# STABILIZATION OF A DUNE SAND WITH ASPHALT EMULSION

by

Jasim Mohammad Al-Rijab

---

A Thesis Submitted to the Faculty of the

DEPARTMENT OF CIVIL ENGINEERING AND ENGINEERING MECHANICS

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN CIVIL ENGINEERING

In the Graduate College

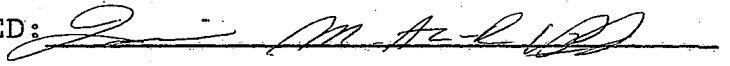
THE UNIVERSITY OF ARIZONA

1 9 7 7

STATEMENT BY AUTHOR

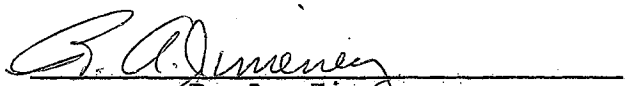
This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: 

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:



R. A. Jiménez
Professor of Civil Engineering

January 31, 1977
Date

ACKNOWLEDGMENTS

I would like to extend my grateful appreciation to my advisor, Dr. R.A. Jimenez, for his continuous constructive criticism during the research.

My special thanks to Dr. H. Sultan for his helpful remarks on certain points in this thesis.

I would also like to mention Dr. S. Ince for his time contribution to this thesis.

TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF TABLES--Continued

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS--Continued

LIST OF ILLUSTRATIONS--Continued

ABSTRACT

This study is concerned with stabilizing dune sand with asphalt emulsions. Specimens fabricated by vibratory kneading compaction were tested for strength by the Hveem and double punch apparatus. Specimens fabricated by Marshall compaction were tested for strength by the Marshall device.

This study investigates the effect of different types of emulsion, the effect of residual asphalt content, the effect of grading of the dune sand, the effect of testing temperature and the effect of the type of mix on density and strength values.

# CHAPTER I

## INTRODUCTION

Dune sand is a wind blown transported material and takes the shape of a mound or a ridge called a sand dune (1). Dune sand range in size between .125-.250 m.m. (2). Quartz (Silica) is the main mineral composition of dune sand (3).

In many parts of the world, especially in the desert areas, there is a shortage of natural materials suitable for road construction. Dune sand, which is often found in the desert, could be utilized as a road construction material by using some form of a stabilizing agent, such as asphalt. Some success has been achieved in stabilizing sand with asphalt binders (4).

Asphalt emulsions are becoming more popular in some areas in the U.S. due to ecological and economic advantages. Unlike asphalt cements, asphalt emulsions can be mixed with wet aggregates, and without heating, which reduces pollution and the energy requirement. This study is concerned with the use of asphalt emulsions for stabilizing dune sand.

Asphalt emulsions are the dispersion of very small asphalt droplets in water. To keep these droplets dispersed, an emulsifying agent is used. Emulsifying agents are acidic

compound (cationic) or basic compound (anionic) (6). Most emulsions come in two categories, anionic emulsion, in which the asphalt droplets carry a negative charge, and cationic, in which the asphalt droplets carry a positive charge. According to early literature, the cationic emulsion is suitable for aggregates which carry negative charges, (Silicious aggregates), whereas the anionic emulsion is suitable for aggregates which carry positive charges (limestone) (6,7). However, it has been reported recently that all aggregates, including limestone, carry negative charge (5).

There are three general classifications of asphalt emulsions, rapid setting (R.S.), medium setting (M.S.), and slow setting (S.S.). These classifications are based on the rate at which the dispersed asphalt droplets coagulate or "break" into a continuous film of asphalt cement. The rate of breaking up is controlled by the type and amount of the emulsifying agent used. The slow setting emulsions are the most stable to mixing and dilution and mix with a variety of damp and wet aggregates without stripping (8).

Asphalt is useful for soil stabilization, because of its cementing and waterproofing qualities. The cementation is generally most important for noncohesive or only slightly cohesive granular soils such as gravel or sand. The waterproofing property is most important to cohesive soil or soil-aggregate mixtures. Increasing the amount of asphalt

to be added to a soil increases waterproofing, but it might lower the mixtures strength. Therefore, the amount of asphalt for desired waterproofing and mixture's strength needs to be determined by laboratory tests.

The most well recognized theories that explain the mechanism of asphalt soil stabilization are the "intimate mix" and the "plug" theories (9). Granular materials seem to best fit the "intimate mix" theory where the individual particles are coated with asphalt and stick together. The theory does not apply to clayey materials due to the difficulty of coating large surface areas. Also, clay possesses natural cohesion and cannot be separated easily into individual particles. Therefore, asphalt tends to coat the soil in small aggregates or clods and acts as a waterproofer by plugging the voids (10).

To summarize the mechanisms: In granular material the asphalt coats the grains and acts as a binder. In soils which contain clay, the clay is a natural binder as long as water is kept out; asphalt is added as a waterproofer for the clay-cemented aggregates.

Stabilization of soil with asphalt emulsion is typically performed by blending the emulsion with wet soil, compacting it, and then curing it. Adding water to the soil prior to the addition of the asphalt emulsion will aid in distributing the asphalt uniformly. Upon evaporation of the

water from the mixture the soil grains are left coated with a protective asphalt film.

## Purpose and Scope of the Study

This study is concerned with stabilizing dune sand with asphalt emulsions. Two types of emulsions, anionic (SS-1) and cationic (CSS-1), and also the SS-1 base asphalt (asphalt cement) were used as stabilizers.

In one part of the investigation, the specimens were compacted by a vibratory kneading compactor, cured, then tested with the Hveem stabilometer and a double punch apparatus. In the other part of the investigation, the specimens were compacted by the Marshall compactor, cured, then tested with the Marshall apparatus.

The investigation was carried out as follows:

1. Specimens were prepared by the vibratory kneading compactor using dune sand and two types of emulsions, SS-1 and CSS-1 at varying amounts of emulsion content. The specimens were compacted at different liquid contents (emulsion plus water) to determine the effect of the liquid contents on density. After twenty-four hours of curing at 140°F, the specimens were tested at 77°F to determine the effect of residual asphalt content on the stability, resistance, tensile strength values.

2. To determine the effect of grading of dune sand, specimens were prepared using modified grading dune sand (dune sand plus 30 percent copper mill tailings), and SS-1 emulsion at varying amounts of emulsion content. The specimens were compacted by the vibratory kneading compactor at different liquid contents. After twenty-four hours of curing at 140°F, the specimens were tested at 77°F for the stability, resistance and tensile strength values.
3. To assess the waterproofing effect of asphalt emulsion, specimens were fabricated by the vibratory compactor using dune sand, and SS-1 emulsion at varying amounts of emulsion contents. After twenty-four hours of curing at 140°F the specimens were subjected to vacuum soak test, then the soaked stability, resistance, and tensile strength were evaluated.
4. Specimens were prepared by the vibratory compactor using dune sand and two types of emulsions (SS-1 and CSS-1) at one emulsion content. After twenty-four hours of curing at 140°F, they were tested at 77°, 104°, and 140°F to determine the effect of testing temperature on the stability, resistance, and tensile strength.
5. To compare properties of hot mixes with those cold mixes, specimens were prepared by the hot mix

process and fabricated by the vibratory kneading compactor using dune sand and varying the amounts of SS-1 base asphalt (asphalt cement). After curing for twenty-four hours at 77°F, the specimens were tested for stability, resistance, and tensile strength values at 77°F.

6. In the second part of the investigation, specimens were fabricated by the Marshall compactor using dune sand and two types of emulsions (SS-1 and CSS-1), at varying amounts of emulsion contents. The specimens were compacted at different liquid contents (emulsion and water) to determine the effect of emulsion content on density. After twenty-four hours of curing at 140°F, the specimens were tested at 77°F to determine the effect of residual asphalt content on the Marshall stability and flow values.
7. For another test condition, specimens were prepared by the Marshall compactor, using dune sand and two types of emulsions (SS-1 and CSS-1), at one emulsion content. After twenty-four hours of curing at 140°F, the specimens were tested at 77°, 104° and 140°F to determine the effect of testing temperature on the Marshall stability and flow values.
8. To compare hot mixes with cold mixes, specimens were prepared by the hot mix process and fabricated by the Marshall compactor using dune sand, and varying

amounts of SS-1 base asphalt (asphalt cement). After curing for twenty-four hours at 77°F, the specimens were tested for Marshall stability and flow values at 77°F.

# CHAPTER II

## REVIEW OF LITERATURE

This study is concerned with the use of asphalt emulsions for the stabilization of a dune sand and the development of information which is lacking. Asphalt emulsion treatment might give acceptable qualities for the dune sand to be used in highway construction.

McKesson and Mohr (11) were the first to describe the stabilization of sand with asphalt emulsions. Sand from different areas in Florida were tested for suitability for emulsion stabilization. Emulsified asphalt mixtures were spread in thin layers and dried out to constant weight at 140°F, then the mix was compacted statically while it was warm. The specimens were tested for stability by the modified Florida Bearing Method at 140°F. From the results of their tests they concluded that sand was satisfactory for stabilization if the Florida Bearing value was greater than 25 lbs, when sand was tested prior to mixing with the emulsion. The mixture was satisfactory if it showed a bearing value by the modified Florida test of more than 100 lbs at 140°F after treatment with the emulsion.

They also showed that sand of low stability can be made suitable for use by the addition of fine, noncohesive fillers.

Gregg, Dehlen and Rigden (12) presented a laboratory and field study of bitumen-stabilized dune sand. In their study, they gave particular attention to two factors, temperature and the rate of loading that influenced the behavior of bituminous stabilized material. Triaxial tests were conducted over a range of temperatures and rates of loading. The results showed the C-intercept decreased markedly with the increase of temperature and the decrease of the rate of loading. Those results pointed out the importance of carrying stability tests at temperatures corresponding to the upper limit of the temperature to be experienced by the material in its life. It is further important that the tests should be carried out at rates of loading corresponding to those occurring in the field.

They also carried out a field investigation on 8 sections of road in Southwest Africa, of 6 inch thick bitumen-dune sand base. Each base was stabilized in place with a different grade of cut-back asphalt. The investigation showed that after two years of service under light to medium traffic those bases performed satisfactorily in spite of the low in situ California Bearing Ratio that was below 30 at a surface temperature of 104$^{o}$F (40$^{o}$C).

It was found that the mixtures containing natural fillers to improve their grading by filling some of the voids between the one-sixed sand particles generally possessed higher strength and moduli of resilient deformation than mixtures lacking fine material.

Dunn and Salem (4) conducted a laboratory study on factors affecting the shear strength of a one-sized grading fine sand stabilized with a cationic asphalt emulsion. Triaxial tests were employed to study the effect of emulsion content on cohesion and angle of friction of stabilized sand. Unconfined compression tests were employed to investigate the influence of the viscosity of the base asphalt and also the effect of varying the initial moisture content on the compressive strength of stabliized sand.

Undrained triaxial tests were carried out on 4 inch high by 2 inch diameter air-dried specimens. The tests showed that the addition of emulsion to the sand had the simultaneous effect of increasing the cohesion and reducing the angle of frictional resistance. For the particular test conditions, maximum cohesion was developed when the residual asphalt content was 4 to 5-1/2 percent. The angle of frictional resistance fell linearly with residual asphalt.

They carried out tests with different types of cationic emulsion, and showed that cationic emulsion having the lowest penetration residual asphalt gave the highest compressive strength. It was found that an optimum initial

moisture content exists for optimum compressive strength. It was shown that sufficient water should be present during the mixing as long as it would not deleteriously affect compaction.

It was shown that the addition of filler to one-sized grading sand increased the dry density and the mechanical stability of sand. Cement filler greatly increased the compressive strength of sand-cement-emulsion mixes and was acting as a stabilizing agent rather than a filler.

Using a vibratory compaction it was shown that the addition of emulsion to sand had the effect of reducing the dry density.

It was found that the order in which the ingredients were added, affected the ultimate strength of the material. The highest strengths were obtained by adding the cement filler last, while the lowest strengths were obtained by adding the cement filler first to dry sand. This was explained by the fact that the asphalt has a chance to adhere to the sand before the cement was added. When the emulsion was added to the sand-cement mix, the greater affinity of asphalt to the finer particles might result in poor coating of the sand.

It was observed that the compressive strength of emulsion stabilized sand significantly increased with the increase of curing period. Tests of cured specimens in air

dry conditions for three months showed that the more emulsion used, the higher the strength.

Dunn and Salem (13), in another paper, conducted a laboratory investigation on the effect of temperature and the rate of loading on the shear strength of one-sized grading sand stabilized with cationic emulsion. The shear strength parameters C and Ø were determined using triaxial tests. It was found that preheating the sand and cationic emulsion to a temperature between 45° and 75°C (113°-167°F) before mixing had an effect of increasing the ultimate strength of dry-cured compacted specimens. The preheating had no significant effect on the angle of shearing resistance.

It was shown that the increase in curing temperature from 20° to 90°C (68°-194°F) will increase the cohesive strength of the stabilized sand. The angle of frictional resistance was increased, but to a lesser extent than the cohesion. It was noted at curing temperatures above 140°F relatively little increase in strength occurred.

The effect of the testing temperature on C and Ø was investigated and it was found that the increase in temperature reduces both C and Ø. The reduction in C values are significant compared to the reduction in Ø values with change in temperature from -5 to 50°C (21.5°-122°F).

It was observed that increasing the rate of loading had the effect of increasing the C and decreasing the Ø values. However, the reduction in strength due to change in

the Ø values are small compared with the increase in the C value, and the net effect is a significant increase in the total strength.

Al Salloum (14) did a study on fatigue characteristics of an asphalt stabilized dune sand (Yuma Dune Sand). The bitumen used to stabilize the dune sand was 60-70 penetration grade asphalt. It was found that the Centrifuge Kerosine Equivalent procedure to estimate the "optimum" amount of asphalt was not applicable to dune sand due to the large surface area. The optimum content based on the Marshall stability alone was found to be 6 percent by the weight of dry sand. The Marshall and Hveem stability were found to be 500 lbs, and 18 percent at 140$^{o}$F, respectively. The relative density at 6 percent asphalt content was about 78 percent of the voidless mix.

The Jimenez deflectometer (15) was used to study the fatigue properties of Yuma sand-asphalt. It was found that the fatigure life increases with a) an increase in the dynamic modulus of elasticity, b) an increase in specimen thickness, c) the decrease in testing temperature, d) the increase in the initial support pressure, and e) the increase in the radius of the loaded area.

Yuma sand-asphalt was characterized by its low stability value and fatigure resistance due to the high percentage of air voids and VMA[1] in the mix.

A tentative two-layer pavement design procedure based on the limitation of both the subgrade vertical strain and the radial horizontal strain at the bottom of the surfacing layer was suggested (14). It was found that roads built with Yuma sand-asphalt, as a surface layer, can resist only light to medium traffic. By comparing Yuma sand-asphalt to the conventional asphalt concrete, it might be stated that one inch of asphalt concrete is equivalent to about five inches of a sand-asphalt. Moreover, for a given thickness of asphalt concrete, it may last up to 20 times as long as the same thickness of sand-asphalt surfacing.

Curing after compaction is probably the most important step in the process of emulsion stabilization. The strength development is limited to the rate of water loss in the mixture. Therefore, it is important that the mixture dries out to the lowest possible water content in order to obtain fully effective stabilization.

Schmidt, Santucci and Coyne (16) demonstrated the importance of curing. They showed that after 30 days of curing, emulsion treated mixes made with different penetration

---

1. VMA (Voids in the mineral aggregate) is the volume of air voids plus the volume of asphalt in the compacted mix.

asphalt have resilient moduli slightly higher than hot mixes made with the same asphalt. It was also shown that complete curing of emulsion treated mixtures results in resistance to water damage approaching that of hot mixes.

They showed that small additions of cement will improve the early cure of emulsion treated mixtures under adverse curing conditions of cool temperature or high humidity.

The presence of moisture in a soil prior to the addition of the emulsion generally aids in mixing and also provides sufficient liquid in the mix to bring it to optimum compaction. Current practice suggests that the amount of water to be added to the soil prior to the addition of emulsion must be determined by observing the asphalt coating over a wide range of moisture contents and choosing the content that gives the best coating (17).

Yazdani (18) studied the effect of premixing water on the stability and cohesiometer values of a well graded river sand stabilized with anionic emulsion. He showed that the amount of premixing water did not affect the stability values and also showed some slight improvement of cohesive strength as the mixing water increased from 5 to 7 percent.

From a practical point of view, a higher level of premixing water will require a more prolonged period for drying to bring it to an efficient compaction. Usually the

mixture is brought to optimum moisture content for compaction (8,19).

Coyne and Ripple (8) reviewed the mix design and construction methods of emulsified mixes. They suggested the use of sand equivalent test to detect the presence of excessive amounts of clay. Material having sand equivalent values between 25 and 35 should be evaluated by a laboratory test prior to use. Material having a sand equivalent value less than 25 is considered not suitable for emulsion stabilization.

It is important that the emulsion be uniformly dispersed in order to achieve the desired water resistance and tensile strength. Variables found to affect dispersion are gradation, asphalt grade and amount, water content, mixing time, and mixing temperature. The best way to evaluate the effect of these variables when using asphalt emulsion is to make and test the mix.

The authors (8) suggested that pneumatic tired rollers are well suitable for compacting normal thickness pavement courses of dense mix. For thick lifts, vibratory steel rollers are preferred. Mixes compacted above optimum water content may shove and rut. Mixes compacted below optimum water content may become stiff and unworkable and raveling may result.

In order to develop the design strength the mixture must be cured properly. The authors (8) stated that under

favorable curing conditions, properly designed emulsified mixtures can be opened to traffic in 45 minutes to one hour. Under adverse conditions of cool temperatures or high humidity the rate of strength development may be slow.

Emulsified asphalt mix design criteria based on the Resistance R-value and cohesiometer C-value after vacuum saturation have been established by the Asphalt Institute (17). Emulsified mixtures having $R_T$ values (R + .05C) of 78 minimum at 77°F were considered comparable to crushed rock base.

# CHAPTER III

# MATERIAL

This chapter describes the properties of dune sand, copper mill tailings, and asphalts used. As mentioned previously, two types of emulsions were used, anionic (SS-1) and cationic (CSS-1). The base asphalt of SS-1 emulsion (asphalt cement) was also used. Copper mill tailings were blended with dune sand to modify the sand's gradation.

## Yuma Dune Sand

Yuma dune sand was obtained from an area 16 miles west of Yuma, Arizona. This sand had a specific gravity of 2.66. The gradation of this material is shown in Figure 1 and Table 2 of Appendix A. The results indicate that 100 percent of the dune sand grains are passing number 30 sieve. The average grain size is approximately .08 inch (.2 m.m.). The moisture-density relationship according to the modified AASHTO compaction is shown in Figure 2. The results indicate an optimum dry density of 109.5 pcf at optimum moisture content of 11.2 percent. The moisture-density relationship obtained by the vibratory kneading compaction and Marshall compaction method are also shown in Figure 2. Values of the dry densities at different moisture content is tabulated in Table 3 and 4 of Appendix A. The results indicate that the

