values for the asphalt cement specimen were not affected by binder content; however, this was not the case for the cold-mix emulsion specimens. The cohesiometer value for the hot-mix specimens generally increased with binder content while the opposite was true for the emulsion specimens. The two mixtures had comparable C values when tested at ambient temperature, and the hot-mix specimen had rather acceptable values of greater than 100 when tested at 140°F (60°F).

3/8-Inch Blend. The statements made above for the river sand comparison can generally be repeated for the 3/8-inch blend aggregate. The main difference lies in that the cohesiometer values for the hot-mix specimens tested at ambient temperature were higher than for the emulsion specimens.

Effects of Treatment on Physical Characteristics of Compacted Specimens

In order to help assess the effects of treatments on the primary soils tested, data have been extracted from the tables in Appendix B and presented in the text as Tables 1, 2 and 3. These tables show the specimen properties when mixed with water only, mixed with emulsion at ambient and 140°F (60°C) and mixed with asphalt cement at 285°F (140.6°C). The emulsion content selected to represent a design value was that yielding an optimum cohesiometer value. As noted all specimens were tested at ambient temperature and hot-mix specimens were also tested at 140°F (60°C).

Table 1 presents the test results for the river sand obtained after the various treatments. Examination of the table shows that the water treatment has the highest "test density"; however, this measurement was made immediately after compaction and the specimens had not been cured as the emulsion-treated ones had been. If we assume that the cured moisture content for the water-treated specimens were 2 percent then the test density would be 137.0 pounds per cubic foot (2192 kg/m^3) which is comparable to the cured emulsion mixtures. The hot asphalt specimens had lower density due most likely to the higher compaction viscosity of the binder.

TABLE 1 EFFECTS OF COMPACTION WATER, EMULSION, OR ASPHALT ON PHYSICAL CHARACTERISTICS OF THE RIVER SAND AGGREGATE

Mixing Temperature Testing Temperature	Water Ambient Ambient	Emulsion				Asphalt	
		Cured	Ambient Ambient	Soaked	140°F Ambient	Ambient	285°F 140°F
Emulsion or Asphalt Content, %	0	5.9	5.9	5.9	5.9	3.6	3.6
Mixing Water, %	5.5	2.5	2.5	2.5	2.5	0	0
Vacuum, In. Hg.	0	0	-4	0	-15	0	0
Test Density,* Pcf	142.0	138.5	141.0	139.0	141.5	135.5	135.0
R Value, %	88	94	89	93	87	96	87
Stability Value, %	40	39	28	41	28	69	36
Cohesimeter Value	100	810	700	1100	790	880	180

* Wet density for soil and water mixture. The density of the emulsion mixtures is at a cured moisture content of less than 2 percent, a soaked moisture content of from 3.3 to 4.5 percent, and a residual asphalt content of 3.6 percent.

The R value for the water-treated soil was lower than for the other treatments; however this measurement was made at the compaction moisture content and not at a cured moisture content which would have probably varied the R value. It is apparent that treatment did not have a significant effect on R-value.

The stability value for the water-treated soil was comparable to those obtained for the cured emulsion mixtures and the hot asphalt mixture tested at 140°F (60°C).

The cohesiometer value of the soil mixtures was the highest for the specimens prepared at temperatures above ambient. The tensile strength as measured by the cohesiometer showed the greatest response to the addition of asphalt.

It is noted that the two soaking procedures yielded comparable effects.

The following comparison for equivalency of strength is not valid because of the test temperature used; however, if the stability values for asphalt at ambient, to soil, to cured emulsion at ambient are compared, then the ratios are 1.00:1.72:1.77. Now if the same comparison is made with the cohesiometer values, then the ratios are 1.00:8.80:1.08.

Inspection of Table 2, which lists the data obtained for the concrete sand, indicates that emulsion treatment was more beneficial than it was for the river sand. All of the Hveem values R, S, and C were improved significantly with the emulsion treatment. It is evident that for this sand the 140°F (60°C) mixing was more effective than the cold mixing.

TABLE 2 EFFECTS OF COMPACTION WATER, EMULSION, OR ASPHALT ON PHYSICAL CHARACTERISTICS OF THE CONCRETE SAND AGGREGATE

Mixing Temperature Testing Temperature	Water Ambient Ambient	Emulsion				Asphalt	
		Cured	Ambient Ambient	Soaked	140°F Ambient	285°F Ambient	140°F
Emulsion or Asphalt Content, %	0	5.6	5.6	5.6	5.6	5.6	5.6
Mixing Water, %	10.2	3.0	3.0	3.0	3.0	3.0	3.0
Vacuum, In. Hg.	0	0	-4	0	-15		
Test Density,* Pcf	135.5	130.0	131.0	132.0	139.5		
R Value, %	72	88	82	90	84		
Stability Value, %	18	32	26	41	31		
Cohesimeter Value	63	360	310	390	340		

* Wet density for soil and water mixture. The density of the emulsion mixtures is at a cured moisture content of less than 2 percent, a soaked moisture content of from 2.8 to 6.4 percent, and a residual asphalt content of 3.4 percent.

The selected test values for the 3/8-inch blend are shown in Table 3. A study of the numbers reveals the same responses to treatment as found for the river sand. If the same qualified comparisons for strength equivalencies are made as for the river sand, then on the basis of stability the ratios are 1.00:2.11:1.12 and for cohesiometer value the ratios are 1.00:13.57:1.22.