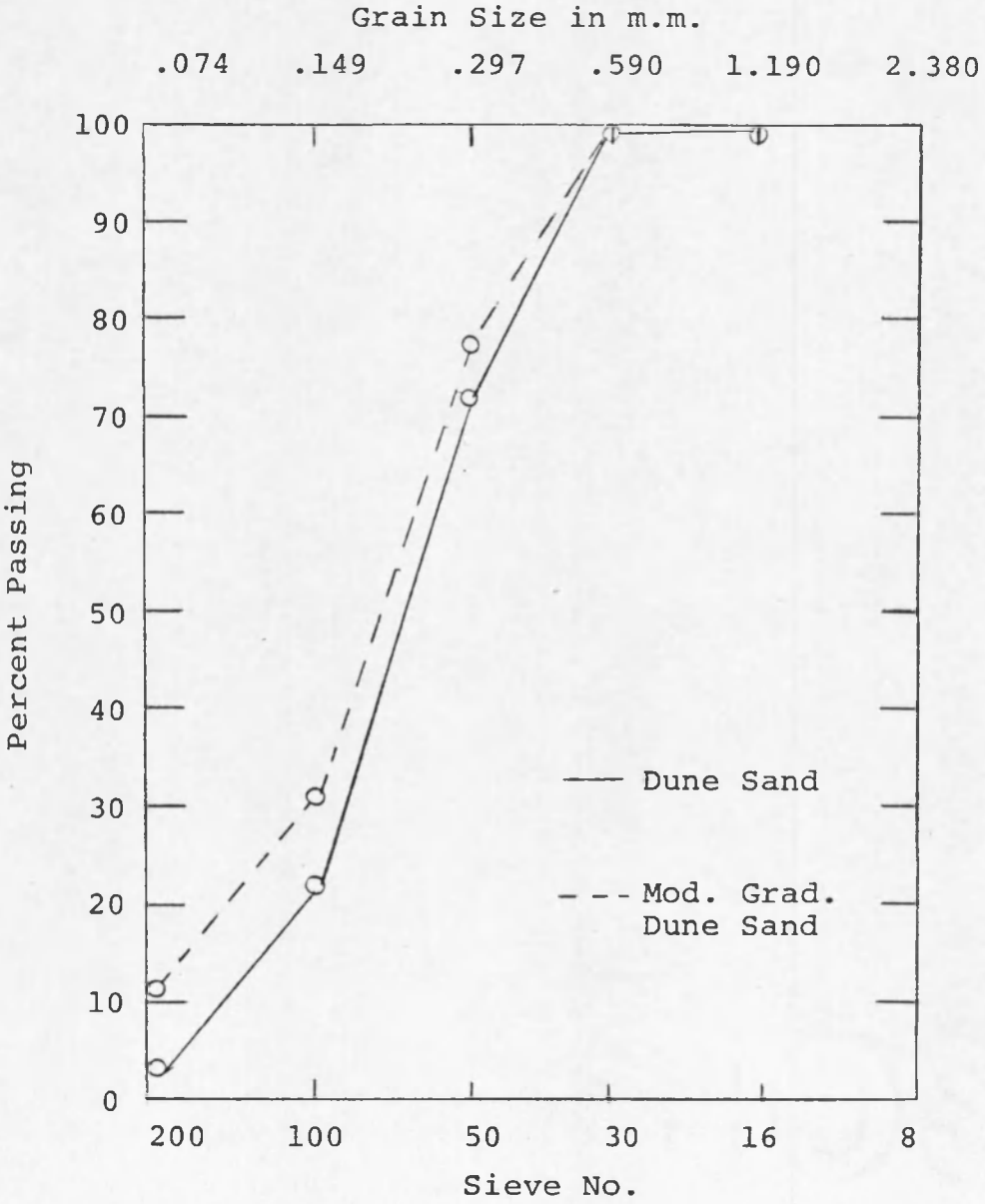



Figure 1. Grain Size Distribution of Dune Sand and Modified Gradation Dune Sand

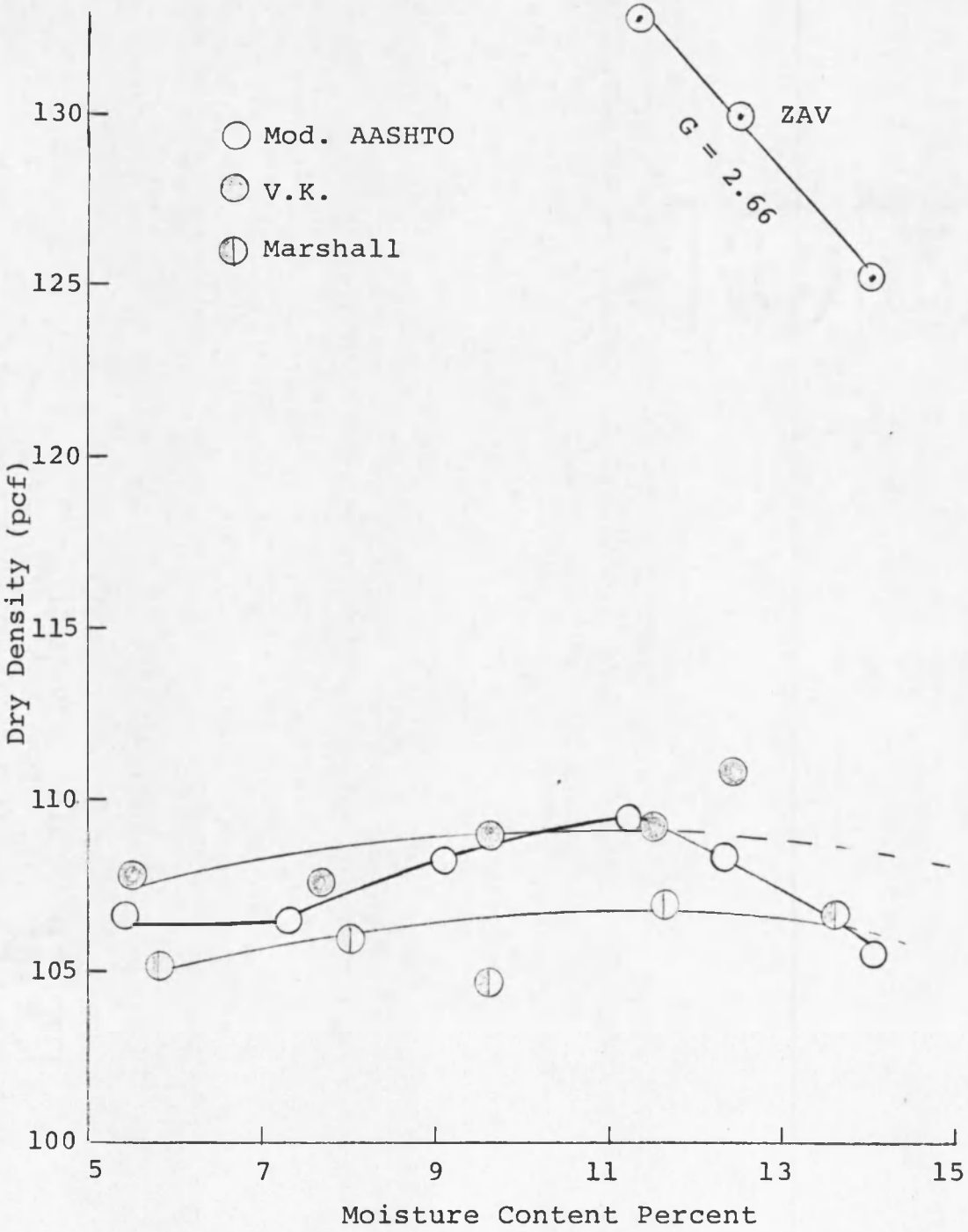



Figure 2. Moisture-Density Relationship of Dune Sand

method of compaction has no appreciable effect on the dry density of dune sand.

## Copper Mill Tailings

Copper mill tailings is a fine powdery material discarded by the mining industries after the extraction of the copper compounds from the copper ore (20,21). The specific gravity of this material is 2.76. The gradation of this material is shown in Figure 3 and Table 2 of Appendix A. The result indicates that 100 percent of copper mill tailings grains pass the number 16 sieve.

A blend of 70 percent dune sand and 30 percent copper mill tailings was made and its gradation is shown in Figure 1 and Table 2 of Appendix A.

## Asphalts

Two emulsions, slow setting anionic (SS-1) and slow setting cationic (CSS-1), and the base asphalt of SS-1 emulsion were obtained through the courtesy of the Chevron Asphalt Company in Tucson, Arizona. The properties of the asphalt emulsions are shown in Table 1 of Appendix A.

The emulsions were supplied in five gallon cans, and transferred to one gallon plastic containers. The base asphalt was supplied in one gallon containers. The asphalt was stored at room temperature prior to use.

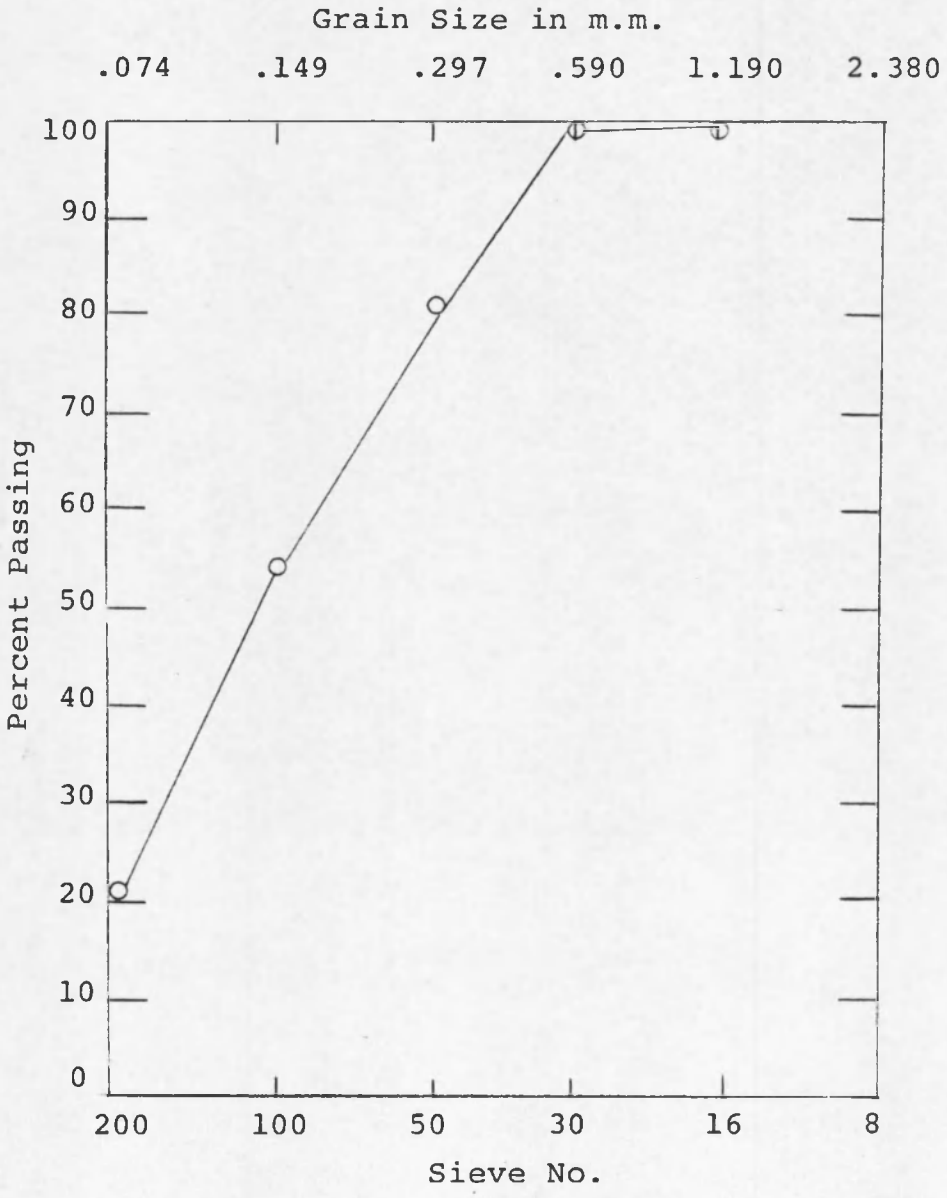



Figure 3. Grain Size Distribution of Copper Mill Tailings

# CHAPTER IV

## LABORATORY PROCEDURE AND EQUIPMENT

This chapter describes the procedure and equipment used in this study.

### Material Preparation

The dune sand and copper mill tailings were kept in a forced-draft oven for twenty-four hours at 140°F (60°C), to insure proper drying, then allowed to cool at room temperature. The asphalt emulsions were stored in one gallon plastic containers and kept at room temperature (77° ± 5°F). The emulsion was thoroughly agitated upward and downward prior to use to insure that the residue of the emulsion was representative of the residue of the emulsion used. The base asphalt was transferred from the one gallon containers to pouring pots for heating asphalt.

### Compaction and Strength Test of Untreated Specimens

The oven-dried dune sand was mixed with predetermined amounts of water in a Hobart laboratory mixer (C-10) for one minute. Approximately 1000 grams of moistened sand was used to fabricate a specimen of 4 inches in diameter and 2.5 ± .1 inches in height. One group of specimens was fabricated

using the vibratory kneading compactor and the other group was fabricated using the Marshall compactor.

The modified gradation is a blend of 30 percent copper mill tailings and 70 percent dune sand. The blend was mixed thoroughly by hand, then mixed in the Hobart mixer. The predetermined amount of water was added to the blend and mixed for one minute. Approximately 1000 grams of the moistened mixture was used to fabricate each specimen using the vibratory kneading compactor.

Immediately after compaction the specimen was extruded from the mold and the total weight and height of the specimen in grams and inches, respectively, were recorded. The moisture content at compaction was then determined according to the ASTM procedure number C-566.

The dry density of the specimens was computed as follows:

$$\gamma_d = \frac{.3W}{H} \left(\frac{100}{100+M}\right)$$

$\gamma_d$ is the dry density in pounds per cubic foot,

W is the total weight of the specimens in grams,

H is the height of the specimen in inches,

M is the moisture content in percent.

Using the vibratory kneading compactor, samples of dune sand and modified gradation dune sand were compacted at 10, 12, and 14 percent moisture content. Three specimens

were prepared for each moisture content, then tested immediately after compaction with the Hveem stabilometer.

## Preparation of Asphalt Treated Specimens

### Trial Emulsified Asphalt Mixtures

The amount of premixing water prior to the addition of the emulsion, which results in the best coating of sand particles, was determined. Approximately 500 grams of oven-dried dune sand was mixed with varying amounts of water in a Hobart mixer for one minute, then a selected amount of emulsion was added and mixed for another minute. These mixes containing the selected amount of asphalt emulsion and varying amounts of premixing water were allowed to air dry at room temperature. Each mix was examined visually for the suitability of the asphalt coating. The uniformity of color is a good indication of coating (17).

Based on dry weight of sand, 5.5 percent, premixing water gave the best coating, when using 9 percent SS-1 emulsion; and 6.5 percent premixing water gave the best coating when using 8 percent CSS-1 emulsion due to the different amount of water in the emulsions.

Based on the above coating test, the premixing water will be adjusted so that the total moisture content (premixing water + water from emulsion) was approximately the same for each mixture. For example, a mixture having

percent SS-1 emulsion and 5.5 percent premixing water, the total moisture content was 9 percent. To obtain the total moisture content of 9 percent, using 8 percent SS-1 emulsion, the premixing water was increased to 5.9 percent. This calculation is based on the SS-1 emulsion contains 61.6 percent asphalt and 38.4 percent water.

Mixing

The Hobart laboratory mixer (C-10) was used for all preparation of mixes (Figure 4). The required amount of water was added to dune sand and mixed for one minute. The desired amount of asphalt emulsion was added, then the contents were mixed again for one minute. Enough mixture was prepared to fabricate three specimens for each emulsion content. Approximately 1,000 grams of mixture was required to fabricate each specimen.

The mixture of sand and base asphalt was prepared by heating both the sand and the asphalt. Enough sand to make three specimens was introduced into the mixing bowl, then heated in a forced-draft oven at temperature of 280°F. The base asphalt was heated to a temperature of 280°F in a pouring pot. The desired amount of hot molten asphalt was poured in the mixing bowl, then the contents were mixed for approximately three minutes. The hot mix was kept in an oven at 280°F in three separate pans, each containing approximately 1,000 grams ready for compaction.

Figure 4. Hobart Laboratory Mixer (C-10)

Vibratory Kneading Compaction

The vibratory kneading (V.K.) compactor developed by Jimenez (15) is shown in Figure 5. This compactor is believed to be more appropriate to compact sand since sand grains respond better to vibratory compaction. In this method of compaction, the top turntable is tilted, so that an horizontal component of compaction force can be obtained. The compaction is affected by impact, and during compaction the tiled mold was rotated at 17.5 r.p.m.. After compaction, the turntable was leveled for a leveling load.

This compactor was used to fabricate specimens of 4 inches in diameter and 2.5 $\pm$ .1 inches in height. Compaction was conducted using one layer and the angle of tilt of one degree with a compaction period of two and a half minutes. The leveling load period was 30 seconds.

The densities of the emulsion treated specimens on a dry aggregate base were determined as follows:

$$\gamma_T = \frac{.3W}{H} \left(\frac{100}{100+F}\right)$$

where:

$\gamma_T$ is the dry density of the treated mixture in pounds per cubic foot,

W is the total weight of the specimen in grams,

H is the height of the specimen in inches,

F is the total liquid content (emulsion + water).

All specimens were compacted at room temperature, except those treated with the base asphalt. The hot mixture

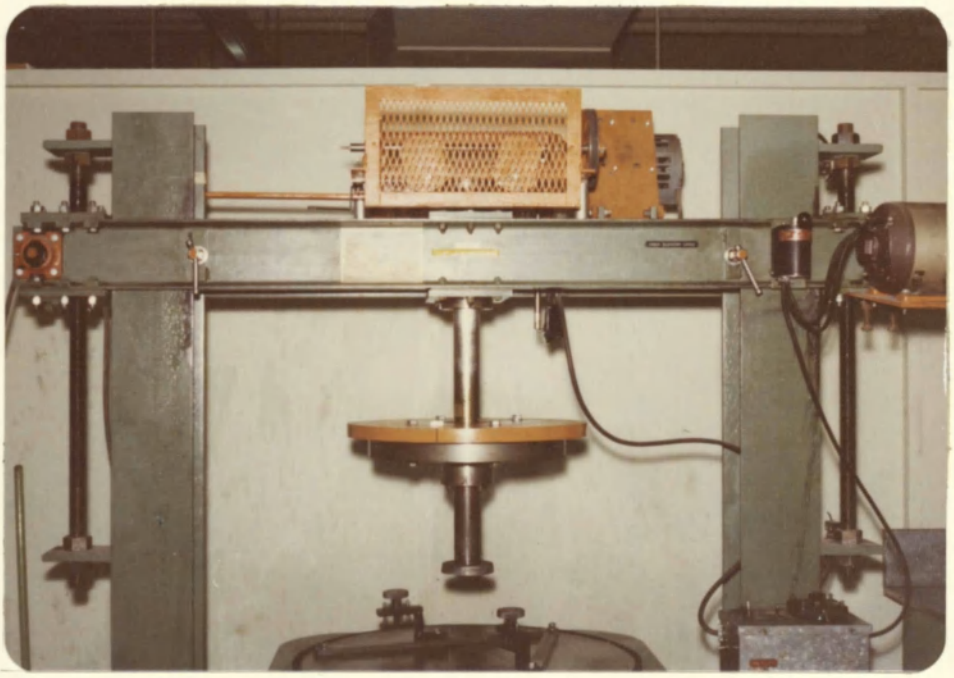


Figure 5. Vibratory Kneading Compactor
(a) Loading System

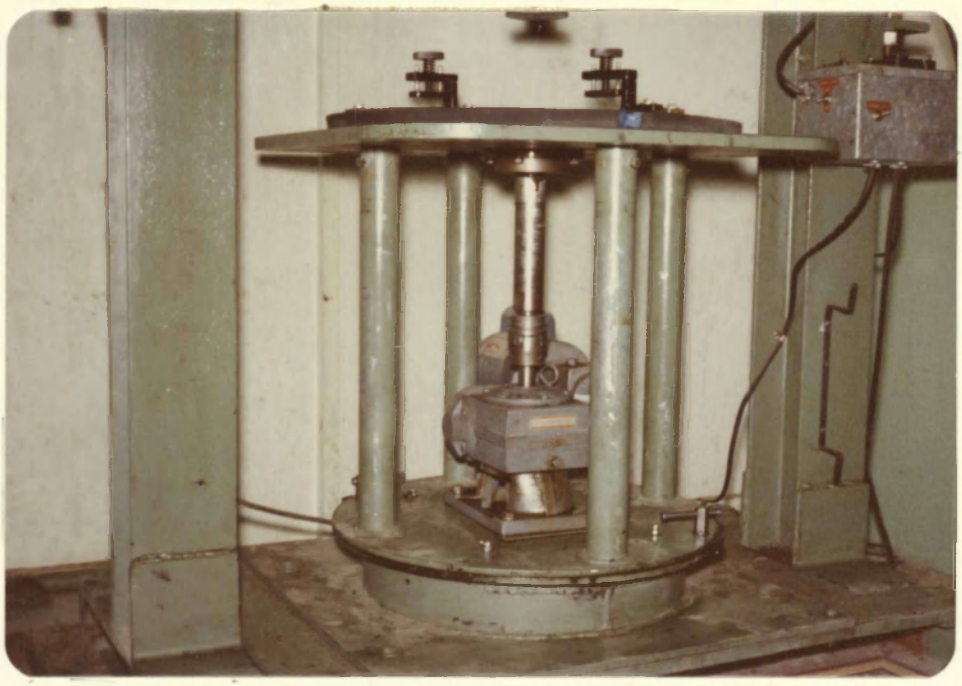


Figure 5, Continued
(b) Turntable

which was kept at 280°F, was brought immediately from the oven and compacted in the preheated molds. The dry density of the treated base asphalt specimens were determined by using the above formula. The asphalt content was considered in the total liquid content.

Marshall Compaction

The Marshall compactor was a 10 pound hammer falling through a height of 18 inches. For detailed information refer to reference (22).

Figure 6 shows a photograph of the compactor in which the hammer was operating by an electric motor. Specimens of 4 inches in diameter and 2.5 $\pm$ .1 inches were fabricated using 50 blows applied to each end of the specimen.

The dry densities of emulsion treated specimens were determined as for specimens compacted by the vibratory kneading compactor.

All specimens were compacted at room temperature except those with the base asphalt. The hot mixture which was kept at 280°F, was brought immediately from the oven and compacted by using the preheated molds and hammer. The dry densities were also determined as for specimens compacted by the vibratory kneading compactor.

Curing

The emulsion treated specimens were cured in an oven at a temperature of 140°F for twenty-four hours. This curing

Figure 6. Marshall Compactor

dries out the specimens completely. The base asphalt treated specimens were cured for twenty-four hours at room temperature ($77^{o} \mp 5^{o}F$).

## Testing of Treated Specimens

The asphalt emulsion treated specimens and the base asphalt treated specimens were tested for strength using three apparatus, the Hveem stabilometer, double punch, and the Marshall device. The specimens were tested at three temperatures, $77^{o}$, $104^{o}$, and $140^{o}F$. For the first testing condition, the specimens were kept at the room temperature of $77^{o}F$ for three hours prior to the test. For the last two testing conditions, the specimens are kept in an oven at $104^{o}$ and $140^{o}F$ for three hours before testing.

Samples were tested in triplicate for each test condition, and the average of the three or two values, depending on the reproducibility, was taken as the final value and reported.

### Hveem Stabilometer Tests

The Hveem stabilometer developed by Hveem in 1930 (23), was used to test specimens for their stability "S" and resistance "R" values. A diagrammatic representation is shown in Figure 7. In this test, when a vertical load is applied to the specimen, a horizontal load is transmitted through the diaphragm to the liquid. The magnitude of this horizontal pressure is read on a gauge. The Hveem

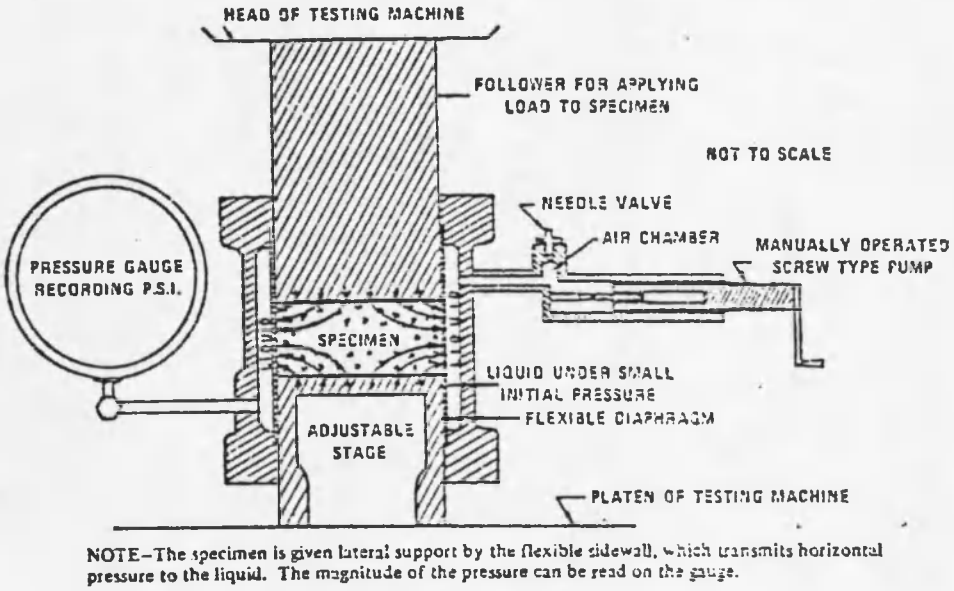



Figure 7. Diagrammatic Sketch of Hveem Stabilometer -- Source: The Asphalt Institute (22, p54)

stabilometer can be considered as a triaxial testing device of the closed type in which the horizontal pressure varies with the application of the vertical loads unlike that of the conventional triaxial test in which the horizontal pressure is kept constant and the specimen is loaded until failure by a vertical deviator stress.

The stability and resistance values are influenced primarily by internal resistance, and only slightly by the resistance of the material due to cohesion. The resistance and the stability values of a mixture was computed on the bases of the horizontal pressure transmitted at vertical loads of 160 p.s.i. and 400 p.s.i. respectively. Hveem ascribed stability as follows (24, p.7), "It was soon evident that the stabilometer principle (which was later designated in certain quarters as a triaxial shear or compression test) primarily measures interparticle friction which is the principle (SIC) variable that contributed to stability".

Hveem established an arbitary scale running from zero to 100 for reporting the stabilometer results. A value of zero corresponds to a liquid having no measurable internal friction to slowly applied loads, and in the other extreme, a value of 100 percent corresponds to a hypothetical solid that will transmit no measurable horizontal pressure.

The photographs in Figures 8 and 9 show the Hveem stabilometer and testing machine. For the details of the test refer to reference (22) by the Asphalt Institute.

The stability, S values, are obtained by the following relationship (23).

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

where:

S is the stability value expressed as a percentage,

$P_v$ is the vertical pressure (400 p.s.i.),

$P_h$ is the horizontal pressure (stabilometer reading at Pv = 400 p.s.i.),

D is the turns displacement reading.

The resistance values are obtained by the following relationship (22):

$$R = \frac{100}{\frac{2.5}{D}\left(\frac{P_v}{P_h} - 1\right) + 1}$$

where:

R is the resistance value expressed as a percentage,

$P_v$ is the vertical pressure (160 p.s.i.),

$P_h$ is the horizontal pressure (stabilometer reading at Pv = 160 p.s.i.),

D is the turns displacement reading

Double Punch Test

A simple indirect tension test that was developed by Fang and Chen (25), was used recently by Jimenez (26) to test asphaltic mixtures for tensile strength.


Figure 8. Hveem Stabilometer

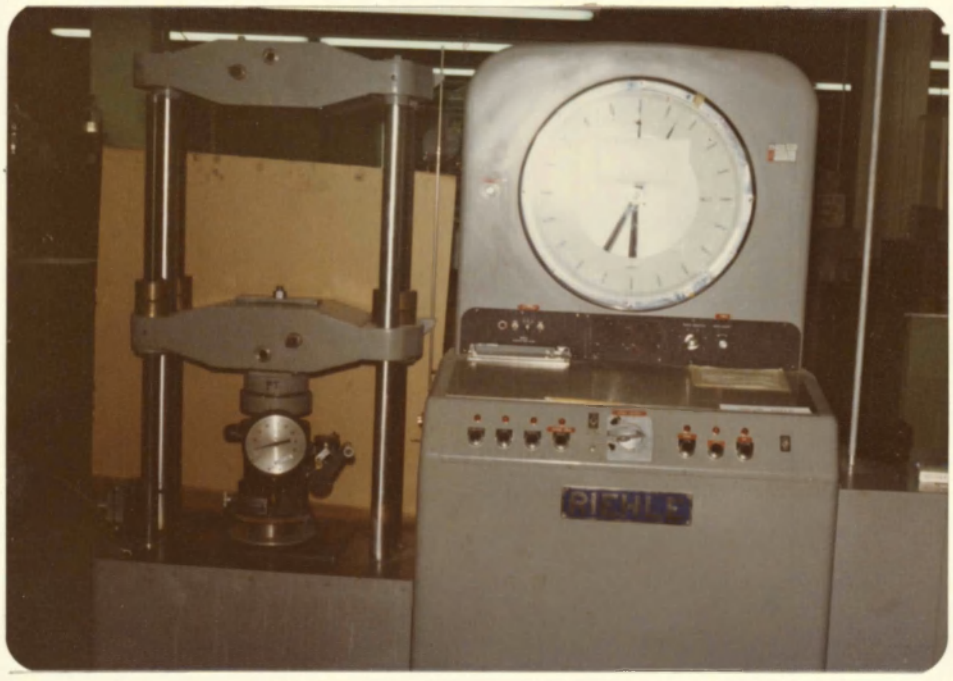


Figure 9. Hveem Stabilometer and Testing Machine

This test consists of loading with two one-inch diameter steel punches, centered on both the top and bottom surface of a cylindrical specimen. The loading rate was set for one inch per minute. The maximum load registered by the testing machine was considered the failure load.

The specimens, after being immediately tested by the Hveem stabilometer, were tested by the double punch device. Figure 10 shows a specimen being tested.

The tensile strength is calculated by the following equation:

$$\sigma t = \frac{P}{\pi(1.2bH-a^2)}$$

where:

$\sigma t$ is the tensile strength in p.s.i.,

p is the maximum load in pounds,

a is the radius of punch in inches,

b is the radius of specimen in inches,

H is the height of specimen in inches.

Vacuum Soak Test

In order to assess the effect of water on the emulsion treated specimens, a vacuum soak test was conducted similar to the test developed by Dunning and Turner (27; in 17). A modification of the test was made by changing the amount of vacuum and the period under vacuum saturation. The modification was made by subjecting the cured specimens to 26 inches of mercury vacuum for 15 minutes, then soaking for

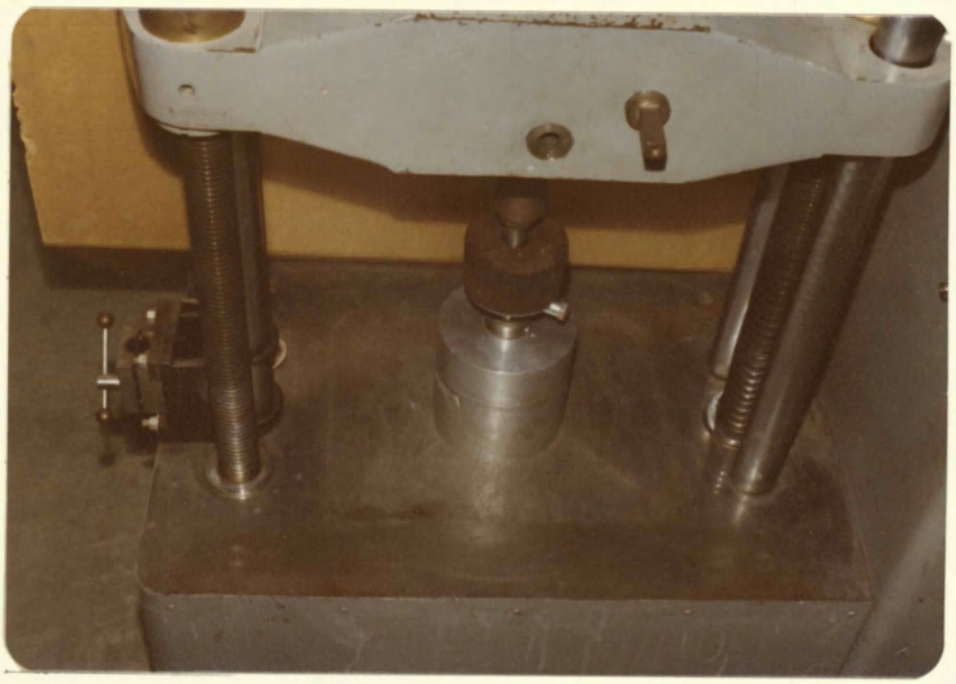


Figure 10. Double Punch Test

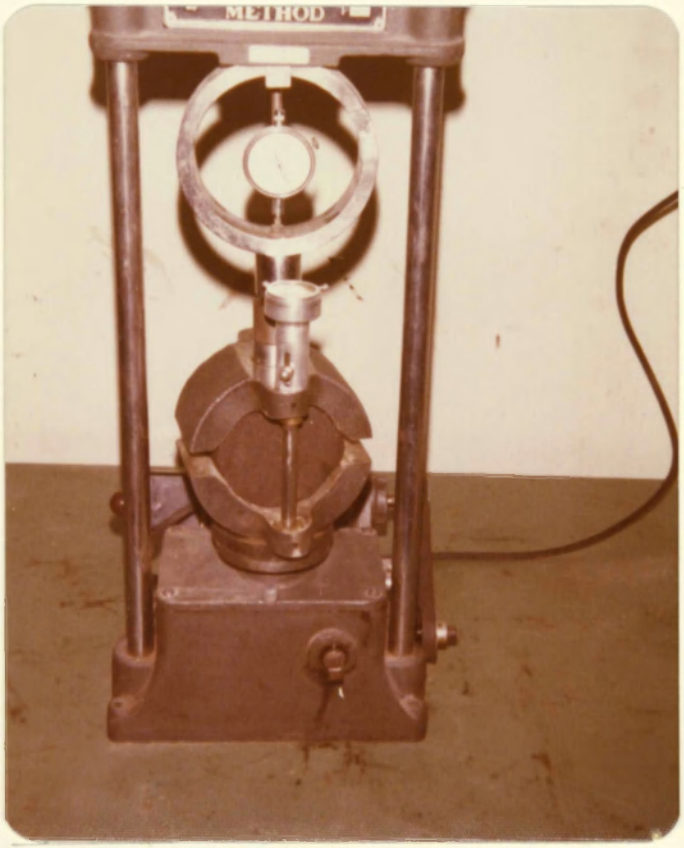
another 15 minutes, instead of using 26 inches of mercury vacuum for one hour, then soaking for another hour.

In this test, the cured specimens in their molds were placed in a bell jar with a cover of water over the specimens. The bell jar was evacuated to 26 inches of mercury for 15 minutes, then the vacuum was released slowly and the specimens were allowed to soak in water for 15 minutes. Figure 11 shows the apparatus being used for vacuum soaking. The specimens were extruded from the molds and weighed to determine the moisture pick-up. Then the specimens were tested immediately by the Hveem stabilometer and double punch.

Marshall Test

The Marshall stability test itself is a type of unconfined compression test, in which the cylindrical specimen was compressed radially by a constant rate of deformation of 2 inches per minute. The maximum load in pounds to cause failure was recorded as the Marshall stability value (M.S.), and the deformation in units of 0.01 inches was recorded at failure as the Marshall flow value (M.F.). For details of the test refer to the reference (22) of the Asphalt Institute. Figure 12 shows the Marshall testing device.

Figure 11. Vacuum Satruation Set Up




Figurel2. Marshall Testing Device

# CHAPTER V

# DATA PRESENTATION AND ANALYSIS

## Effect of Emulsion Content on the Vibratory Kneading Density

Vibratory kneading was used to compact the untreated and emulsion treated dune sand with the results shown in Figure 13 and Table 4 and 6 of Appendix B. The results show that the density of emulsion treated specimens decreased with the increase of the liquid content (emulsion plus water). Specimens treated with CSS-1 emulsion gave higher densities than those that were treated with SS-1 emulsion. This was due to the fact that SS-1 emulsion had lower penetration base asphalt than CSS-1 base asphalt (Table 1, Appendix A). The harder the asphalt (low penetration) contained in the mixture the higher the resistance to compaction, which results in lower densities.

## Effect of the Residual Asphalt Content on S, R, and $C_t$

Figures 14 and 15 demonstrate the effect of residual asphalt content on the resistance and stability values of emulsion treated dune sand specimens. The amount of asphalt influences the interparticle friction. With the increasing quantities of asphalt, the interparticles friction was reduced, consequently the resistance and stability values which

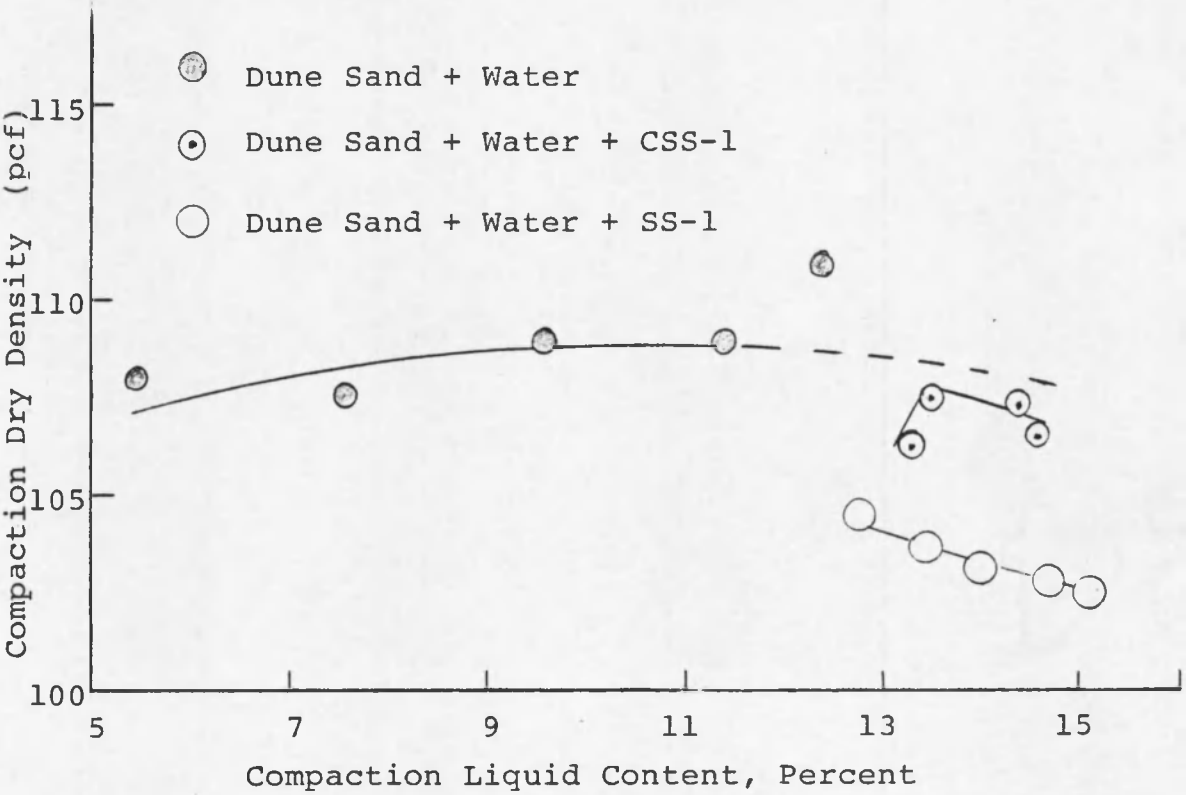



Figure 13. Compaction Dry Densities versus Compaction Liquid Content for Untreated and Treated Specimens (Vibratory Kneading Compaction)

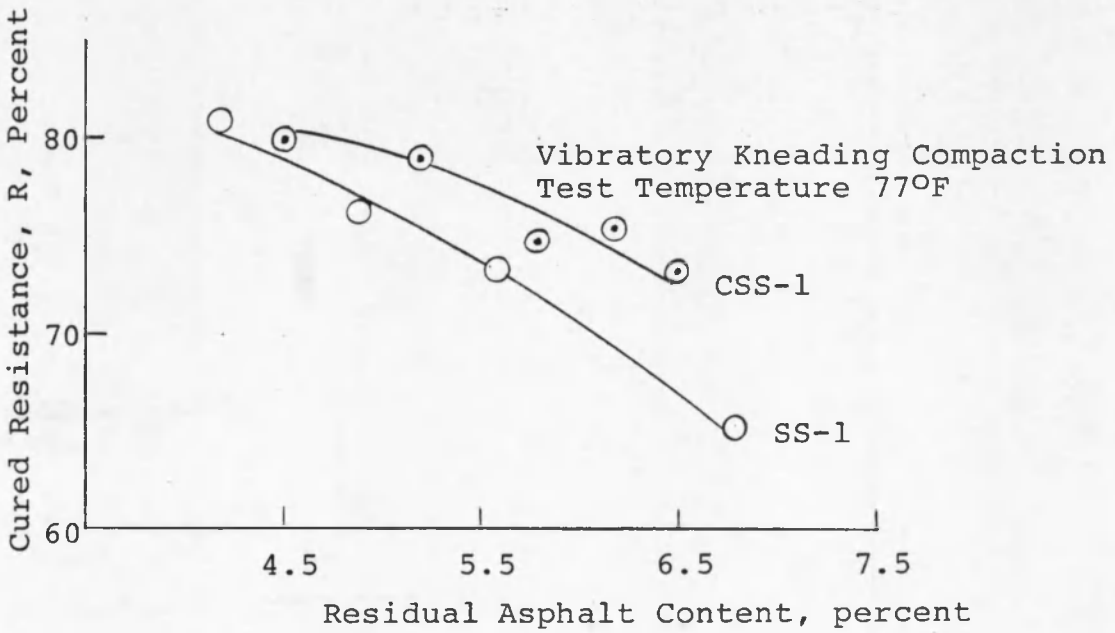



Figure 14. "R" versus Residual Asphalt Content for Treated Dune Sand

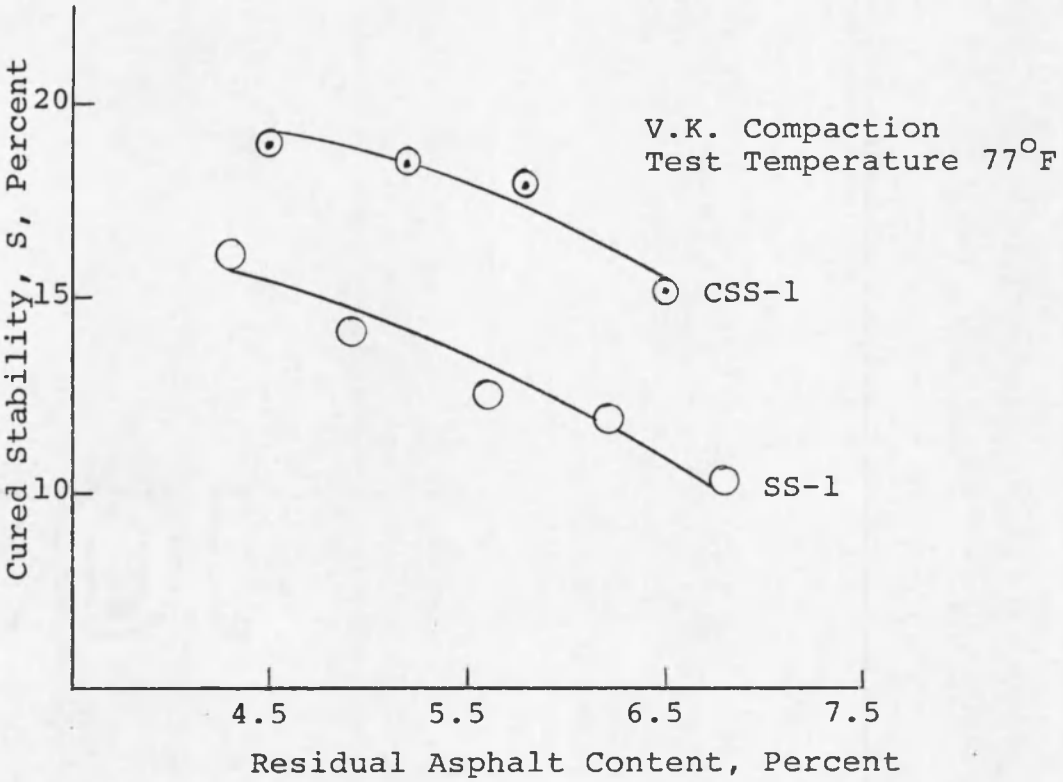



Figure 15. "S" versus Residual Asphalt Content for Treated Dune Sand

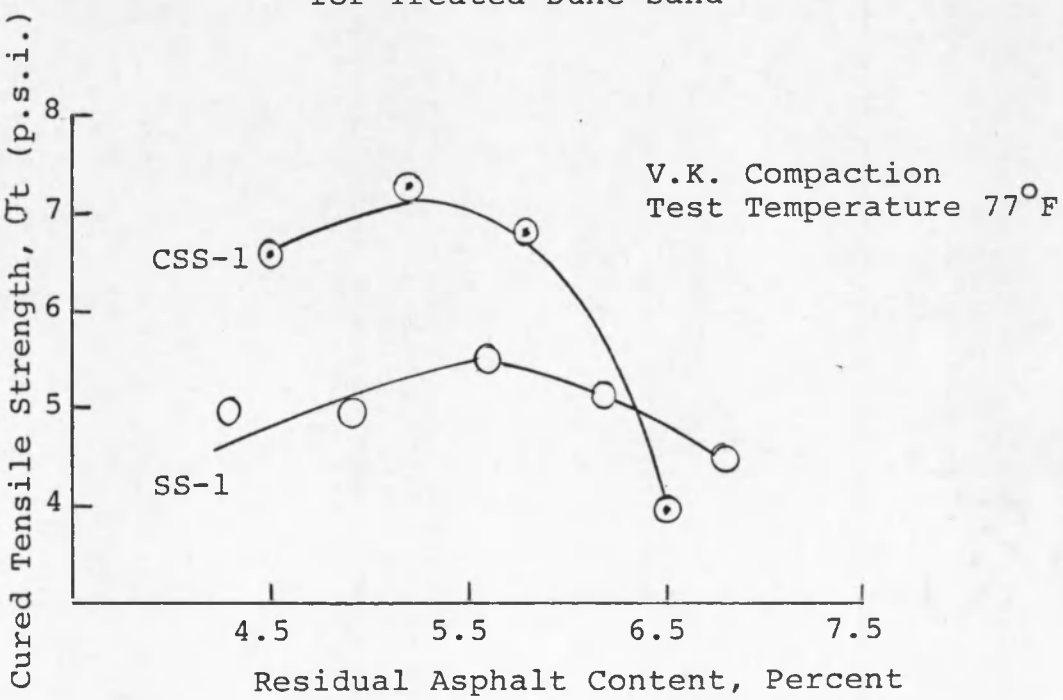



Figure 16. Tensile Strength versus Residual Asphalt Content for Treated Dune Sand

are a measure of internal friction were reduced. Figures 14 and 15 also show that CSS-1 emulsion treated dune sand specimens gave higher resistance and stability values than those treated with SS-1 emulsion. These results could be attributed to the higher densities obtained with the specimens treated with CSS-1 emulsion.