TABLE 3 EFFECTS OF COMPACTION WATER, EMULSION, OR ASPHALT ON PHYSICAL CHARACTERISTICS OF THE 3/8-INCH BLEND AGGREGATE

Mixing Temperature Testing Temperature	Water Ambient Ambient	Emulsion				Asphalt	
		Ambient		140°F		Ambient	285°F
		Cured	Soaked	Cured	Soaked		140°F
Emulsion or Asphalt Content, %	0	4.8	4.8	4.8	4.8	2.9	2.9
Mixing Water, %	5.5	2.5	2.5	2.5	2.5	0	0
Vacuum, In. Hg.	0	0	-4	0	-15	0	0
Test Density,* Pcf	143.5	141.5	142.5	140.5	144.0	135.5	137.0
R Value, %	83	93	88	93	86	94	86
Stability Value, %	26	49	27	49	29	55	36
Cohesimeter Value	70	780	540	880	400	950	150

* Wet density for soil and water mixture. The density of the emulsion mixtures is at a cured moisture content of less than 2 percent, a soaked moisture content of from 3.1 to 4.3 percent, and a residual asphalt content of 2.9 percent.

DISCUSSIONS AND CONCLUSIONS

The work performed in this study was aimed at investigating and developing a laboratory procedure for evaluating asphalt emulsion mixtures. The conclusions are based on the materials and methods used in the investigation. It is noted that the aggregates utilized were sandy materials and a blend of sand with 3/8-inch chips. The emulsion used was anionic in nature of the SS-1 grade.

As indicated earlier, the specific areas of emphasis in developing the evaluation procedure centered about mixing, compaction, and testing of the emulsion mixtures. The findings and conclusions of the investigation can be summarized as follows:

1. It was sufficient to evaluate the soils for gradation, apparent specific gravity, sand equivalent, and for kerosene absorption used in the oil ratio calculations.
2. A proper amount of premixing water content was determined to be that required for darkening of the aggregate using the amount of soil and mixing procedure described in the text.
3. Efficient mixing was achieved using a Hobart C-10 mixer, a 10-quart bowl, a type D wire whip and a medium mixer speed. With this set-up sufficient material could be mixed to produce 3 standard sized specimens. Mixing should be performed at ambient temperature.

4. The amount of emulsion to determine optimum Hveem strengths can be established by testing at 1.1, 1.3, and 1.5 times the oil ratio found for the aggregate.
5. Compaction at ambient temperature and immediately after mixing can be effected using the T.I. compactor with 150 tamps at 500 psi (3,447 kPa) and then followed with the standard leveling load.
6. Specimens cured in the compaction mold at 77°F (25°C) for 3 days will come to a constant moisture content of about 2 percent.
7. Soaking of specimens at a vacuum of -15 inches (381.0 mm) of mercury for 15 minutes plus 15 minutes at ambient pressure was equivalent to soaking for one hour at a vacuum of -4 inches (101.6 mm) of mercury followed by one hour of plain submersion.
8. The effects of emulsion treatment were not reflected with the R value test; however, they were apparent with the Hveem stability and cohesiometer tests.
9. The study was not intended to develop strength criteria for emulsion mixtures; however, because of the similarity in design procedures with Asphalt Institute's method, the recommendation of their publication (reference 28) may be used as a guide.

The most uncertain procedure in the laboratory tests described is that of saturation. It seems to be less severe than the Chevron or Asphalt Institute's procedure since less vacuum was used for

soaking; however, at this time there is no evidence to indicate that one soaking procedure is preferred to the other.

There are some misgivings on our part to accept the high contact pressure used in the T.I. procedure for making specimens. Although high densities are required to evaluate the specimens properly we believe the vibratory kneading compactor of our laboratory can produce the required densities without the high contact pressures. Evidence to this capability was presented in reference 29.

This report is concluded by recommending that future emulsion mixtures be evaluated by the procedures described in the text and in greater detail in Appendix C, and that existing and future emulsion mixtures placed in road beds be sampled and tested to characterize their physical properties during service conditions.

ACKNOWLEDGEMENT

The cooperation received from the Arizona Department of Transportation is greatly appreciated. In particular we wish to acknowledge the help from Elmer Green of ADOT for furnishing the emulsion on a schedule consistent with our needs. We also acknowledge the information and discussions received from Cliff Wimberley from Chevron Asphalt Co. in Tucson.

Finally, we sincerely appreciate the sponsorship of this work by ADOT and FHWA because it is only through efforts such as the ones presented here that a unified emulsion mixture design procedure will be developed.

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APPENDIX A
MATERIAL CHARACTERISTICS

TABLE 1A GENERAL CHARACTERISTICS OF THE SS-1 ASPHALT
EMULSION AND OF ITS BASE ASPHALT

Emulsion SS-1	Specs.	Avg. Value
Viscosity, SSF @ 77°F, sec.	20-100	21
Residue by Evaporation, %, min.	57	62
Settlement, 5 days, %, max.	5	
Sieve, Retained on No. 20, %, max.	0.1	
Test on Residue		
Ductility, 77°F, 5 cm/m, cm, min.	40	
Solubility in C Cl ₄ , %, min.	97.5	
Viscosity, abs., 140°F, p.	1500-2500	
Asphalt - AR 2000		
Flash, P-M, °F, min.		490
Penetration, 100 g, 5 sec., 77°F		93
Viscosity, abs., 140°F, p.		923
Viscosity, kin. 275°F, cs		147
Test on 75 min. RTFC Residue		
% Penetration of Original		69
Ductility, 77°F, 5 cm/m, cm, min.	100	100+
Viscosity, abs. 140°F, p.	2000±400	2040 .
Viscosity, kin. 275°F, cs		273
Aging Index, max.	2.2	2.1
Specific Gravity 77/77°F		1.026