Figure 16 shows the effect of residual asphalt content on the double punch tensile strength values of emulsion treated dune sand specimens. The results show an optimum residual asphalt content of 5.6 percent using SS-1 emulsion, and 5.2 percent using CSS-1 emulsion for maximum tensile strength. The results also show higher tensile strength obtained with CSS-1 emulsion treated specimens than those obtained with SS-1 emulsion treated specimens. These results could be attributed to the higher densities obtained with CSS-1 emulsion treated specimens and may be also due to the preferential of silicious material (sand) to cationic emulsion treatment.

Specimens of untreated dune sand compacted by the vibratory kneading at 10, 12, and 14 percent moisture content, which were tested immediately after compaction showed higher resistance and stability values than emulsion treated specimens (Figures 17 and 18). The effect of the increase in moisture content on the resistance and stability values of untreated dune sand was similar to the effect of increasing

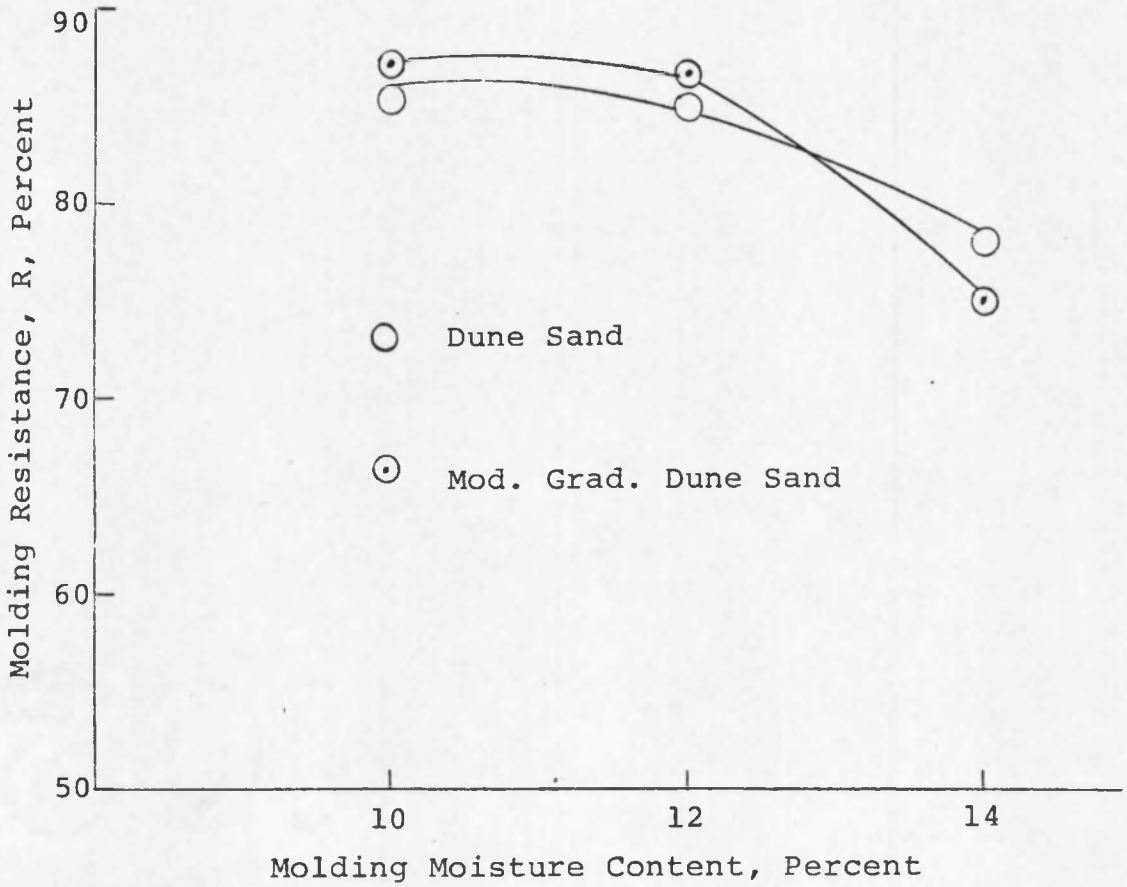



Figure 17. "R" versus Molding Moisture Content for Untreated Specimens (Vibratory Kneading Compaction)

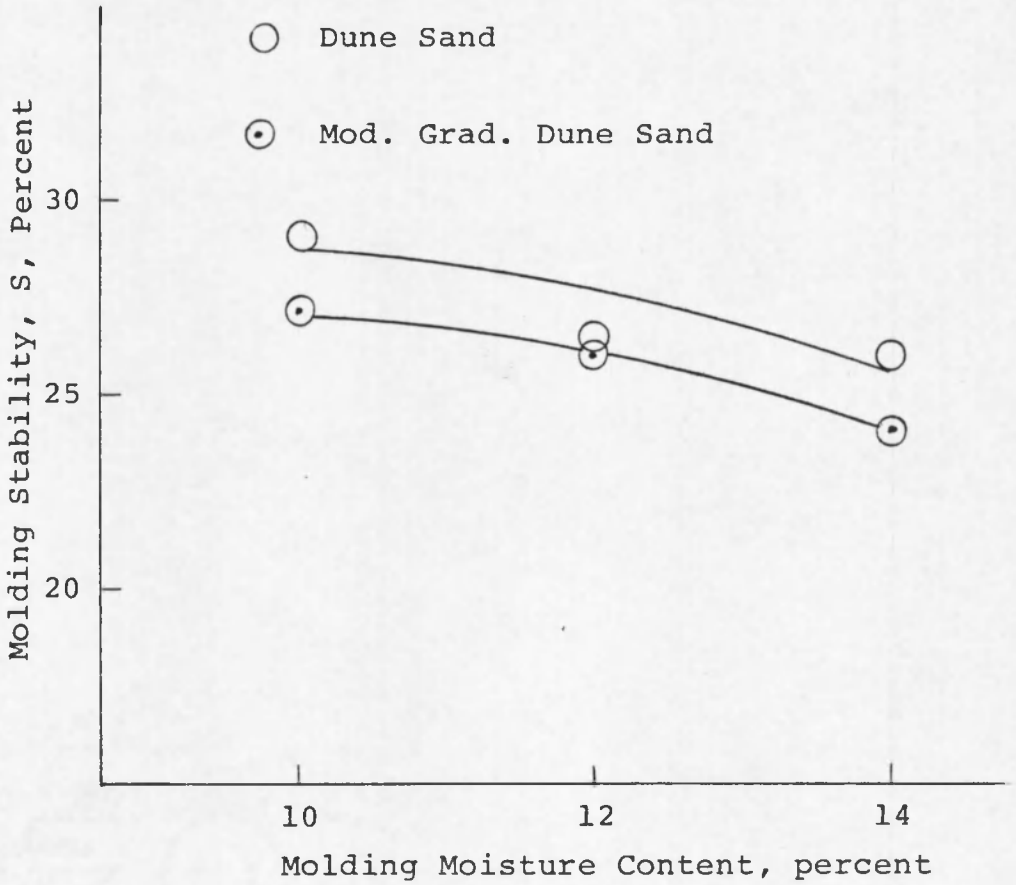



Figure 18. "S" versus Molding Moisture Content for Untreated Specimens (Vibratory Kneading Compaction)

the residual asphalt content in decreasing the resistance and stability values of the emulsion treated dune sand specimens.

## Effect of Dune Sand Gradation

A modification to the gradation of dune sand was made by adding 30 percent copper mill tailings to the dune sand (Figure 1). The effect of grading dune sand on the densities of the untreated and treated emulsion specimens are illustrated in Figure 19 and Tables 4, 6, and 8 of Appendix B. The results show that the addition of the copper mill tailings to the dune sand had the effect of increasing both the untreated and treated emulsion specimens densities.

Figures 17 and 18 show the resistance and stability values of untreated dune sand and modified gradation specimens compacted at 10, 12, and 14 percent moisture content. Although the untreated modified gradation dune sand showed higher densities than untreated dune sand, the results show no improvement in the resistance and stability values. The increase in density for the modified gradation dune sand might be caused by the high specific gravity of copper mill tailings compared to dune sand alone, more than that of the copper mill tailing acting as a filler.

Figures 20 and 21 demonstrate the effect of grading dune sand on the resistance and stability values of emulsion treated specimens. The results show an increase in the

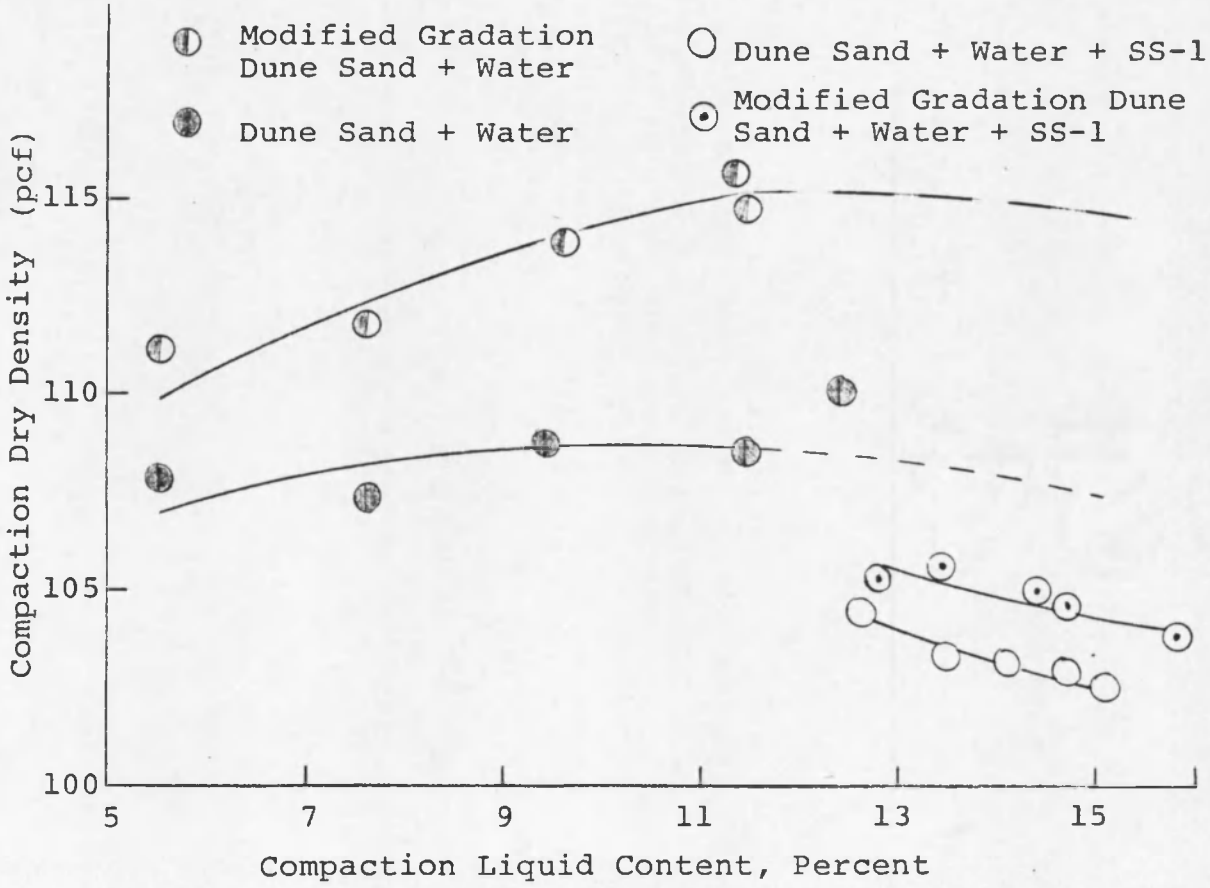



Figure 19. Compaction Dry Densities versus Compaction Liquid Content for Untreated and Treated Dune Sand and Modified Gradation Dune Sand (Vibratory Kneading Compaction)

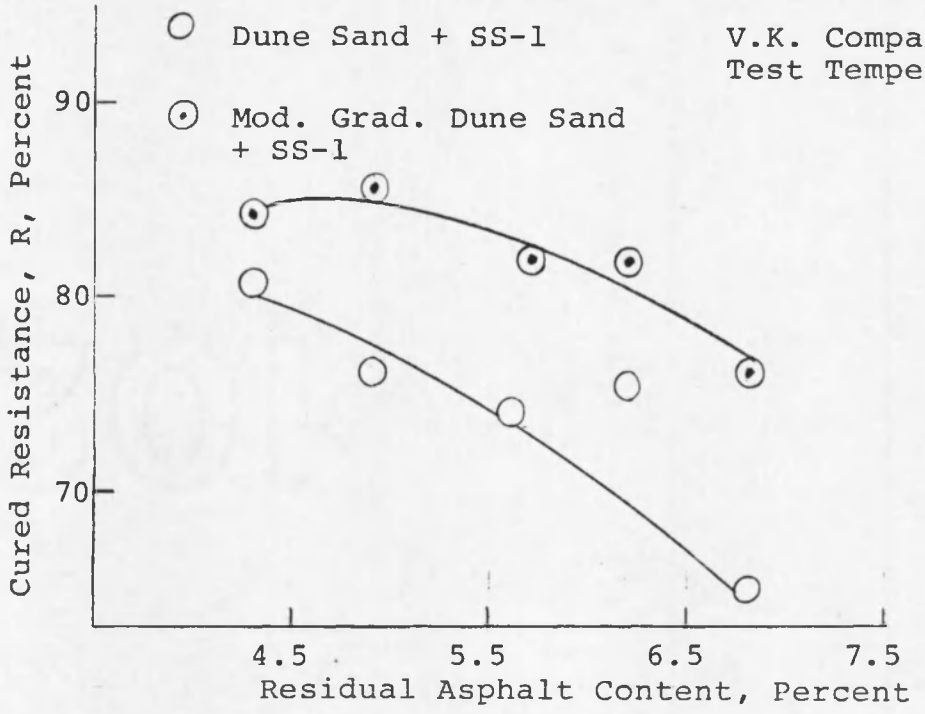



Figure 20. "R" versus Residual Asphalt Content for Treated Dune Sand and Modified Gradation Dune Sand

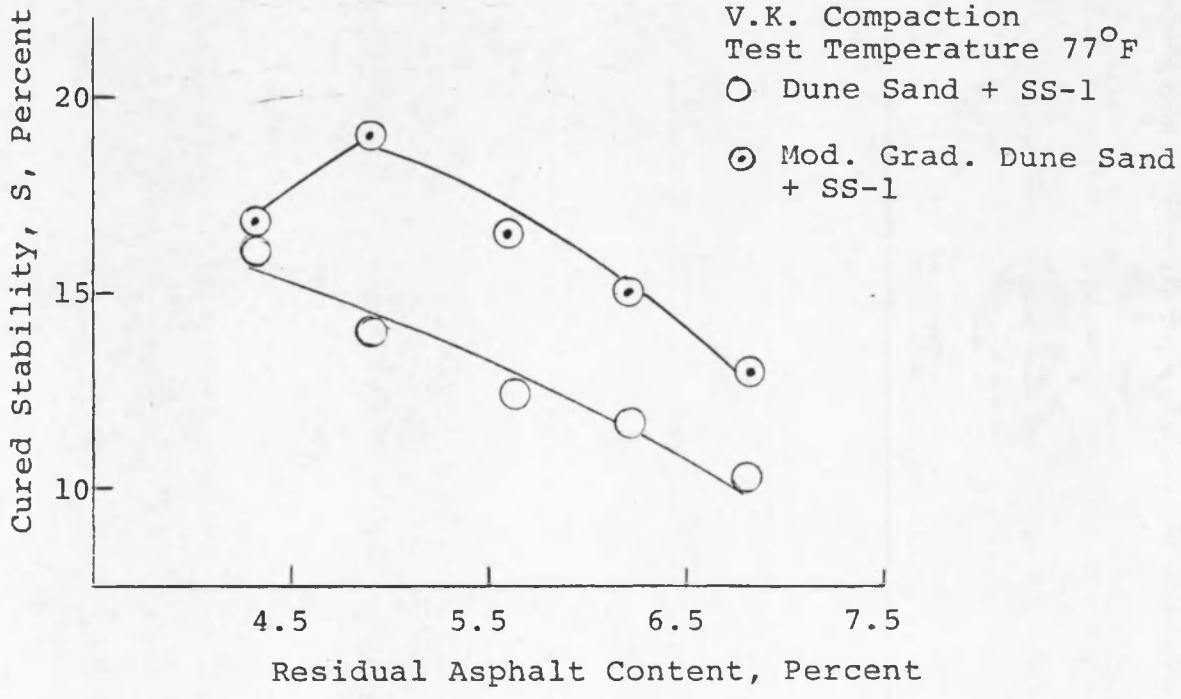



Figure 21. "S" versus Residual Asphalt Content for Treated Dune Sand and Modified Gradation Dune Sand

resistance and stability values by modifying the gradation of dune sand. The modified gradation dune sand have higher surface area than dune sand, therefore, at one residual asphalt content, the modified gradation dune sand has a thinner asphalt film coating the particles compared to dune sand. It may be for this reason that the modified gradation sand gave higher resistance and stability values.

Figure 22 shows no improvement in the double punch tensile strength observed by modifying the gradation of dune sand. This may be due to the noncohesive characteristic of copper mill tailings.

Figure 23 shows the effect of grading of dune sand on the air voids with VMA of the treated specimens. The results indicate a very high percentage of air voids and VMA. The addition of copper mill tailings to dune sand had no significant reduction in the percentage of air voids or VMA. The results also indicate that an increase in residual asphalt content causes a reduction in the percentage of air voids, but has no effect on the VMA.

The high percentage of air voids and VMA may not be critical for a base course, which is sealed with asphaltic surfacing to keep out harmful air and water that might cause a reduction in durability.

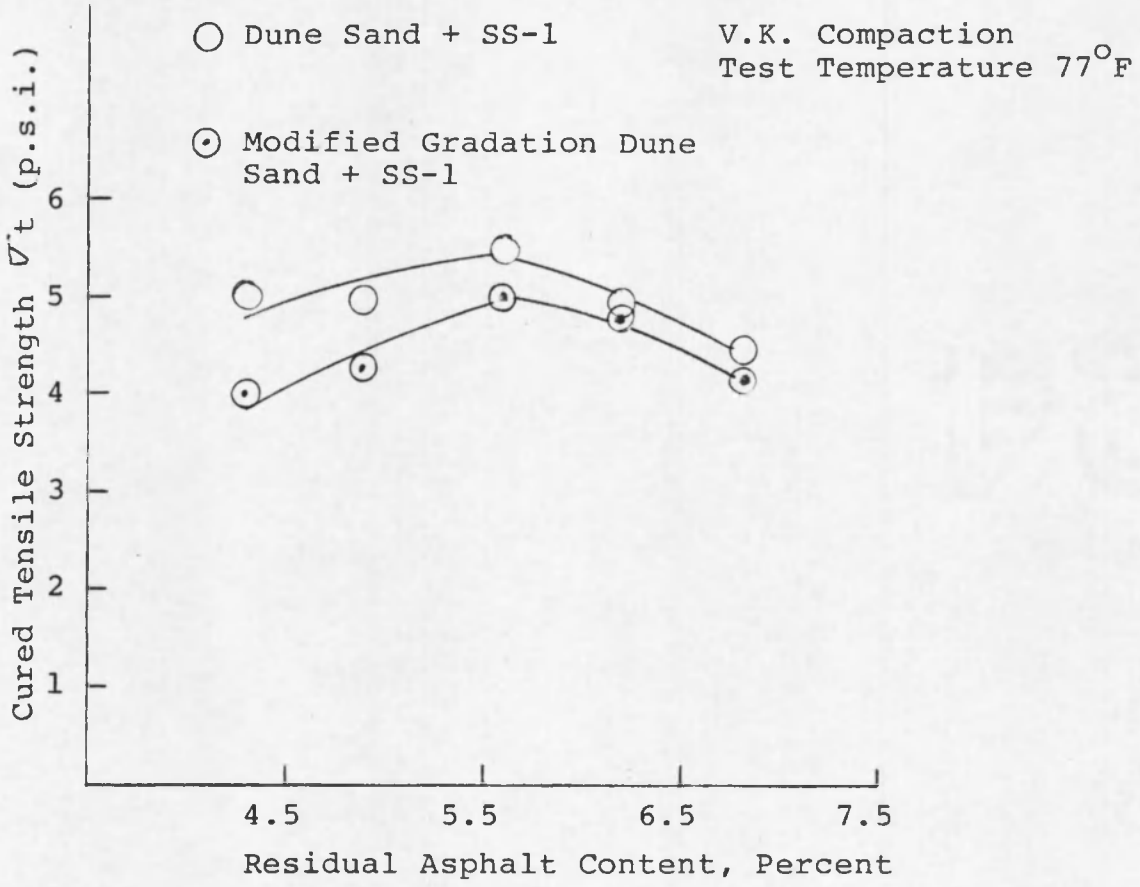



Figure 22. Tensile Strength versus Residual Asphalt Content for Treated Dune Sand and Modified Gradation Dune Sand

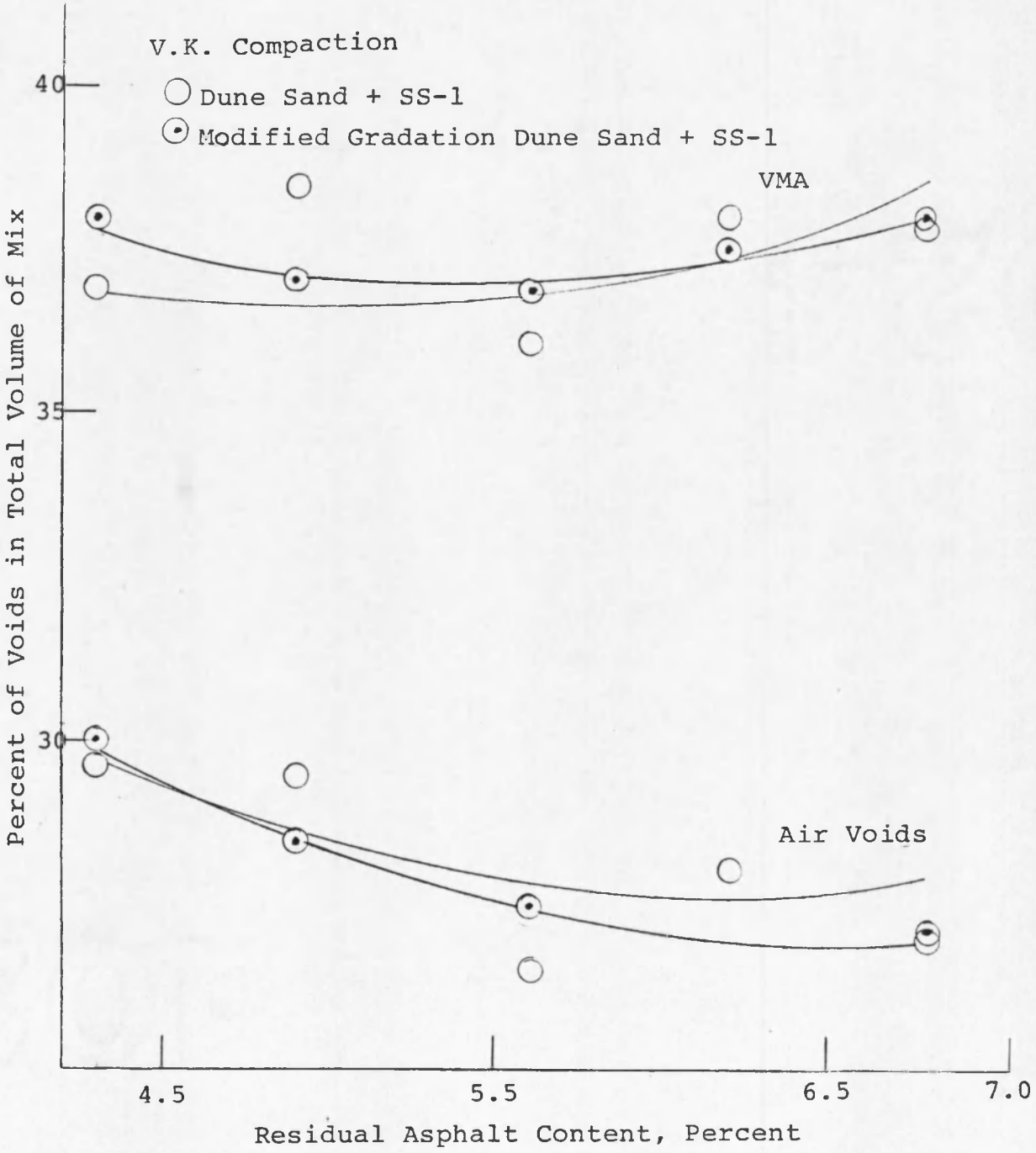



Figure 23. Relationship between Air Voids, VMA and Residual Asphalt Content for Treated Specimens

## Vacuum Soak Test

To determine the waterproofing effect of asphalt emulsion, the stabilized dune sand specimens were subjected to a vacuum soak test. The soaked resistance, stability and double punch tensile strength are shown in Figures 24, 25, and 26. The detrimental effect on the strength values was evident. The results indicated that moisture has a more detrimental effect on the tensile strength than the resistance and stability values. For the emulsion treated dune sand specimens, the moisture pick-up[1] at residual asphalt content 4.3, 4.9, and 5.6 percent, are 12.2, 12.3, and 12.4 respectively (Table 10, Appendix B).