TABLE 2A SOME PHYSICAL CHARACTERISTICS OF THE AGGREGATES

Aggregate	River Sand	Concrete Sand	3/8-in. Blend	P3/4 - R#8	Dune Sand	Fica Sand
Gradation						
Sieve Size	Percent Passing					
3/4-inch				100		
3/8-inch	100		100	34		100
#4	92	100	81	3		99
#8	79	90	59	0		92
#16	64	71	46		100	77
#30	48	45	34		99	55
#50	34	18	24		82	25
#100	18	5	13		22	10
#200	11	3	8		4	6
Surface Area ft ² /lb	58	32	42	2	74	45
Sand Equivalent	32	79	32	NA	62	62
"Darkening" Moisture Content, %	2.5	3.0	2.5	1.0	1.5	2.7
CKE Oil Ratio	4.5	4.3	3.7	NA	4.8	5.5
Specific Gravity 77/77°F	2.65	2.63	2.64	2.65	2.65	2.63

APPENDIX B

TEST DATA FROM VARIOUS TESTING PROGRAMS ON
SOILS AND ASPHALTIC MIXTURES

TABLE 1B TEST RESULTS ON THE THREE PRINCIPAL SOILS EVALUATED

SOILS	RIVER SAND		CONCRETE SAND		3/8-INCH BLEND	
	Dry Density pcf	Moisture Content %	Dry Density pcf	Moisture Content %	Dry Density pcf	Moisture Content %
Compaction Test T.I. 150 Tamps at 500 PSI	130.5	2.2	120.5	4.7	132.5	2.1
	132.0	2.8	116.5	5.6	135.0	2.9
	133.0	3.2	116.0	7.9	136.5	3.6
	135.0	4.0	119.0	8.8	137.5	4.3
	136.0	4.8	119.5	9.2	138.0	5.0
	136.5	5.6	121.5	9.6	138.0	5.5
	137.0	6.2	122.5	10.0	138.0	6.0
	136.0	7.2	123.5	10.5	137.0	7.1
			124.5	11.0		
Strength Tests (γ_D , w)	(134.5, 5.5)		(123.0, 10.2)		(136.0, 5.5)	
R Value %	88		72		83	
S Value %	40		18		26	
Cohesimeter Value	99		63		70	

TABLE 2B EFFECTS OF MIXING WATER CONTENT AND EMULSION CONTENT ON STRENGTH OF RIVER SAND. COLD^a MIXING, COLD COMPACTION AND COLD TESTING

Emulsion Content, % Mixing Water, %	2.0	4.9 2.5	3.0	2.0	5.9 2.5	3.0	2.0	6.7 2.5	3.0
HVEEM METHOD									
Test Density, pcf Cured	138.5	139.5	138.5	139.0	138.5	137.0 (137.5) ^c	139.5	138.5	138.0
Soaked ^b	141.0	141.0	140.5	140.5	141.0	138.5 (139.0)	141.5	140.0	139.0
Moisture Content, % Cured	2.2	2.2	1.6	1.7	1.9	1.9 (1.6)	1.7	1.8	2.0
Soaked	3.8	3.5	3.1	3.6	3.3	3.6 (2.8)	3.5	3.3	2.8
R Value, % Cured	95	94	94	94	94	93 (94)	93	93	94
Soaked	90	89	93	87	89	84 (92)	84	77	91
Stability Value, % Cured	62	52	47	59	39	36 (36)	31	34	27
Soaked	41	40	25	32	28	19 (28)	18	16	20
Cohesimeter Value Cured	710	850	870	530	810	480 (855)	670	370	640
Soaked	600	690	640	380	700	430 (730)	310	550	570
MARSHALL METHOD									
Test Density, pcf Cured			133.0			137.0			128.5
Soaked			136.0			141.0			134.0
Moisture Content, % Cured			2.2			1.8			1.7
Soaked			4.7			3.9			3.7
Stability, lb. Cured			4220			4280			4450
Soaked			1350			1560			2210
Flow, 0.01 in. Cured			11			16			14
Soaked			8			7			8

^aCold refers to ambient temp.

^bSoaked under water for 1 hour at a vacuum of -4 inches of mercury.

Repeatability test made at least 1-1/2 months later. Soaking was performed at -15 inches of mercury for 15 minutes plus 15 minutes at ambient pressure.

TABLE 3B EFFECTS OF MIXING WATER CONTENT AND EMULSION CONTENT ON STRENGTH OF CONCRETE SAND. COLD^a MIXING, COLD COMPACTION AND COLD TESTING