It should be recognized that the Asphalt Institute design criteria for emulsified asphalt road base can not be applied to the treated dune sand, since the method of compaction, soaking, and testing are different than that used in this study (17).

## Effect of Testing Temperature on S, R, and $\sigma t$

Dune sand treated with SS-1 and CSS-1 emulsion were tested at 77°, 104° and 140°F for strength by the Hveem stabilometer and double punch apparatus. Figures 27 and 28 show that the testing temperature had no effect on the

---

1. Moisture pick-up is found by subtracting cured specimen weight from soaked specimen weight, then dividing this result by the cured specimen weight.

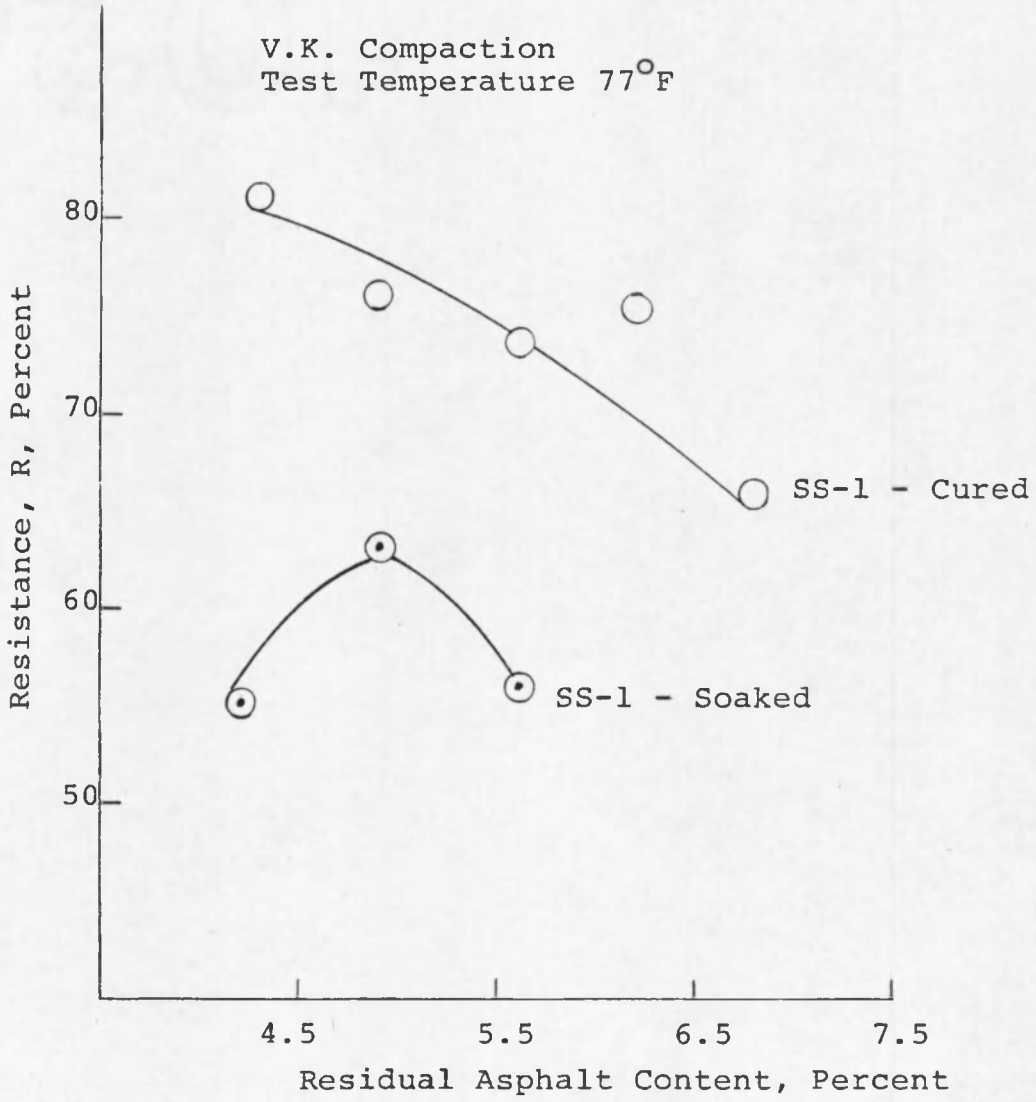



Figure 24. "R" versus Residual Asphalt Content for Cured and Soaked Treated Dune Sand

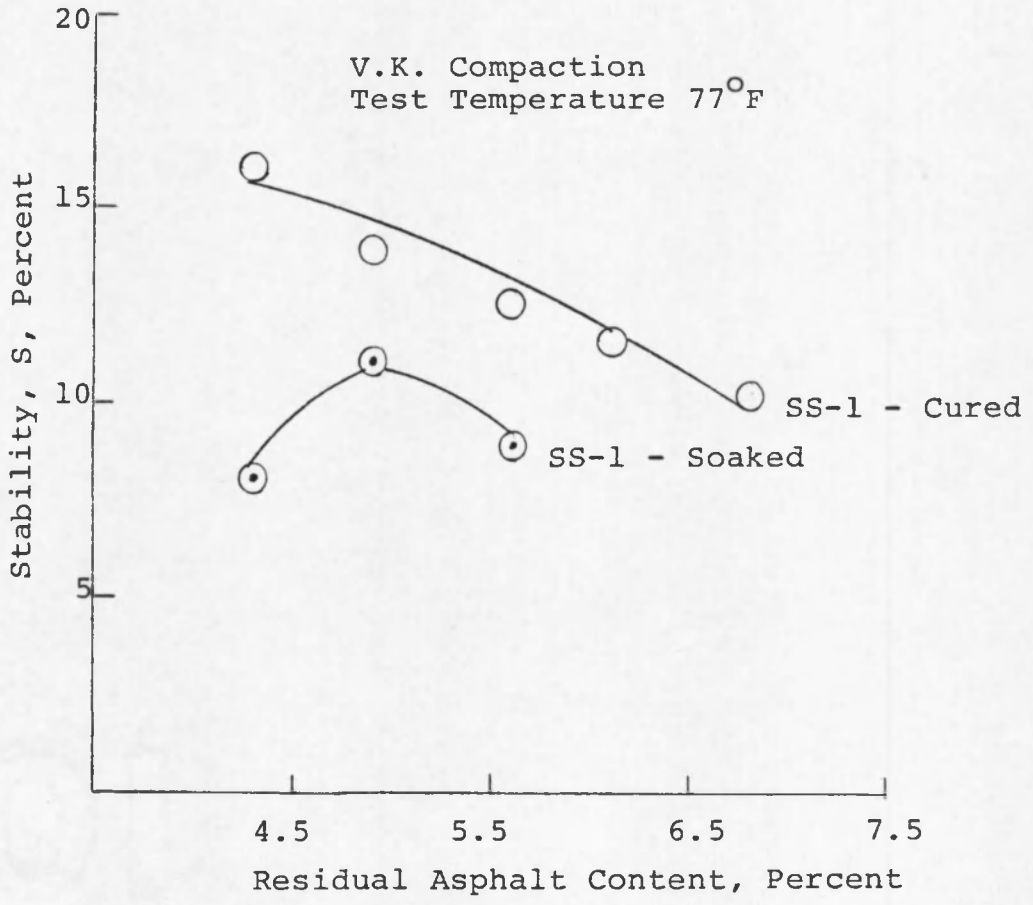



Figure 25. "S" versus Residual Asphalt Content for Cured and Soaked Treated Dune Sand

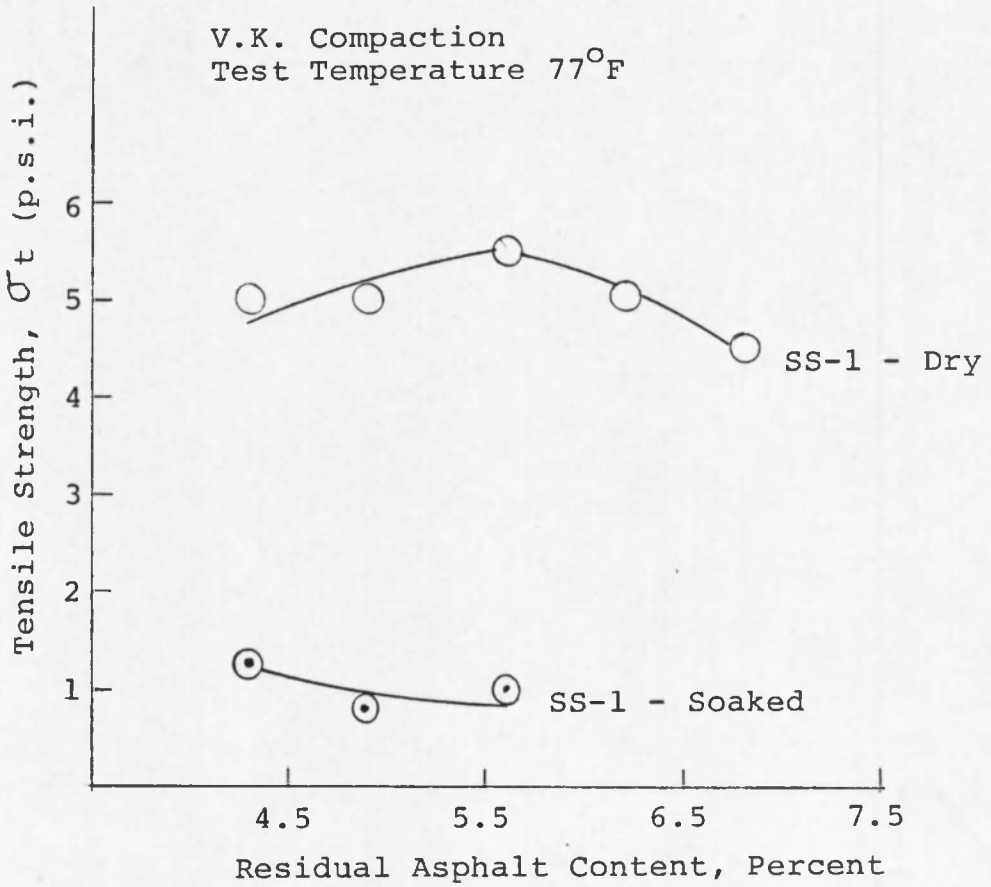



Figure 26. Tensile Strength versus Residual Asphalt Content for Cured and Soaked Treated Dune Sand

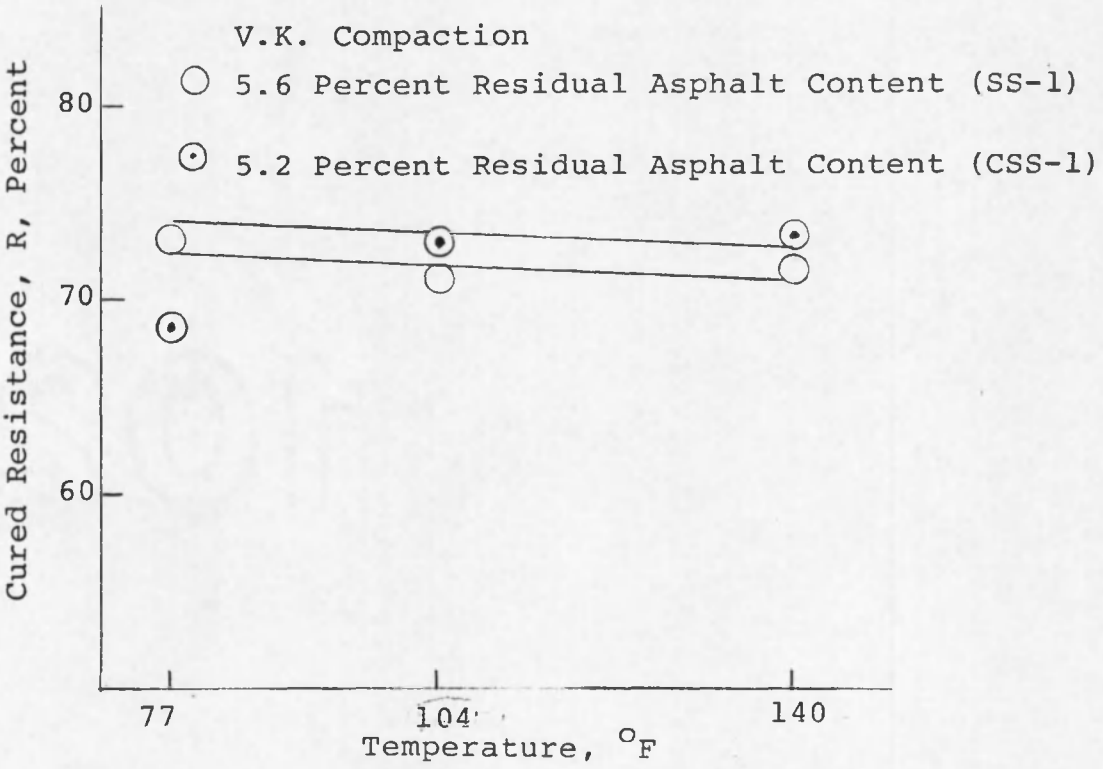



Figure 27. "R" versus Testing Temperature of Treated Dune Sand

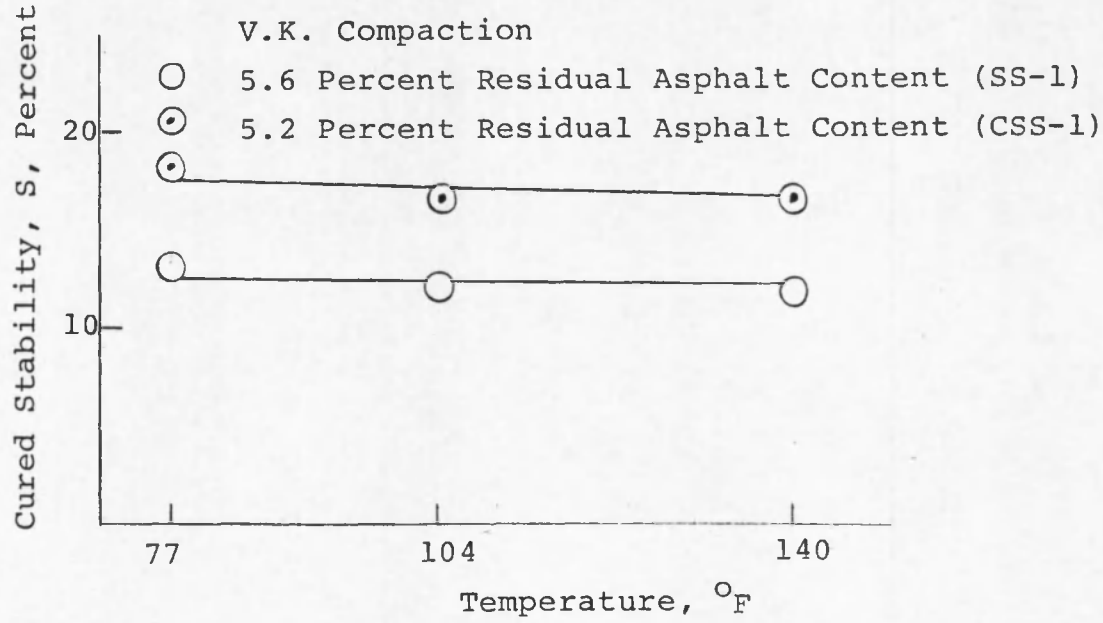



Figure 28. "S" versus Testing Temperature of Treated Dune Sand

resistance and stability values as expected. The frictional resistance is independant of testing temperature.

Figure 29 indicates with the increase in testing temperature, the double punch tensile strength drops significantly. This is due to the thermoplastic characteristics of asphalt in which its viscosity decreases with the increase in temperature. The drop in the tensile strength between 77°-104°F temperature range was higher than the 104°-140°F temperature range.

It can be concluded that at higher temperatures, such as 140°F, the asphalt contributed nothing to the cohesive part of the stability, as measured by the double punch. Also frictional resistance as measured by the stabilometer remains unaffected by temperature changes.