Emulsion Content, % Mixing Water, %	2.5	4.7 3.0	3.5	2.0	5.6 2.5	3.0	2.5	6.5 3.0	3.5
HVEEM METHOD									
Test Density, pcf Cured Soaked ^b	129.0 130.5	128.0 132.0	129.0 130.5	128.5 131.0	131.0 132.0	130.0 (127.5) ^c 131.0 (129.5)	130.5 131.5	129.0 132.5	130.5 126.5
Moisture Content, % Cured Soaked	1.1 4.1	1.6 4.3	1.7 2.2	1.0 3.4	1.2 4.0	1.2 (1.4) 2.8 (2.6)	1.7 3.9	1.9 3.5	1.9 2.8
R Value, % Cured Soaked	88 83	84 79	85 81	87 85	83 80	88 (86) 82 (82)	86 83	86 83	83 82
Stability Value, % Cured Soaked	34 30	30 23	28 27	30 30	27 24	32 (33) 26 (28)	31 29	25 25	24 23
Cohesimeter Value Cured Soaked	300 200	300 200	290 230	390 330	390 440	360 (390) 310 (360)	340 310	320 350	310 340
MARSHALL METHOD									
Test Density, pcf Cured Soaked		114.0 (118.0) ^c 118.0 (124)				115.0 120.0		117.5 123.0	
Moisture Content, % Cured Soaked		-- --	(2.5) (6.7)			1.2 5.4		1.8 6.9	
Stability, lb. Cured Soaked		1660 1160	(1430) (540)			1560 800		2250 580	
Flow, 0.01 in. Cured Soaked		9 10	(15) (7)			6 6		9 6	

^aCold refers to ambient temp.

^bSoaked under water for 1 hour at a vacuum of -4 inches of mercury.

^cRepeatability test made at least 3 months later. Soaking was performed at -15 inches of mercury for 15 minutes plus 15 minutes at ambient pressure.

TABLE 4B EFFECTS OF MIXING WATER CONTENT AND EMULSION CONTENT ON STRENGTH OF 3/8-INCH BLEND. COLD^a MIXING, COLD COMPACTION AND COLD TESTING

Emulsion Content, % Mixing Water, %	2.0	4.1	2.5	3.0	2.0	4.8	2.5	3.0	2.0	5.5	2.5	3.0
HVEEM METHOD												
Test Density, pcf Cured	138.5	138.5	140.0	140.0	140.5	141.5	141.5	139.0 (139.5) ^c	139.5	139.0	138.5	
Soaked ^b	141.5	141.0	141.5	141.5	142.0	142.5	142.5	141.0 (142.0)	141.5	142.0	140.0	
Moisture Content, % Cured	1.7	1.7	1.4	1.4	1.6	1.6	1.6	1.4 (1.6)	1.7	1.5	1.7	
Soaked	3.5	3.4	2.9	2.9	3.1	3.1	3.1	3.1 (3.7)	3.1	3.5	2.9	
R Value, % Cured	94	94	96	96	94	93	93	94 (95)	92	92	92	
Soaked	90	88	92	92	90	88	88	87 (88)	88	83	88	
Stability Value, % Cured	61	57	64	64	60	49	49	44 (43)	36	29	28	
Soaked	45	40	35	35	40	27	27	21 (19)	31	19	20	
Cohesimeter Value Cured	610	780	820	820	790	780	780	780 (740)	720	750	730	
Soaked	440	410	610	610	540	540	540	510 (470)	540	450	520	
MARSHALL METHOD												
Test Density, pcf Cured			134.0	134.0				133.5			135.5	
Soaked			136.0	136.0				136.5			138.0	
Moisture Content, % Cured			1.8	1.8				1.5			1.5	
Soaked			3.7	3.7				3.2			2.8	
Stability, lb. Cured			4140	4140				4380			5440	
Soaked			1790	1790				2300			3120	
Flow, 0.01 in. Cured			9	9				17			10	
Soaked			10	10				9			14	

^aCold refers to ambient temp.

^bSoaked under water for 1 hour at a vacuum of -4 inches of mercury.

^cRepeatability test made at least 1 month later. Soaking was performed at -15 inches of mercury for 15 minutes plus 15 minutes at ambient pressure.

TABLE 5B EFFECTS OF MIXING WATER CONTENT AND EMULSION CONTENT ON
STRENGTH OF RIVER SAND. 140°F MIXING, 140°F
COMPACTION AND COLD^a TESTING

Emulsion Content, %	4.9		5.9		6.7
Mixing Water, %	2.0	2.0	2.5	3.0	2.0
HVEEM METHOD					
Test Density, pcf					
Cured	148.0	137.5	139.0	137.0	140.0
Soaked ^b	140.0	141.0	141.5	141.5	142.0
Moisture Content, %					
Cured	1.5	2.5	2.5	2.3	2.0
Soaked	4.3	4.8	4.5	4.6	3.9
R Value, %					
Cured	95	94	93	93	94
Soaked	90	86	87	84	87
Stability Value, %					
Cured	69	48	41	34	35
Soaked	41	28	28	22	23
Cohesimeter Value					
Cured	920	1070	1100	930	760
Soaked	660	890	790	730	590

^aCold refers to ambient temperature.

^bSoaked under water for 15 minutes at a vacuum of -15 inches of mercury plus 15 minutes at ambient pressure.

TABLE 6B EFFECTS OF MIXING WATER CONTENT AND EMULSION CONTENT ON
STRENGTH OF CONCRETE SAND. 140°F MIXING, 140°F
COMPACTION AND COLD^a TESTING

Emulsion Content, %	4.7		5.6		6.5
Mixing Water, %	2.5	2.0	2.5	3.0	2.5
HVEEM METHOD					
Test Density, pcf					
Cured	131.0	129.0	130.0	132.0	132.0
Soaked ^b	138.0	134.0	135.5	139.5	137.0
Moisture Content, %					
Cured	1.8	2.0	1.9	1.5	2.1
Soaked	6.4	7.2	6.6	6.4	6.3
R Value, %					
Cured	87	87	86	90	87
Soaked	81	80	80	84	73
Stability Value, %					
Cured	30	34	32	41	33
Soaked	20	26	25	31	25
Cohesimeter Value					
Cured	420	420	360	390	490
Soaked	190	220	200	340	150

^aCold refers to ambient temperature.

^bSoaked under water for 15 minutes at a vacuum of -15 inches of mercury,
plus 15 minutes at ambient pressure.

TABLE 7B EFFECTS OF MIXING WATER CONTENT AND EMULSION CONTENT ON
STRENGTH OF 3/8-INCH BLEND. 140°F MIXING, 140°F
COMPACTION AND COLD^a TESTING

Emulsion Content, %	4.1		4.8		5.5
Mixing Water, %	2.0	2.0	2.5	3.0	2.0
HVEEM METHOD					
Test Density, pcf					
Cured	138.0	140.5	140.5	140.0	140.5
Soaked ^b	143.0	143.0	144.0	144.0	142.5
Moisture Content, %					
Cured	1.3	1.7	2.2	1.9	2.2
Soaked	3.8	4.5	4.3	4.5	4.2
R Value, %					
Cured	93	94	93	94	93
Soaked	89	86	86	84	87
Stability Value, %					
Cured	71	55	30	44	32
Soaked	53	35	29	23	21
Cohesimeter Value					
Cured	580	740	880	800	710
Soaked	480	410	400	430	460

^aCold refers to ambient temperature.

^bSoaked under water for 15 minutes at a vacuum of -15 inches of mercury plus 15 minutes at ambient pressure.

TABLE 8B THE EFFECTS OF ASPHALT CEMENT CONTENT ON THE STRENGTH
OF RIVER SAND. 285°F MIXING, 250°F COMPACTION,
COLD^a AND 140°F TESTING

Test Temperature, °F	Ambient			140		
Asphalt Content, %	3.0	3.6	4.1	3.0	3.6	4.1
HVEEM METHOD						
Test Density, pcf	134.0	135.5	136.0	132.5	135.0	136.5
R Value, %	95	96	96	87	87	87
Stability Value, %	67	69	68	34	36	35
Cohesimeter Value	670	880	830	100	180	300

^a Cold refers to ambient temperature

TABLE 9B THE EFFECTS OF ASPHALT CEMENT CONTENT ON THE STRENGTH
OF 3/8-INCH BLEND. 285°F MIXING, 250°F COMPACTION,
COLD^a, AND 140°F TESTING

Test Temperature, °F	Ambient			140		
Asphalt Content, %	2.5	2.9	3.4	2.5	2.9	3.4
HVEEM METHOD						
Test Density, pcf	134.5	135.5	137.0	133.5	137.0	138.0
R Value, %	93	94	95	83	86	85
Stability Value, %	54	55	61	29	36	34
Cohesimeter Value	840	950	1060	80	150	200

^a Cold refers to ambient temperature

NOTE: The concrete sand mixtures could not be compacted using the procedure for the above aggregates; therefore, no measurements were performed.

APPENDIX C

A DETAILED PROCEDURE FOR LABORATORY EVALUATION OF ASPHALT EMULSION MIXTURES

PROCEDURE FOR LABORATORY EVALUATION OF ASPHALT EMULSION TREATED AGGREGATES

General

The evaluation procedure is directed to the testing of specimens made from asphalt emulsions mixed with granular soils. The granular soils considered are essentially noncohesive, have less than 15 percent passing the #200 sieve, and have a sand equivalent value greater than 25. The evaluation is made from test results obtained from specimens formed with the T.I. compactor and tested with the Hveem stabilometer and cohesiometer.

Component Material Characteristics

The following properties of the aggregate and emulsion to be used in the mixture must be known or determined prior to making specimens to be tested.

Asphalt Emulsion

The emulsion to be used will be of the mixing type and meet general requirements as specified in Table 205-5 for Section 705 of the Standard Specifications of ADOT. It is important to know if the emulsion is anionic or cationic and it is absolutely necessary to know asphalt content in the emulsion. The emulsion's asphalt content and particle charge are established through AASHTO test method T-59. The specific gravity of the residual asphalt is assumed to be 1.02 at 77°F (25°C) if it is not determined.

Aggregate

As indicated earlier, the aggregate will generally be a granular material with maximum particle size limited to about 1 inch (25.4 mm). The aggregate is evaluated for gradation, apparent specific gravity, sandequivalent, and for kerosene absorption. The kerosene absorption is determined with the Centrifuge Kerosene Equivalent procedure (ARIZ 805). The CKE oil ratio is calculated according to the procedure of ARIZ 805.

In order to achieve a good coating of emulsion on the aggregate, the aggregate must be prewetted. The purposes of prewetting the aggregate are to keep the emulsion from coming in contact with the dry surface (to prevent "balling" and/or breaking of the emulsion) and to fill the surface voids of the aggregate (to serve as a lubricant for spreading the emulsion). The least amount of water to accomplish the stated purposes is desired and the following procedure has been found satisfactory for most aggregates.