Hot Mix versus Cold Mix Strength (R,S, t)

The base asphalt of SS-1 (asphalt cement) was mixed with dune sand and compacted by the vibratory compactor using the hot mix process. Figure 30 indicates an optimum asphalt content of 5 percent for maximum density. Figures 31 and 32 show that the base asphalt treated dune sand specimens gave higher resistance and stability values than SS-1 treated specimens tested at 77°F. For example, at 5 percent residual asphalt content the emulsion treated dune sand showed a resistance value of 77 and a stability value of 14.5 compared to a resistance value of 82 and a stability value of 25

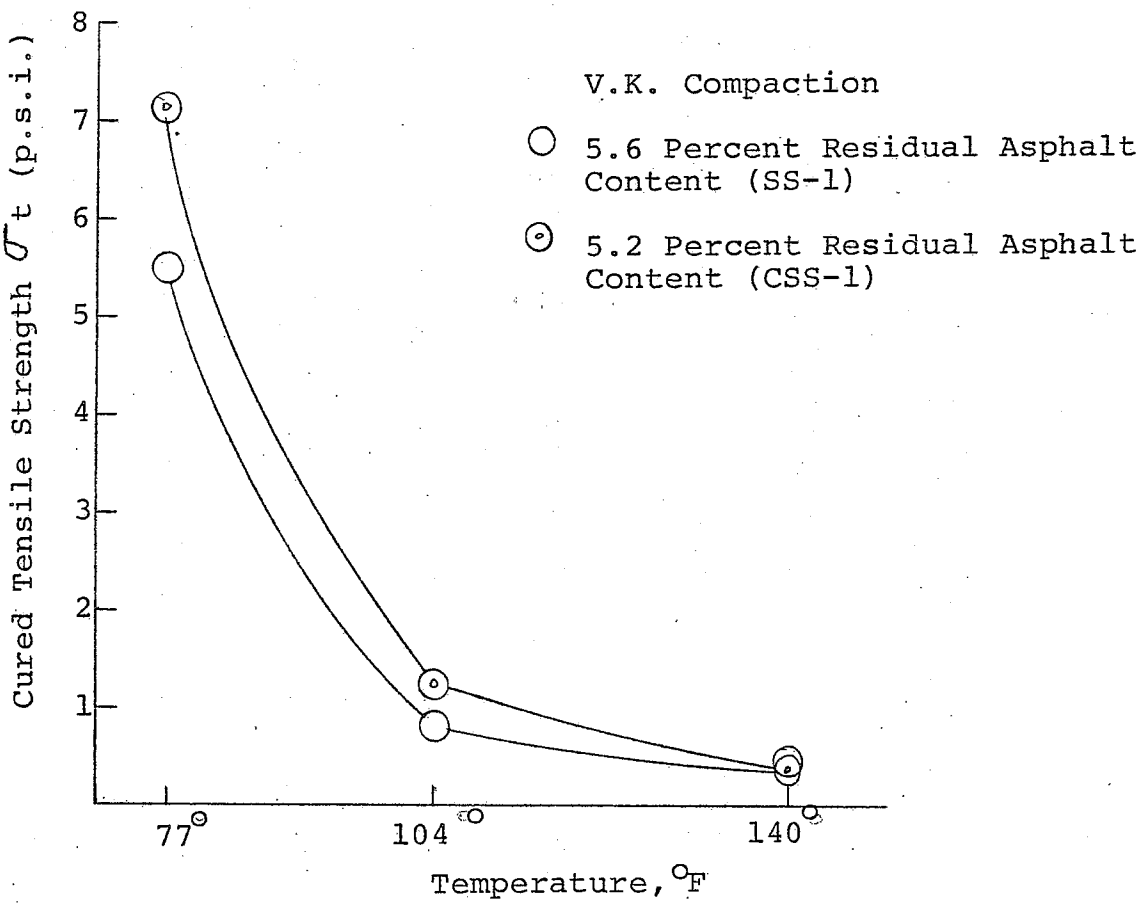



Figure 29. Tensile Strength versus Testing Temperatures of Treated Dune Sand

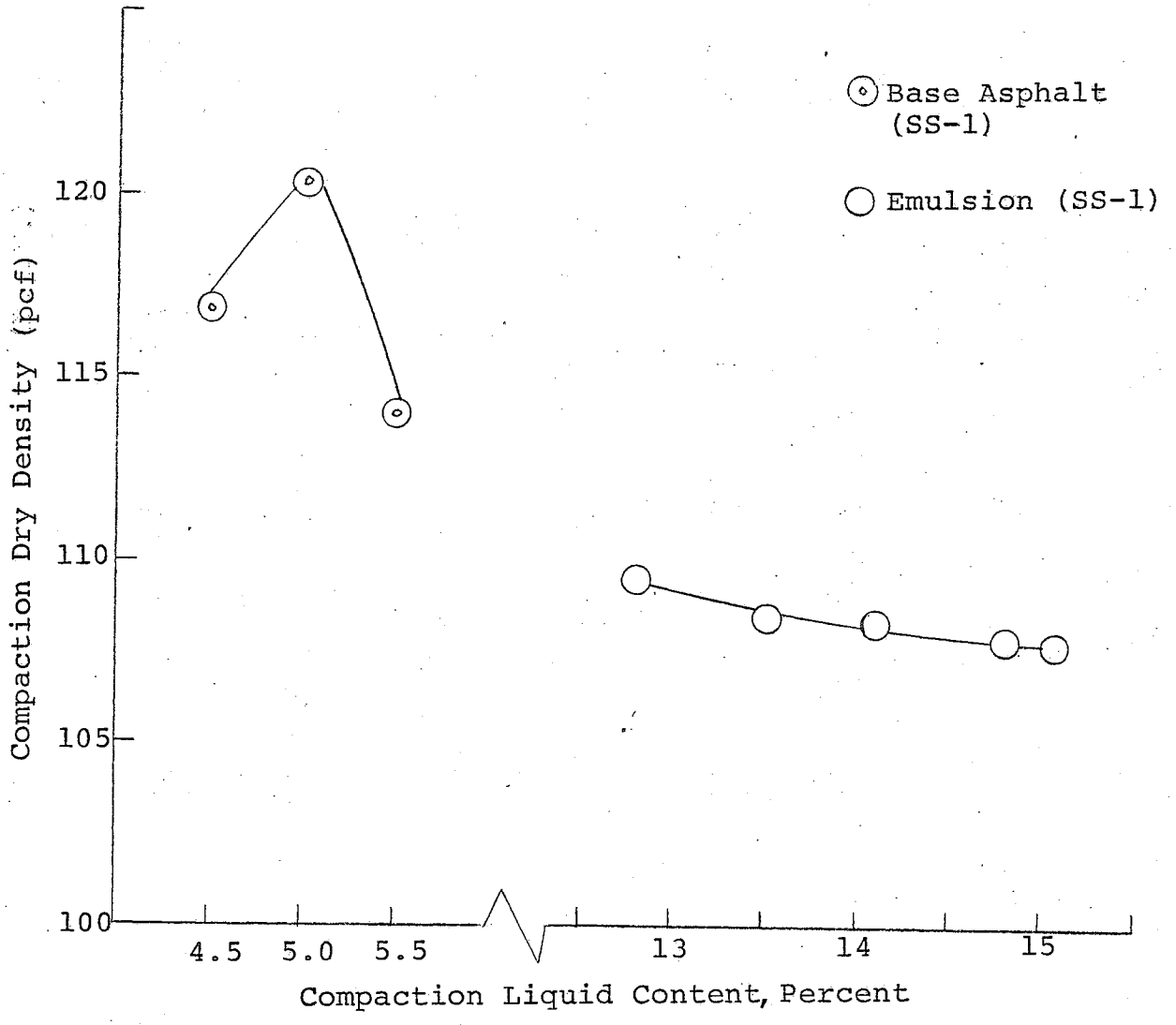



Figure 30. Compaction Dry Densities versus Compaction Liquid Content for Base Asphalt and Emulsion Treated Dune Sand

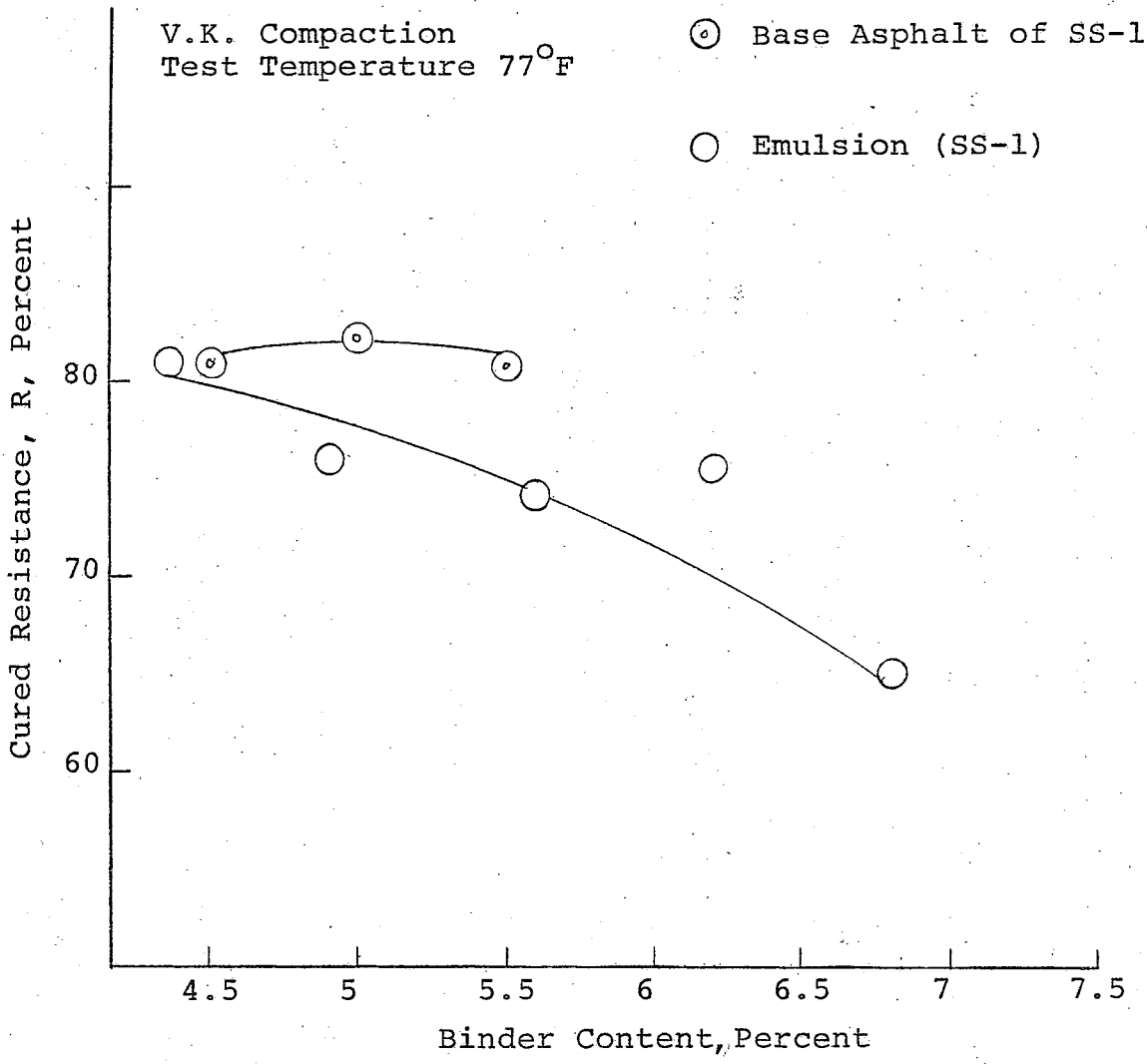



Figure 31. "R" Values versus Binder Content for Base Asphalt and Emulsion Treated Dune Sand

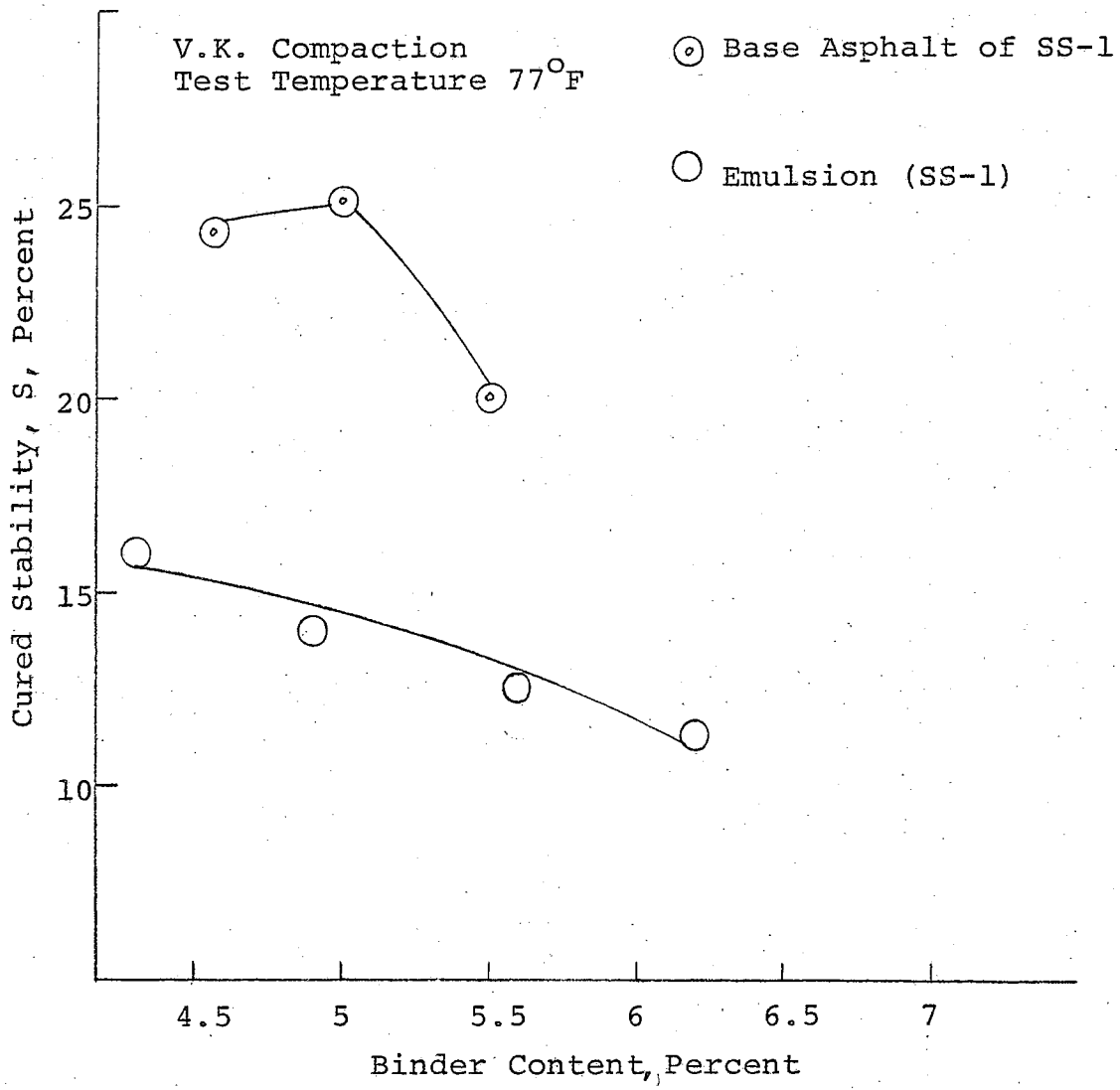



Figure 32. "S" versus Binder Content for Base Asphalt and Emulsion Treated Dune Sand

for the base asphalt treated dune sand. This was probably due to the higher densities of the base asphalt treated specimens compared to the emulsion treated specimens.

Figure 33 indicates that the double punch tensile strength of SS-1 base asphalt specimens was higher than the double punch tensile strength of SS-1 emulsion treated specimens. For example, at 5 percent residual content, the tensile strength is 5 p.s.i. for the SS-1 emulsion treated dune sand compared to a tensile strength of 19 p.s.i. of base asphalt treated dune sand. The reason for this was due to the difference in coating of the sand particles. The hot mix gave a better coating of the sand particles than the cold mix. In the cold mix it was observed that asphalt failed to coat all the sand particles properly and some of the asphalt was left in the form of globules immediately after mixing.

The base asphalt treated specimens became very soft and failed to hold together when subjected to 104°F temperature prior to testing. At 77°F temperature, the SS-1 base asphalt treated dune sand is more stable than SS-1 emulsion treated specimens. At high temperatures of 104° and 140°F the SS-1 base asphalt treated dune sand showed no strength compared to SS-1 emulsion treated dune sand.

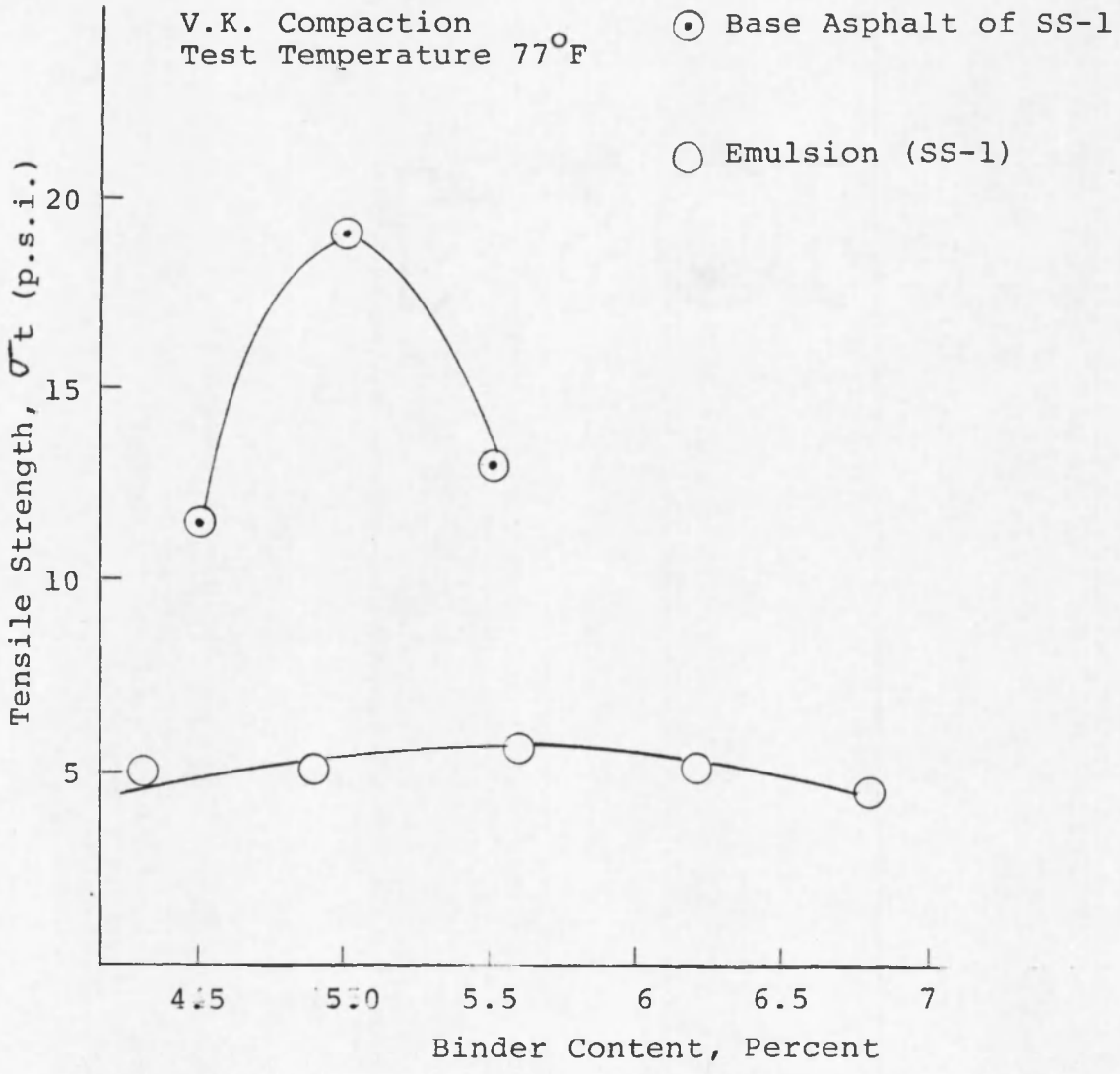



Figure 33. Tensile Strength versus Binder Content For Base Asphalt and Emulsion Treated Dune Sand

## Effect of Emulsion Content on Marshall Density

The untreated and emulsion treated dune sand was compacted by the Marshall compactor and the results are shown in Figure 34; Tables 4 and 14, Appendix B. The results indicate that the emulsion treated densities decrease with the increase in the liquid content (emulsion plus water). The results also indicate that emulsion treated specimens give lower densities than untreated specimens. Again, as resulted with the vibratory kneading compaction, the CSS-1 emulsion treated specimens gave higher densities than the SS-1 emulsion treated specimens.

The compaction results demonstrated that the vibratory kneading compaction gave higher densities than the Marshall compaction.

## Effect of Residual Asphalt Content on M.S. and M.F.

Figure 35 illustrates the effect of residual asphalt on the Marshall stability (M.S.) of emulsion treated dune sand specimens tested at 77°F. The stability value of treated specimens increases with the residual asphalt content until maximum value is obtained, after which stability decreases. An optimum residual asphalt was obtained for maximum stability at 4.9 percent using SS-1 emulsion, and 5.8 percent using CSS-1 emulsion. The CSS-1 emulsion treated specimens show higher stability values than SS-1 emulsion. This is due to the higher densities resulted with the CSS-1

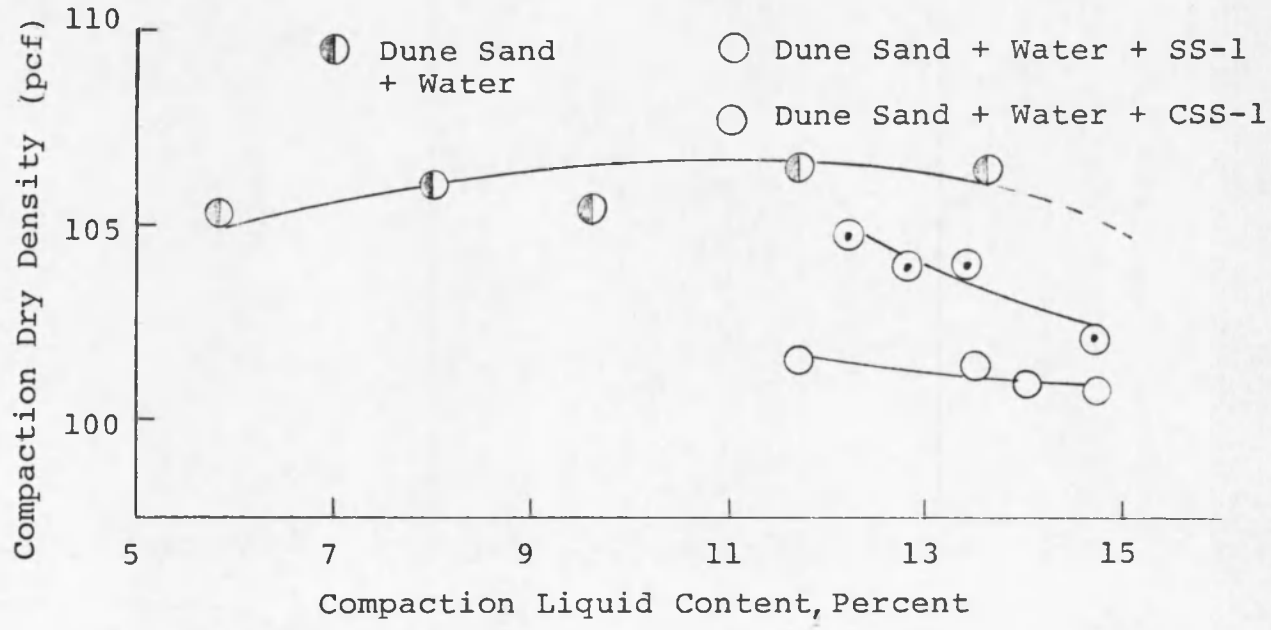



Figure 34. Compaction Dry Densities versus Compaction Liquid Content for Untreated and Treated Specimens (Marshall Compaction)

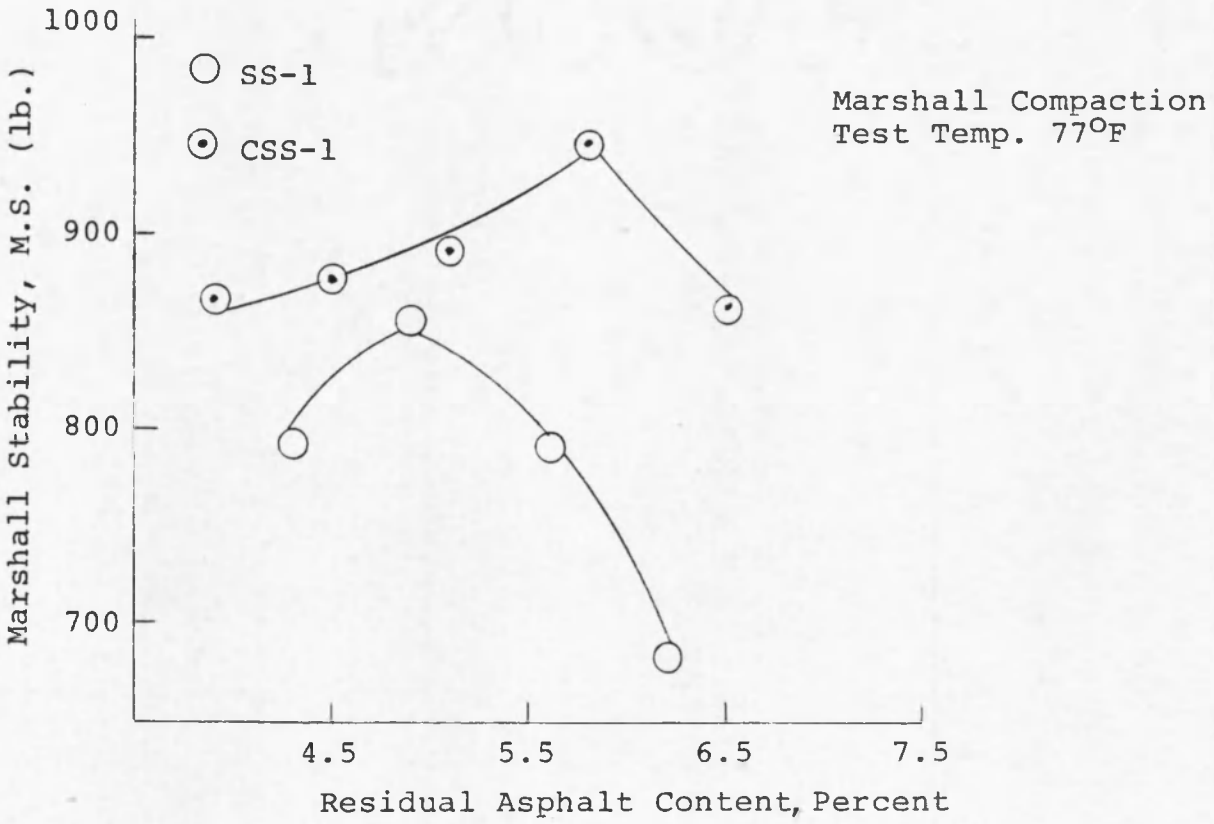



Figure 35. M.S. versus Residual Asphalt Content for Treated Dune Sand

emulsion treated specimens and also may be due to the preferential of silicious material to cationic emulsion treatment.