The sample size is 1000 grams of air-dry ($w < 1\%$) aggregate and the mixer is a Hobart C-10 model using a type D wire whip (see page 26 of text). The sample in the mixing bowl is placed on the mixer and the medium (no. 2) mixing speed is selected. A preweighed plastic squeeze water bottle is held ready for introducing water into the mixing bowl. The mixer is started, the bowl is raised to the mixing position, and then water is squirted into the bowl to settle the dust. The mixer is stopped and the aggregate is checked for approaching "darkening" of the surface. The agitation of the aggregate is resumed and more water is added until the desired condition is reached. [The novice should practice to recognize the just-darkening condition by hand mixing the sand and water; however, the amount of water required is a function of

sample size and speed of mixing.] The amount of water added to the aggregate is found by weight difference of the water bottle. The "darkening" moisture content is calculated from the total water in the aggregate.

Mixing and Compaction of Specimens

At least three emulsion contents should be used for making test specimens. These amounts are 1.1, 1.3 and 1.5 times the oil ratio obtained for the aggregate. Note that both prewetting water and emulsion content are expressed as a percentage of the dry aggregate weight. A batch of mixed materials should provide for three specimens and at least 100 grams for determination of total moisture at the time of compaction. A standard sized specimen has a compacted weight of about 1100 grams. The preweighed air-dry aggregate in the mixing bowl is stirred with the mixer's wire whip and at no. 2 speed, the proper amount of the mixing water is added, and then the calculated amount of emulsion is introduced while the wet aggregate is being mixed. The emulsion is poured from a preweighed beaker and care is taken to minimize splashing. Stirring is continued until a uniform color of the mixture is obtained; this takes about 1½ minutes. It may be necessary to raise the bowl by hand to insure that the whip reaches the fines at the bottom of the bowl. At the end of the mixing period, the mixture is placed in a large dampened pan for additional hand mixing if necessary and for separation into test sample size. Each test sample size is weighed out into a metal pan and then covered with a damp paper towel to minimize evaporation of water prior to compaction. At this time a sample of the mixture is taken for total moisture content determination.

The T.I. compactor is used for making the test specimens. The procedure is similar to that of ARIZ 803 except that ambient temperature is used. This procedure calls for placing one-half of the mixture into the mold onto the lightly oiled base of the mold holder (do not use 4" diameter paper disc here) and rod 20 times with the 3/8" diameter bar. Add the remainder of the material into the mold and rod it as before. Place the mold and holder assembly on the compactor and start initial compaction using 250 psi foot pressure. Continue the initial compaction until the foot penetrates the sample about 1/8 inch; between 10-50 tamps are required to bring about this condition. The material may not be able to withstand the initial compaction stresses; in this case use double plunger compaction at 40,000 lbs. held for two minutes for the forming procedure. After initial compaction at 250 psi, release the mold, remove the 1/4 inch shims, and change the foot pressure to 500 psi. Apply 150 tamps at the higher pressure and then remove from the compactor and prepare for the leveling load.

Place the mold upside down on a lightly oiled metal plate. Place the plate and mold on the compression machine with the load ram on the bottom of the specimen which is now in a higher elevation. Apply a compressive load to push the specimen approximately 2 inches until it comes in contact with the oiled plate and continue loading to 12,500 lb. (1000 psi) and hold at this load for 2 minutes, then release the load to end the compaction procedure.

Weigh and determine the height of the specimen immediately after compaction and then store in a 77°F room with the mold laid on its side for a curing period of three days.

Following the 3-day curing period, a set of 3 specimens may be tested directly with the stabilometer or will undergo a stauration procedure prior to testing. Immediately after curing the weight of the specimen in the mold is determined. The soaking procedure has not been set; however, the following method is recommended for present usage. Place three specimens still in the molds on the base of the bell jar device (shown on page 30 of the text), place the glass jar on the base, and secure it with the three bolts. Introduce water through the base of the jar until water reaches the top of the mold and flows in to cover the specimen's surface to a depth of at least one inch. Close the water inlet and then connect the vacuum pump to the riser tube in the bell jar assembly. Reduce the air pressure in the jar (evacuate) by 15 inches of mercury and hold for 15 minutes.* After the vacuum is released, allow the specimens to soak more water (blotter effect) for 15 minutes more. Drain the water from the soaking device, remove the specimens, dry the mold and specimens' surfaces, and then determine the weight of the soaked specimens.

Testing for stability and cohesiometer values for both the "cured" and "soaked" specimens are identical. These tests are performed after the specimen is extruded out of the mold. The specimen should be identified so that the "top" of the specimen receives the applied load. The stabilometer is calibrated and the test is performed according to ARIZ 803 except as noted. The stabilometer test is performed at ambient temperature and the transmitted pressure is read off the gage at vertical loads of 500, 1000, 2000, and 5000 pounds; that is, if the safety pressure

*It is now believed that a preferred procedure is to apply the vacuum first and then introduce the water.

valve attached to the gage is not activated. After the 6000 lb. force is reached, the load is reduced to 1000 lbs. and the "final displacement" is determined. This final displacement is used for the calculation of both R and S values. Following the stability measurement, the cohesiometer test is performed.

For the cohesiometer test, follow the procedure of ARIZ 804. Prior to testing, identify the failure plane with a chalk line on the top of the specimen. The test is performed at ambient temperature.

After the cohesiometer test is performed, determine the moisture content of the whole specimen by drying in an oven at 250°F.

Standard calculating procedures are used to obtain the following.

- a. compaction density
- b. "cured" and "soaked" test density
- c. "cured" and "soaked" moisture content
- d. "cured" and "soaked" values for R, S, and cohesiometer

APPENDIX D

THIS SECTION CONTAINS A DISCUSSION OF DATA OBTAINED
AFTER THE TEXT OF THE REPORT WAS WRITTEN FOR REVIEW

ADDENDUM

In this section, additional work performed and related to the text will be presented. This work is covered under three headings titled: a) Concho Mixtures, b) Soaking Effects, and c) Base Density.

Concho Mixtures

During the latter part of the work period of the project, ADOT evaluated cinder-asphalt emulsion mixtures for the construction of road S180 north of the town of Concho. Samples of the cinder and the CSS-1 emulsion were sent to the University's laboratory for pre-construction evaluation by the proposed mixture design method. Because of the limited amount of the cinders sent and time, complete testing of the cinders and emulsion was not performed. Table 1D presents the characterization test results performed. As noted in the table our gradation differed from that reported by ADOT in that it was coarser (lesser amounts passing the same sieve) except for the 3/4" and #200 sieves. It is anticipated that after compaction our gradation would approach ADOT's.

The cinders were mixed with the emulsion to produce three different mixtures. Table 2D shows the blends and test results obtained. The proportioning of the materials are quite different from that reported by ADOT. The state recommended using 8.0 percent prewetting water and 13.5 percent emulsion. It is pointed out that our procedure called for 4.0 percent prewetting water; however, the amount of emulsion used was estimated since the CKE test was not performed.

A review of the data listed in Table 2D indicates the following:

- a. The range of test density obtained and that the "soaked" densities were always greater than for the "cured" specimen.
- b. The moisture content of the cured specimens became stabilized at less than 3 percent after the 3-day curing period. As expected, the increase in moisture of around 6 percent for the soaked specimens was greater than the average value of about 1.5 percent for the other aggregates tested.
- c. The cured values of R and S are relatively high and soaking did not cause drastic reductions.
- d. The cohesiometer values were low compared to the River Sand (Table 2B) and Concrete Sand (Table 3B) but the percentage lost from soaking is about the same for these three aggregates.

It appears that the cinder in this evaluation need improvement in cohesiometer value for use as a base with a thin surfacing.

Soaking Effects

The soaking procedure used to determine the resistance to water of the emulsion treated aggregate consisted of submerging the specimen in water, holding a vacuum of four inches of mercury for one hour and then followed with an additional hour of plain soaking. This procedure was considered to be not as severe as that recommended by the Chevron Company and also the Asphalt Institute. Some testing was done using 15 inches of mercury vacuum and followed with 15 minutes of plain soaking. The severity of this latter procedure appeared to be the same as that of the former. In order to assess the difference in effects of the three soaking procedures, a limited work program was followed using one sand and one emulsion.

The river sand and emulsion of the principal study, unfortunately, were not available for this evaluation; however, the sand from the Pantano Wash used was quite similar to the river sand. The emulsion utilized was an SS-1 made with the same base asphalt that was in the emulsion for the main work. Characteristics of the Pantano Sand and the emulsion are listed in Table 3D. The compaction densities obtained with the T.I. compactor are shown as well as the tensile strength obtained by a double punch procedure.

Test specimens were prepared according to the recommended procedure (Appendix C) except that the soaking method was varied. The soaking procedure variations listed on Table 4D are defined as follows:

- a. "None" means the standard 3-day curing and without soaking.
- b. "-4" means that after curing, the specimen was soaked under 4 inches of mercury vacuum for one hour and then followed with another hour of soaking without vacuum.
- c. "-15" means that the soaking was effected with 15 inches of mercury vacuum for 15 minutes and then followed with another 15 minutes of soaking without vacuum.
- d. "-26" means that the soaking was effected with 26 inches of mercury vacuum for one hour and then followed with another hour of plain soaking.

The results obtained in this testing and presented in Table 4D are discussed in the following listing:

- a. The test density of the specimen increased as the soaking vacuum increased. The emulsion content did not significantly affect the specimen density.

- b. The moisture content of the test specimen increased as the soaking-vacuum increased which caused the increase in test density discussed above. The moisture pick-up from the cured (None) condition ranged from 0.7 to 2.8 percentage points.
- c. The R and S values of the cured (None) specimens decreased as the emulsion content increased as was the case for the mixtures evaluated in the principal part of the study. The "soaked" strength decreased as the soaking-vacuum increased; however, optimum or highest soaked R and S values were obtained at the middle value of emulsion content equal to 5.9 percent.
- d. The double punch tensile strength of the cured (None) specimens decreased as the emulsion content increased. A review of the River Sand data shows that the cohesiometer value also decreased as the emulsion content increased. The "soaked" tensile strength was decreased as the soaking-vacuum was increased. For the 4-inch vacuum soaking, the tensile strength increased as emulsion content increased; however, both the 15-inch and 26-inch vacuum soaked specimens showed an optimum strength at 5.9 percent emulsion and also the individual values were similar to each other.

A review of Table 3D shows that the tensile strength values of the soil-water specimens ranged from 1 to 10 psi. The maximum tensile strength value for the emulsion treated mixture was about 50 psi. Although R and S values were not obtained for the Pantano Sand, it was shown in the text that improvement to the materials tested was principally to the tensile

(cohesiometer) strength. The data show that treating sands with emulsions can improve tensile strength without loss of stability as determined by the R and S values. It is then indicated that the emulsion-aggregate design strength criterion should be based on tensile strength. The soaking tests performed on the Pantano Sand showed that the 15-inch of mercury vacuum soaking procedure was as effective as the 26-inch of mercury vacuum with reference to the double punch tensile strength. Since the 15-inch of mercury vacuum is more efficient in time consumption, there seems to be no compelling reason to change the soaking method at this time.