Figure 36 shows that an increase in the residual asphalt content has the effect of increasing the Marshall flow (M.F.). Mixtures with low flow and high stability values will not deform easily, but are likely to be brittle. Flow value of less than 8 is generally considered brittle. Mixtures with high flow value and low stability value will deform easily.

Effect of Testing Temperature on M.S. and M.F.

Dune sand specimens treated with SS-1 and CSS-1 emulsions were tested at $77^{o}$, $104^{o}$ and $140^{o}F$ for the Marshall stability and flow values. Figures 37 and 38 show that an increase in testing temperature has the effect of decreasing the Marshall stability values and increasing the Marshall flow values. The drop in Marshall stability is higher in the range $77^{o}$-$104^{o}F$ temperature range than in the $104^{o}$-$140^{o}F$ temperature range.

Since the Marshall stability and flow values are affected by the testing temperature, this proves that the Marshall test was more of a measure of the cohesive component of stability rather than the internal friction (28).

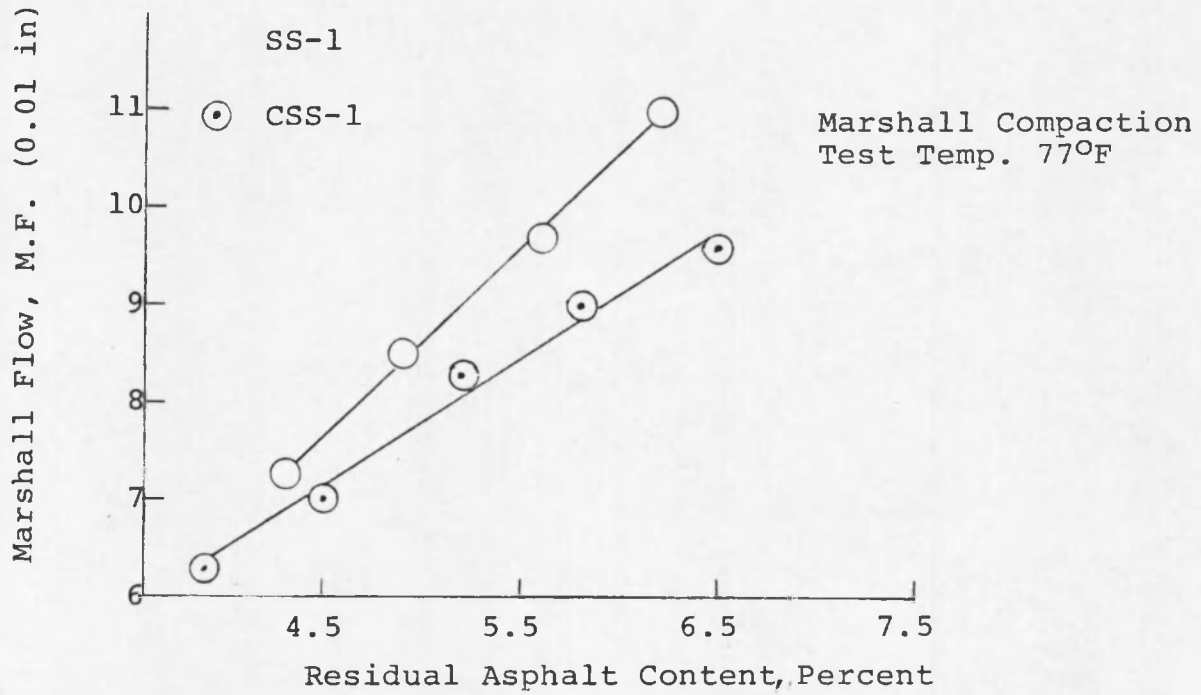



Figure 36. M.F. versus Asphalt Residual Asphalt Content for Treated Dune Sand

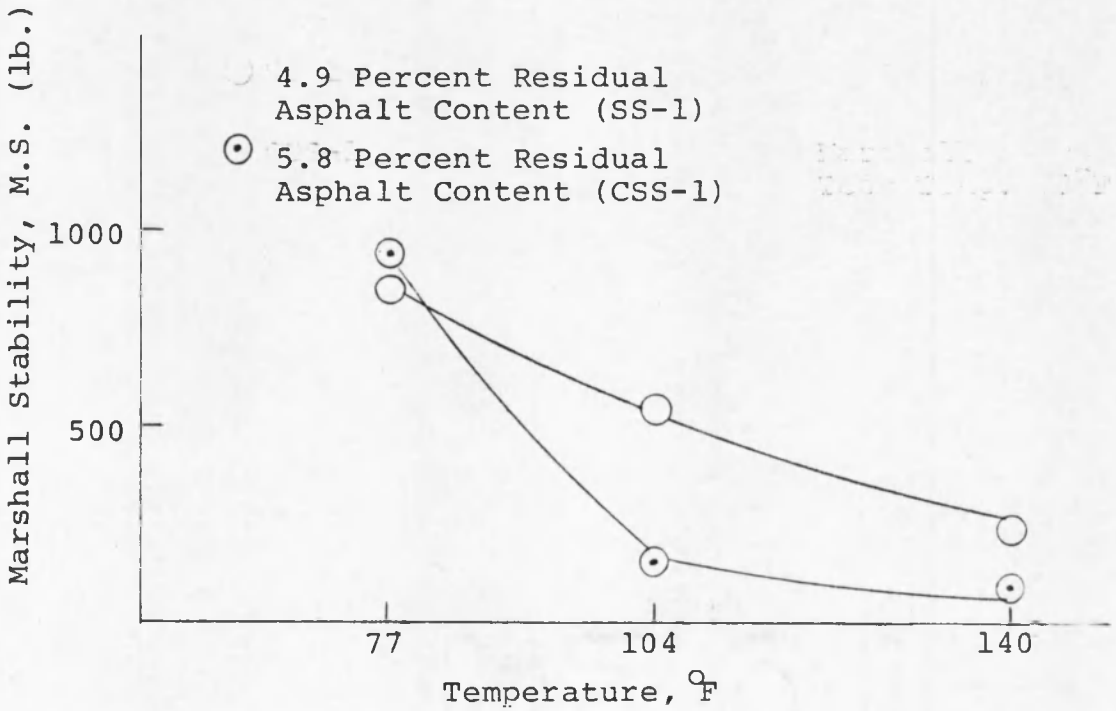



Figure 37. M.S. versus Testing Temperature for Treated Dune Sand

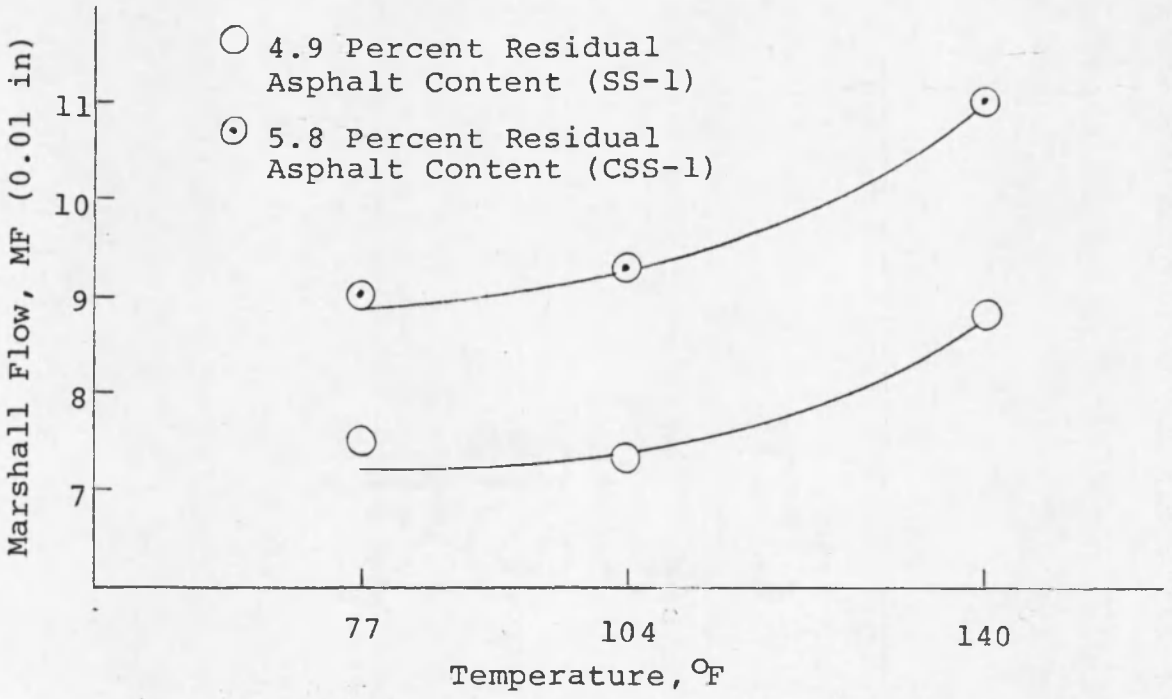



Figure 38. M.F. Versus Testing Temperature for Treated Dune Sand

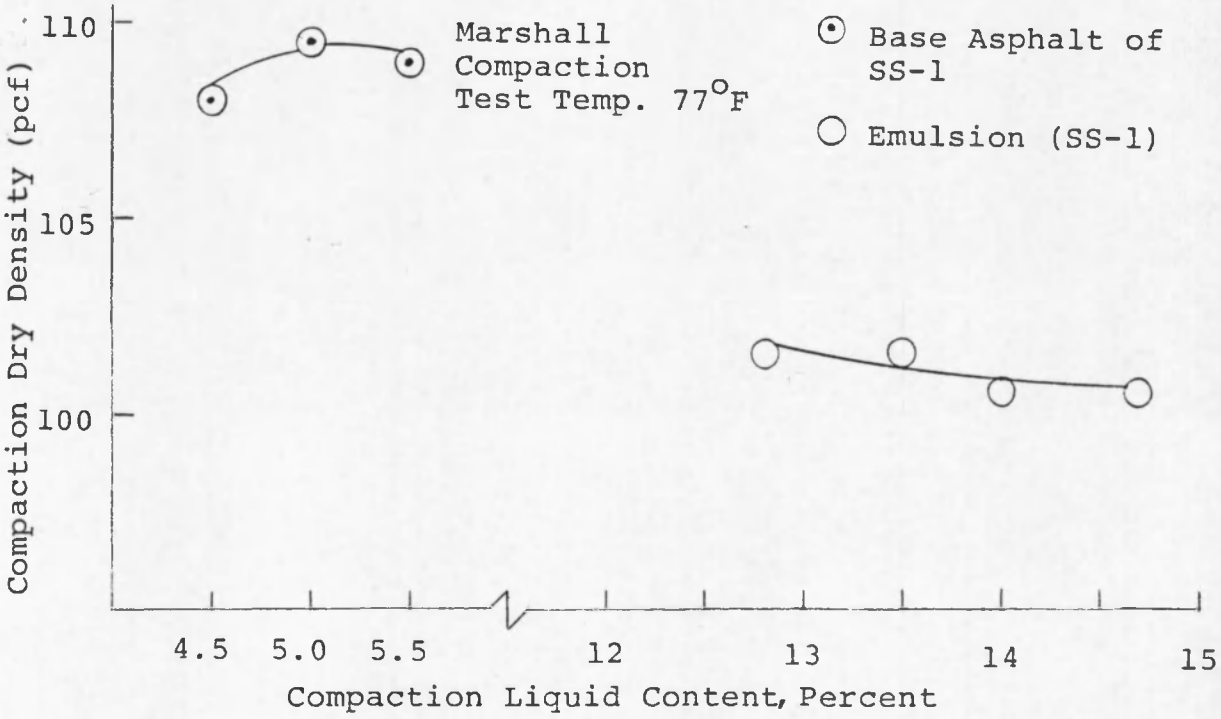



Figure 39. Compaction Dry Density versus Compaction Dry Density for Base Asphalt and Emulsion Treated Dune Sand

Hot Mix versus Cold Mix (M.S., M.F.)

Specimens of dune sand treated with the base asphalt of SS-1 emulsion were prepared by the hot mix process and compacted by the Marshall compactor, and the compaction results are shown in Figure 39. The results indicate that an optimum asphalt content exists for maximum dry density.

Figure 40 shows that the SS-1 base asphalt treated specimens gave higher Marshall stability values than those treated with SS-1 emulsion. As mentioned earlier, this was due to the hot mix process, because it gave better coating of the particles than the hot mix. Figure 41 shows that SS-1 base asphalt gave higher Marshall flow values than those treated with SS-1 emulsion, because SS-1 base asphalt gave higher Marshall stability values than those treated with SS-1 emulsion.

At 5 percent residual asphalt content the emulsion treated dune sand shows a Marshall stability value of 840 and a Marshall flow value of 8.5, compared to a Marshall stability value of 3259 and a Marshall flow value of 17.6 at 77°F for the base asphalt treated specimens (Figures 40 and 41). The base asphalt treated dune sand became very soft and failed to hold together when subjected to 104°F temperature prior to testing. At 77°F temperature the SS-1 base asphalt treated dune sand is more stable than the SS-1 emulsion treated specimen. At higher temperatures of 104° and 140°F

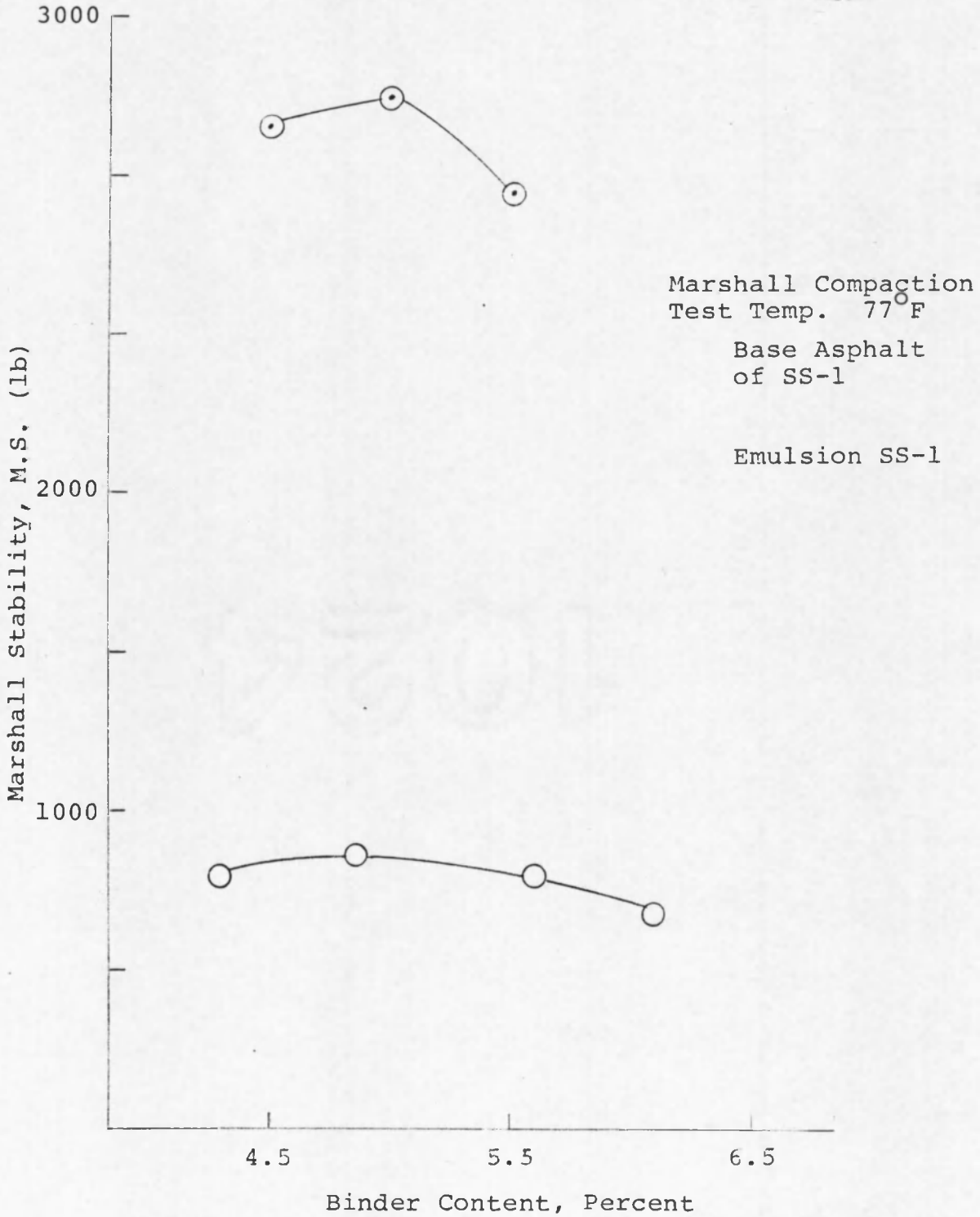



Figure 40: M.S. versus Binder Content for Base Asphalt and Emulsion Treated Dune Sand

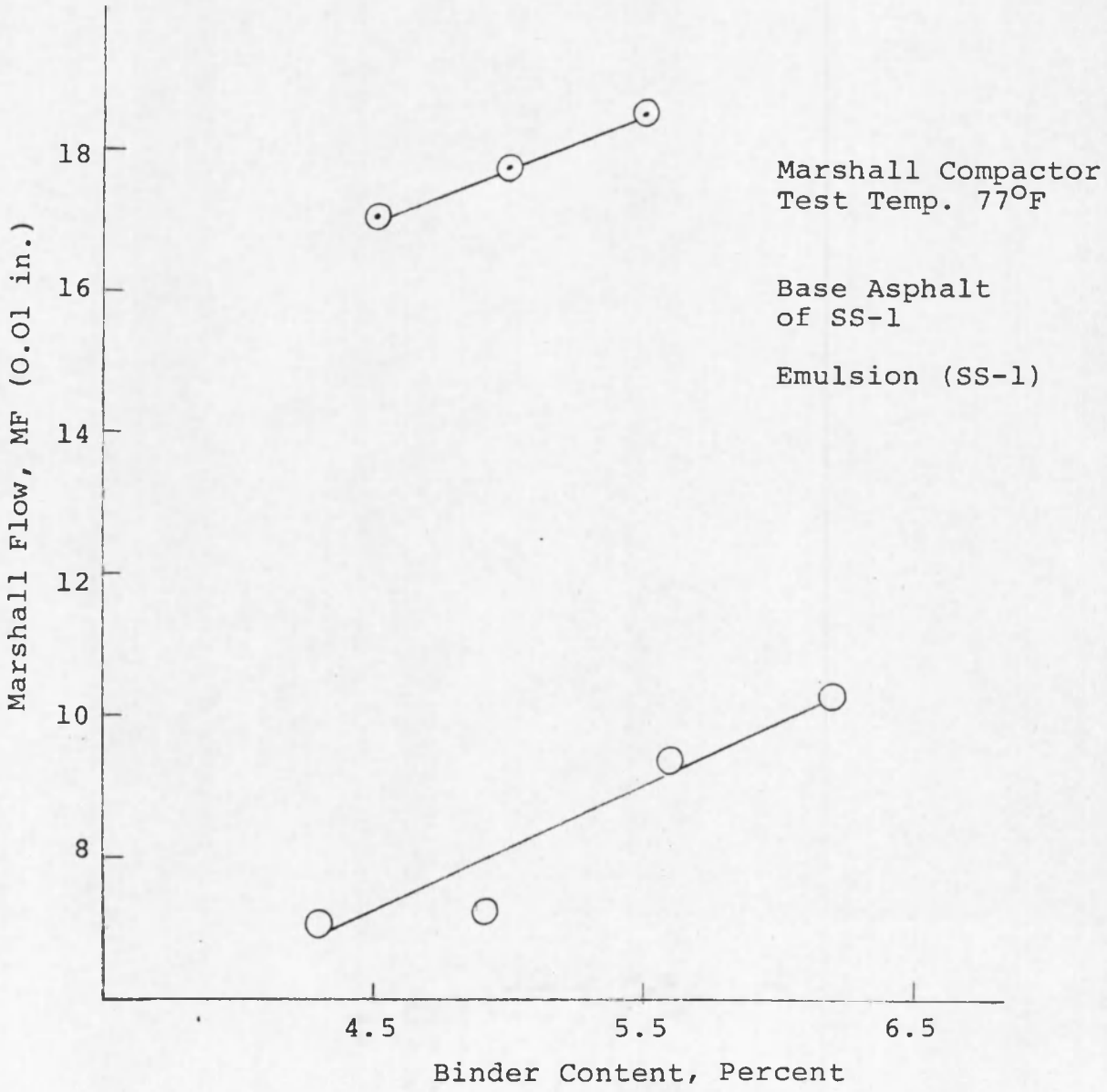



Figure 41. M.F. versus Binder Content For Base Asphalt and Emulsion Treated Dune Sand

the SS-1 base asphalt treated dune sand showed no strength compared to SS-1 emulsion treated dune sand.

# CHAPTER VI

## SUMMARY AND CONCLUSION

The results of stabilizing dune sand with asphalt emulsions and base asphalt are reported in this study. Specimens fabricated by the vibratory kneading compaction were tested for strength by the Hveem stabilometer and the double punch apparatus. Specimens fabricated by the Marshall compaction were tested for strength by the Marshall device.

This study investigated the effect of type of emulsion, the effect of residual asphalt content, the effect of grading of the dune sand, the effect of testing temperature, and the effect of the type of mix on density and strength values. Some general conclusions are presented below; however, it should be borne in mind that these conclusions are limited to the scope of this investigation.

1. For the given range of emulsion content, an increase in the liquid content (emulsion plus water) had the effect of decreasing the dry density.
2. Specimens of dune sand treated with CSS-1 emulsion gave slightly higher densities than those treated with SS-1 emulsion, using both types of compactions, the vibratory and the Marshall.

3. An increase in the residual asphalt content had the effect of reducing the stability and the resistance values.
4. Specimens of dune sand treated with CSS-1 emulsion showed higher stability and resistance values than those treated with the SS-1 emulsion.
5. There exists an optimum residual asphalt content of 5.6 percent using SS-1 emulsion and 5.2 percent using CSS-1 emulsion for maximum tensile strength.
6. Specimens of dune sand treated with CSS-1 showed higher tensile strength and Marshall stability than those treated with SS-1 emulsion at 77$^{o}$F due to the higher densities obtained with the CSS-1 emulsion treated specimens.
7. The modification of dune sand grading by adding 30 percent copper mill tailings to the dune sand failed to reduce the high percentage of air voids in the emulsion treated specimens.
8. A modification of the grading of dune sand had a slight effect on the increase of stability and the resistance values, but had no effect on the tensile strength of emulsion treated specimens.
9. The vacuum soak test demonstrated the effect of moisture on the strength values of emulsion treated dune sand. The results indicated that moisture had

more detrimental effect on the tensile strength than on the stability and resistance values.

10. An increase in the testing temperature had the effect of reducing the tensile strength, but it had no major effect on the stability and resistance values.
11. An increase in the testing temperature had the effect of reducing the Marshall stability and increasing the Marshall flow values.
12. There exists an optimum residual asphalt content of 4.9 percent using SS-1 emulsion and 5.8 percent using CSS-1 emulsion for maximum Marshall stability.
13. An increase in residual asphalt content had the effect of increasing the Marshall flow values.
14. The base asphalt of SS-1 treated dune sand specimens showed higher strength values than the specimens treated with SS-1 emulsion at 77°F. This is probably due to the denser SS-1 base asphalt treated specimens compared to SS-1 emulsion treated specimens.
15. The base asphalt of SS-1 treated dune sand failed to show any strength at temperature of 104°F.
16. The optimum asphalt content for maximum strength is affected by the type of emulsion, type of test, mode of compaction, and type of mix.
17. The Hveem stabilometer along with the double punch device can be utilized to study the strength of

stabilized material in terms of friction and cohesive strength, respectively.

18. Although emulsion treated dune sand might not be suitable for a road base, adding asphalt emulsion to dune sand would ease compaction by preventing the tendency of sand particles to move laterally under the action of compaction.

## Recommendations and Further Research

A comprehensive study of the effect of grading dune sand by varying the amount of sand passing a No. 200 sieve should be investigated. The effect of the addition of cement, along with asphalt emulsion in the dune sand should be investigated also.

The effect of mixing temperature, curing temperature, and the period of curing should be studied.

It should be recognized that the Asphalt Institute design criteria are based on test procedures not used in this study, so that the differences should be investigated in the laboratory and field.

# APPENDIX A

## MATERIALS CHARACTERISTICS

Table 1. Properties of Emulsions

| | Test Results | | Specification* | |
|---|---|---|---|---|
| | SS-1 | CSS | SS-1 | CSS-1 |
| Test on Emulsion<br>Viscosity, Saybolt-Furol<br>77°F, Sec | 36 | 32 | 20-100 | 20-100 |
| Residue by Evaporation, % | 61.62 | 64.67 | 57 min | 57 min |
| Settlement, 5 days, % | - | - | 5 max | 5 max |
| Sieve, Retained No. 20% | - | - | .10 max | .10 max |
| Tests on Residue<br>Penetration, 77°F<br>100 qm, 5 Sec | 40-50 | 60-70 | 40-100 | 40-100 |
| Ductility, 77°F<br>5 cm per min<br>cm. | - | - | 100 min | 100 min |
| Solubility in carbon<br>tetrachloride, % | - | - | 97.5 min | 97.5 min |

*Arizona

Table 2. Particle Size Distribution

| Sieve Size | Dune Sand | | Copper Mill Tailings | | Combination % Passing |
|---|---|---|---|---|---|
| | % Passing | 70% | % Passing | 30% | (Modified Dune Sand) |
| No. 8 | 100 | 70 | 100 | 30 | 100 |
| No. 16 | 99.8 | 69.9 | 99.5 | 29.9 | 99.8 |
| No. 30 | 99.4 | 69.6 | 97.5 | 29.3 | 98.9 |
| No. 50 | 73.8 | 51.7 | 81.7 | 24.5 | 76.2 |
| No. 100 | 22.0 | 15.4 | 54.5 | 16.4 | 31.8 |
| No. 200 | 3.2 | 2.2 | 31.8 | 9.5 | 11.7 |

Table 3. Modified AASHTO Compaction Moisture Density Data for Dune Sand

| Determination # | Moisture Content % | Dry Density pcf |
|---|---|---|
| 1 | 5.4 | 106.6 |
| 2 | 7.3 | 106.1 |
| 3 | 9.1 | 108.1 |
| 4 | 11.2 | 109.5 |
| 5 | 12.3 | 108.4 |
| 6 | 14.1 | 105.5 |

Table 4. Compaction Results by Different Compaction of Untreated Specimens

| Vibratory Kneading Dune Sand | | | Marshall Dune Sand | |
|---|---|---|---|---|
| Determination # | Moisture Content % | Dry Density pcf | Moisture Content % | Dry Density pcf |
| 1 | 5.5 | 107.8 | 5.8 | 105.2 |
| 2 | 7.6 | 107.6 | 8.0 | 106.0 |
| 3 | 9.6 | 108.9 | 9.6 | 104.6 |
| 4 | 11.4 | 108.9 | 11.7 | 106.5 |
| 5 | 12.4 | 111.0 | 13.6 | 106.3 |
| | Modified Gradation Dune Sand | | | |
| 1 | 5.5 | 111.3 | | |
| 2 | 7.6 | 111.9 | | |
| 3 | 9.6 | 114.1 | | |
| 4 | 11.3 | 115.6 | | |
| 5 | 11.4 | 114.8 | | |

Table 5. Test Results of Untreated Specimens
(Vibratory Kneading Compaction)

| Dune Sand | | | Modified Grad. Dune Sand | |
|---|---|---|---|---|
| Molding Moisture Content % | Molding R Values % | Molding S Values % | Molding R Values % | Molding S Values % |
| 10 | 85.5 | 29.0 | 85.7 | 27.0 |
| 12 | 83.0 | 26.3 | 84.3 | 26.0 |
| 14 | 79.0 | 25.8 | 75.0 | 19.7 |

# APPENDIX B

## TREATED MIXTURES CHARACTERISTICS

Table 6. Compaction Results for Emulsion Treated Dune Sand (Vibratory Kneading Compaction)

| Emulsion Type | Emulsion Content % | Mixing Water % | Moisture Content % | Compaction Liquid Content % | Compaction Dry Density pcf |
|---|---|---|---|---|---|
| SS-1 | 7 | 5.8 | 8.5 | 12.8 | 104.6 |
| | 8 | 5.5 | 8.6 | 13.5 | 103.5 |
| | 9 | 5.1 | 8.5 | 14.1 | 103.2 |
| | 10 | 4.8 | 8.6 | 14.7 | 102.8 |
| | 11 | 3.9 | 8.3 | 15.1 | 102.7 |
| CSS-1 | 7 | 6.5 | 9.0 | 13.5 | 107.6 |
| | 8 | 5.3 | 8.1 | 13.3 | 106.3 |
| | 9 | 5.4 | 8.6 | 14.4 | 107.3 |
| | 10 | 4.6 | 8.1 | 14.6 | 106.5 |

Table 7. Test Results for Emulsion Treated Dune Sand at Different Residual Asphalt Contents (Vibratory Kneading Compaction)

| Emulsion Type | Residual Asphalt Content % | R Values % (Cured Dry) | S Values % (Cured Dry) | $\sigma t$ p.s.i. (Cured Dry) |
|---|---|---|---|---|
| SS-1 | 4.3 | 80.7 | 16.1 | 5.0 |
| | 4.9 | 76.0 | 14.0 | 5.1 |
| | 5.6 | 73.7 | 12.6 | 5.5 |
| | 6.2 | 75.5 | 11.9 | 5.1 |
| CSS-1 | 4.5 | 79.6 | 19.0 | 6.6 |
| | 5.2 | 68.5 | 18.5 | 7.2 |
| | 5.8 | 78.4 | 18.3 | 6.7 |
| | 6.5 | 72.6 | 15.3 | 3.9 |

Test Temperature: 77°F

Table 8. Compaction Results for Emulsion Treated Modified Gradation Dune Sand (Vibratory Kneading Compaction)

| Emulsion Type | Emulsion Content % | Mixing Water % | Moisture Content % | Compaction Liquid % | Compaction Density pcf |
|---|---|---|---|---|---|
| SS-1 | 7 | 5.8 | 8.50 | 12.80 | 105.1 |
| | 8 | 5.4 | 8.50 | 13.40 | 105.6 |
| | 9 | 5.4 | 8.80 | 14.40 | 105.0 |
| | 10 | 4.6 | 8.40 | 14.60 | 104.8 |
| | 11 | 4.8 | 9.0 | 15.80 | 103.8 |

Table 9. Test Results for Emulsion Treated Modified Gradation Dune Sand at Different Residual Asphalt Contents (Vibratory Kneading Compaction)

| Emulsion Type | Residual Asphalt Content | R Values % (Cured-Dry) | S Values % (Cured-Dry) | $\sigma_t$ p.s.i. (Cured-Dry) |
|---|---|---|---|---|
| SS-1 | 4.3 | 84.5 | 16 | 3.9 |
| | 4.9 | 85.6 | 19 | 4.4 |
| | 5.6 | 81.7 | 16 | 4.9 |
| | 6.2 | 82.0 | 15 | 4.8 |
| | 6.8 | 76.3 | 13 | 4.2 |

Test Temperature: $77^{\circ}F$

Table 10. Test Results for Emulsion Treated Dune Sand at Different Residual Asphalt Contents after Vacuum Soak Test (Vibratory Kneading Compaction)

| Emulsion Type | Residual Asphalt Content % | R Values % (Cured-Soaked) | S Values % (Cured-Soaked) | $\sigma t$ p.s.i. (Cured-Soaked) | Moisture Pick-Up % |
|---|---|---|---|---|---|
| SS-1 | 4.3 | 54.7 | 8.0 | 1.2 | 12.2 |
| | 4.9 | 62.6 | 11.0 | 0.8 | 12.3 |
| | 5.6 | 55.7 | 8.7 | 1.0 | 12.4 |

Test Temperature 77°F

Table 11. Test Results for Emulsion Treated Dune Sand at Different Test Temperature (Vibratory Kneading Compaction)

| Test Temperature | | | 77°F | 104°F | 140°F |
|---|---|---|---|---|---|
| Emulsion Type | Residual Asphalt Content % | Strength Values (Cured-Dry) | | | |
| SS-1 | 5.6 | R | 73.7 | 71.0 | 71.5 |
| | | S | 12.6 | 12.0 | 11.7 |
| | | $\sigma t$ | 5.5 | 0.8 | 0.4 |
| CSS-1 | 5.2 | R | 68.5 | 73.5 | 72.7 |
| | | S | 18.5 | 16.3 | 16.2 |
| | | $\sigma t$ | 7.2 | 1.2 | 0.2 |

Table 12. Air Voids and VMA for SS-1 Emulsion Treated Mixtures (Vibratory Kneading Compaction)

| Residual Asphalt Content % | Bulk Specific Gravity (Cured-Dry) | Max. Theoretical Specific Gravity (Cured-Dry) | Air Voids % | VMA % |
|---|---|---|---|---|
| | Dune Sand | | | |
| 4.3 | 1.747 | 2.486 | 29.7 | 36.8 |
| 4.9 | 1.739 | 2.465 | 29.5 | 37.4 |
| 5.6 | 1.795 | 2.446 | 26.6 | 35.9 |
| 6.2 | 1.745 | 2.425 | 28.0 | 38.0 |
| 6.8 | 1.757 | 2.406 | 26.9 | 37.7 |
| | Modified Gradation Dune Sand | | | |
| 4.3 | 1.756 | 2.513 | 30.1 | 37.9 |
| 4.9 | 1.769 | 2.491 | 28.4 | 37.1 |
| 5.6 | 1.791 | 2.471 | 27.5 | 36.7 |
| 6.2 | 1.782 | 2.450 | 27.3 | 37.4 |
| 6.8 | 1.771 | 2.430 | 27.1 | 38.1 |

Table 13. Test Results for SS-1 Base Asphalt Treated Dune Sand at Different Asphalt Contents (Vibratory Kneading Compaction)

| Asphalt Content % | Dry Density pcf | R Values % | S Values % | t p.s.i. |
|---|---|---|---|---|
| 4.5 | 111.7 | 81.0 | 24.3 | 11.4 |
| 5.0 | 115.3 | 82.0 | 25.0 | 19.3 |
| 5.5 | 109.1 | 80.7 | 20.2 | 13.0 |

Test Temperature: 77°F

Table 14. Compaction Results for Emulsion Treated Dune Sand (Marshall Compaction)

| Emulsion Type | Emulsion Content % | Mixing Water % | Moisture Content % | Compaction Liquid Content % | Compaction Dry Density pcf |
|---|---|---|---|---|---|
| SS-1 | 7 | 5.7 | 8.40 | 12.70 | 101.5 |
| | 8 | 5.5 | 8.60 | 13.53 | 101.5 |
| | 9 | 5.0 | 8.40 | 14.00 | 100.7 |
| | 10 | 4.7 | 8.50 | 14.70 | 100.5 |
| CSS-1 | 6 | 6.2 | 8.30 | 12.20 | 104.7 |
| | 7 | 5.9 | 8.40 | 12.90 | 104.4 |
| | 8 | 5.4 | 8.20 | 13.40 | 103.5 |
| | 9 | 7.1 | 10.3 | 16.10 | 100.5 |
| | 10 | 4.7 | 8.20 | 14.70 | 102.5 |

Table 15. Test Results for Emulsion Treated Dune Sand at Different Residual Asphalt Contents (Marshall Compaction)

| Emulsion Type | Residual Asphalt Content % | M.S. lbs (Cured-Dry) | M.F. 0.01 in. (Cured Dry) |
|---|---|---|---|
| SS-1 | 4.3 | 788 | 7.3 |
| | 4.9 | 854 | 7.5 |
| | 5.6 | 785 | 9.7 |
| | 6.2 | 681 | 11.0 |
| CSS-1 | 3.9 | 865 | 6.3 |
| | 4.5 | 872 | 7.0 |
| | 5.2 | 892 | 8.3 |
| | 5.8 | 945 | 9.0 |
| | 6.5 | 863 | 9.6 |

Test Temperature: 77°F

Table 16. Test Results for Emulsion Treated Dune Sand at Different Test Temperature (Marshall Compaction)

| Test Temperature | | | 77°F | 104°F | 140°F |
|---|---|---|---|---|---|
| Emulsion Type | Residual Asphalt Content % | Strength Values (Cured-Dry) | | | |
| SS-1 | 4.9 | M.S. | 854 | 532 | 263 |
| | | M.F. | 7.5 | 7.3 | 8.7 |
| CSS-1 | 5.80 | M.S. | 945 | 149 | 106 |
| | | M.F. | 9.0 | 9.3 | 11.0 |

Table 17. Test Results for SS-1 Base Asphalt Treated Dune Sand at Different Asphalt Contents (Marshall Compaction)

| Asphalt Content % | Dry Density pcf | M.S. lbs | M.F. 0.01 in |
|---|---|---|---|
| 4.5 | 107.8 | 3149 | 17.0 |
| 5.0 | 109.5 | 3259 | 17.6 |
| 5.5 | 108.9 | 2925 | 18.0 |

Test Temperature: 77°F

## REFERENCES


1. Rula A. A., W. E. Graham, and R. D. Milles, "Forecasting Trafficability of Soils, Air Photo Approach" U.S. Army Cops. of Engineers, Waterways Experiment Station, Vicksburg, Miss. (Tech Mem 3-331), Report 6, 2 Vols., 1963.

2. Smith, B. S. U. "Migration and Wind Regime of Small Barcham Dunes within the Algodones Dune Chain, Imperial County Calif." M. S. Thesis, U. of A., 1970.

3. Bagnold, R. A., The Physics of Blown Sand and Desert Dunes, Chapman Hall, London, 1971.

4. Dunn, C. S. and M. N. Salem, "Influence of Processing and Procedure on Strength of Stabilized Sand Stabilized with Cationic Emulsion", HRR No. 351, Highway Research Board, 1971, 50-56.

5. Jimenez, R. A., "Asphalt Emulsion Treated Aggregates", unpublished report to Arizona Highway Dept. of Transportation--Highway Division, June 1976.

6. Traxler, R. N., Asphalt: Its Composition, Properties and Uses, Reinhold Pub. Corp. N. V. 1961, 159-160.

7. Borgfeldt, N. J. and R. L. Ferm "Cationic Mixing Grade Asphalt Emulsion", HRR No. 41, Highway Research Board, 1962, 195-204.

8. Coyne, L. D. and R. M. Ripple "Emulsified Asphalt and Mix Design and Construction", Proceeding, The Association of Asphalt Paving Technologists, Vol. 44, 1975, 281-301.

9. Endesby, v. A. "Fundamental Research in Bituminous Stabilization", Proceeding, Highway Research Board, Vol. 22, 1942, 442-259.

10. Katti, R. K., D. T. Davidson, and J. B. Scheeler, "Water in Cutback Asphalt Stabilization of Soil", Highway Research Bulletin, 241, Highway Research Board, 1959, 14-47.

11. McKesson, C. L. and A. W. Mohr, "Soil Emulsified Asphalt and Sand Emulsified Asphalt Pavement", Proceeding, Highway Research Board, 1941, 500-515.

12. Gregg, J. S., C. L. Dehlen, and P. J. Rigden, "On the Behavior and Design of Bituminous Stabilized Sand Bases", Proceeding, 2nd International Conf. on Design of Structural Design of Asphalt Pavement, Univ. of Mich., Aug. 1967, 709-729.

13. Dunn, C. S. and M. N. Salem, "Temperature and Time Effect on the Shear Strength of Sand Stabilized with Cationic Emulsion", HRR No. 442, Highway Research Board, 1973, 113-123.

14. Al Salloum, N. M. "Fatigue Characteristics of an Asphalt Stabilized Dune Sand", Ph.D. Dissertation, U. of Arizona, 1973.

15. Jimenez, R. A., Fatigue of Compacted Bituminous Aggregate Mixtures, Special Pub. No. 508, American Society for Testing and Materials, 1972, 3-8.

16. Schmidt, R. J., Santucci, L. E., and L. D. Coyne, "Performance Characteristics of Cement--Modified Asphalt Emulsion Mixes", Proceeding, The Association of Asphalt Paving Technologists, Vol. 42, 1973, 300-319.

17. The Asphalt Institute, "Mix Design Method for Liquid Mixtures", Feb. 1974.

18. Yazdani, Z., "Conditioning of Asphalt Emulsion Bases for Hveem Stability", M. S. Thesis, U. of A., 1974.

19. McKesson, C. L. "Recent Development in the Design and Construction of Soil-Emulsion Road Mixes", Proceeding, Highway Research Board, Vol. 20, 1940, 856-864.

20. Zakhour, K. J., "The use of Copper Mill Tailings for Brick Manufacturing", M.S. Thesis, U. of A., 1973.

21. Qaqish, S. S., "The Use of Copper Mill Tailings as a Cement Replacement, and Stabilized Soil", M. S. Thesis, U. of A., 1975.

22. The Asphalt Institute, "Mix Design Method for Asphalt Concrete and Other Hot Mix Types", (M. S.-2), March 1974.

23. Hveem, F. N. and H. E. Davis, "Some Concepts Conerning Triaxial Compression Testing of Asphaltic Mixtures and Subgrade Materials", Special Technical Pub. No. 106: Triaxial Testing of Soil and Bitominous Mixtures, American Society for Testing and Materials, 1951.

24. Hveem, F. N., "Development in Design of Bituminous Material and Pavement in Western United States", Calif. Highway and Public Work, July 1956.

25. Fang, H. Y. and W. F. Chen, "New Method for Determination of Tensile Strength of Soils", HRR No. 345, Highway Research Board, 1971.

26. Jimenez, R. A., "Testing for Debonding of Asphalt from Aggregates", A Report to Arizona Highway Department, Research Division, May 1973.

27. Dunning, R. L. and F. E. Turner, "Asphalt Emulsion Stabilized Soils as a Base Material in Roads", Proceedings, The Association of Asphalt Paving Technologists, Vol. 34, 1965, 356-395.

28. O'Flaherty, C. A., Highways, Edwards Arnold Publishers Ltd., London, 1967, 500-501.