Base Density

The Chevron Asphalt Company of Tucson has been assisting in the design and construction of emulsion treated bases in Pima County. The sandy materials that have been used were evaluated in Tucson and in California following the Chevron mixture design procedure. The Chevron Company in Tucson has been sampling some of these bases and has made available some of the data presented in Table 5D.

The pre-construction data presented in Table 5D corresponds to the values obtained at the design emulsion content for a standard sized specimen obtained with the T.I. compactor. The road cores were 4 inches in diameter and were trimmed to be approximately 2-1/2 inches high for each portion identified as top, middle, and bottom. Examination of the data shows that field compaction was quite effective in being able to attain and exceed laboratory density. The table does not show the moisture content of the cores since this was not desired at that time. However, the sampling done by the University for Canyon del Oro Estates and Flowing Wells Road at 48 months did consider this point and measurements showed that moisture content was less than 0.2 percent.

TABLE 1D PHYSICAL CHARACTERISTICS OF THE MATERIALS* USED IN THE
CONCHO CINDER-EMULSION MIXTURES

CONCHO CINDERS

Gradation

Sieve Size	3/4"	3/8"	#4	#8	#16	#30	#50	#100	#200
Percent Passing	100	67	35	23	15	11	8	6	3

Surface Area,
ft²/lb

17

Darkening Moisture
Content, %

4.0

CSS-1 EMULSION

Residue, %

60.9

*These materials were received from ADOT. The cinders came separated into 5 sizes and were then combined in the University of Arizona lab to use all of the cinders. The resulting gradation shown above did not correspond to the stated job gradation.

TABLE 2D EFFECTS OF MIXING WATER CONTENT AND EMULSION^a CONTENT ON STRENGTH OF CONCHO CINDERS. COLD^b MIXING, COLD COMPACTION AND COLD TESTING

Emulsion Content, %	10.0		12.0
Mixing Water, %	4.0	0	4.0

HVEEM METHOD

Test Density, pcf			
Cured	116.0	112.0	117.0
Soaked ^c	116.5	115.0	119.0
Moisture Content, %			
Cured	2.3	2.4	2.7
Soaked	8.1	6.4	9.1
R Value, %			
Cured	93	93	84
Soaked	97	95	82
Stability Value, %			
Cured	38	43	32
Soaked	33	34	32
Cohesimeter Value			
Cured	220	180	180
Soaked	90	110	70

^aADOT design was 8% mixing water plus 13.5% emulsion.

^bCold refers to ambient temperature.

^cSoaked under water for 15 minutes at a vacuum of 15 inches of mercury plus 15 minutes at ambient pressure.

TABLE 3D PHYSICAL CHARACTERISTICS OF THE MATERIALS USED IN
THE PANTANO SAND-EMULSION MIXTURES

PANTANO SAND

Gradation

Sieve Size	3/8"	#4	#8	#16	#30	#50	#100	#200
Percent Passing	100	87	68	49	34	21	13	8

Surface Area, ft^2/lb 42

Darkening Moisture
Content, %

2.5

CKE Oil Ratio, %

4.3

Specific Gravity, 77/77°F

2.61

T.I. Compaction

Dry Density, pcf	128.5	130.0	132.0	135.0	134.0	130.0
Moisture Content, %	3.2	4.1	5.1	7.5	7.9	10.1
Tensile Strength, σ_T , by Double Punch, psi	7	10	7	3	2	1

SS-1 EMULSION (#2)

Residue, %

65.3

TABLE 4D
EFFECTS OF EMULSION CONTENT AND SOAKING PROCEDURE ON THE STRENGTH OF
PANTANO SAND, COLD^a MIXING, COLD COMPACTION, AND COLD TESTING

Emulsion Content, % Mixing Water, %	4.9 2.5		5.9 2.5		6.7 2.5	
	None	-4 ^b -15 ^c -26 ^d	None	-4 -15 -26	None	-4 -15 -26
Vacuum Soaking, Inches of Hg						
Test Density, pcf	137.5	140.5	138.5	139.5	137.5	139.5
Test Moisture Content, %	2.3	4.0	2.4	3.5	2.8	4.7
R Value, %	97	89	94	90	92	72
Stability Value, %	49	24	35	24	24	8
Double Punch σ_T , psi	51	25	47	36	43	24

^a Cold refers to ambient temperature.

^b -4" Hg for 1 hour and 1 hour without vacuum.

C -15" Hg for 15 minutes and 15 minutes without vacuum.

d -26" Hg for 1 hour and 1 hour without vacuum.

TABLE 5D DENSITIES OF EMULSION TREATED BASES CONSTRUCTED IN PIMA COUNTY

Construction Location	Date	Pre-construction ^a		Road Cores			
		Dry Density pcf	R Value	Age mo	Dry Density pcf	Age mo	Dry Density pcf
Canyon del Oro Estates	January 1969	---	---	48	131.5	105 ^b	127.5
					124.5		127.5
49'er Country Club	Summer 1969	122.5	82	42	132.0		
					123.0		
Flowing Wells Road	August 1972	130.0	88	5	135.5	26 ^b	48 ^b
					136.0		133.5
					129.5		133.5
Duval Mine Road	September 1972	127.5	85	2	130.5		
					129.5		

^a Laboratory compaction was effected with 150 tamps at 500 psi of the T.I. compactor. Pre-construction data and first sampling was done by the Chevron Asphalt Company of Tucson.

^b Samples and data obtained by the University of Arizona

