

**A comparison of Properties of laboratory prepared Cold Mixed Emulsified and Hot Mixed Asphalt Mixtures**

**Phase II**

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## Summary

Asphalt emulsion cold mixes for construction of base and surface courses of bituminous pavements have been used in the United States since the 1930~s. These mixes were primarily used on lightly traveled roads with very little, if any, documentation of their physical properties either before or after construction. In addition, until recently very little effort was made to develop a generally acceptable laboratory design method for asphalt emulsion cold mixes. A method which engineers could use as a tool for comparison to other asphalt paving materials and methods for pavement thickness determinations<sup>5</sup>

During the past ten years Armak Company has expended a considerable amount of investigative and developmental effort toward determining those factors which are most important in developing an acceptable laboratory design method for asphalt emulsion cold mixes and those factors which are necessary to obtain layer equivalency to hot mix. Concurrently, asphalt emulsion formulations of the cationic type that would adequately mix with almost any type of aggregate without the benefit of the lubricating effect of solvent, were developed and are still being refined<sup>5</sup> These formulations, which solely rely upon the inherent properties of the emulsifier and the proper use of water, are essential for preparing cold mixes that adequately compare to the pavement-thickness criteria of hot mix.

Simply stated, in the field, asphalt emulsion layer equivalency to hot mix can be attained by: (1) having field paving crews learn the proper use and handling of water and solvent-free cationic asphalt emulsions, (2) the use of an asphalt cement in the cold mix which is similar in viscosity or stiffness to the asphalt cement recovered from the hot mix, and (3) allowing the cold mix to cure to near its optimum stability, keeping all other variables equal.

Developing an acceptable laboratory design method for cold mixes, which reflects their potential equivalency to hot mix in the field, has been considerably more difficult.

Armak has, thus far, sponsored two studies at an independent testing laboratory to determine those factors which most significantly effect the mix design criteria and resilient moduli of asphalt emulsion cold mix compared to hot mix using two different laboratory of specimen preparation and evaluation -- Marshall ASTM, D-1559 and Kneading Compaction ASTM, D-1561 with the Hveem Method ASTM, D-1560.

Phase I of this investigation was reported at the AEMA Annual meeting, March 17-18, 1982, Las Vegas, Nevada.

The premise of this initial investigation was to emulsify an asphalt cement that has viscosity (stiffness) properties similar to the asphalt extracted from a hot mix after the hot mixing had been completed and to use the emulsion in the preparation of cold mixes for comparison to the original hot mix. This was done to determine whether a cold mix versus a hot mix, both containing asphalt cement of similar stiffness or viscosity, would indicate similar pavement thickness requirements.

The cold mix formula used 2% pre-wet water basis dry weight of aggregate and four sets of three specimens each at 4.0, 4.5, 5.0 and 6.0 residual asphalt respectively. A CSS-1 asphalt emulsion which contained no volatile hydrocarbon was used for the cold mix. The hot mix specimens were also prepared at the same asphalt content for direct comparison.

The Marshall Method of lab specimen compaction and testing was used to obtain specimen density and stabilities. With the development of the density/air voids data, it became evident that Marshall Compaction, as detailed in ASTM D-1559, is not the best method of compaction for these cold mix specimens. Densities and air voids equivalent to that of the hot mix was impossible to obtain with the Marshall Compaction Hammer, particularly with the dense aggregate.

The major problem with specimen compaction for cold mixes using the Marshall Method is that it was designed for hot mix which contains only trace volatiles at compaction temperatures. The mold assembly is non-porous and the tamping foot of the compaction hammer is essentially the same diameter as the inside diameter of the mold. Although 50 to 75 blows of the Compaction Hammer are specified for each flat side of the specimen, the water containing cold mixes often attain maximum attainable density after only 20 blows with rapidly developing hydraulic pore pressure causing the hammer to bounce for the remaining blows and generating an accumulation of emulsified asphalt on the flat surfaces of the specimen.

Some work has been done with the Marshall Compaction of specimens in porous molds. However this approach has not been found to be entirely adequate because of insufficient reduction of pore pressure under the tamping foot of the Marshall Hammer and the tendency of some aggregate projections to become wedged in the holes causing specimen tearing when removed from the mold.

Surprisingly the Resilient Modulus ( $M_r$ ) (elastic Modulus) data is considerably higher for the emulsion mixes than for the hot mixes. Resilient Modulus (Elastic Moduli) values have many meanings to design engineers; however, if only these numbers were used to determine pavement thickness design, they would imply that the hot mix should be placed thicker than the cold mix for equivalent load bearing.

This study - Phase II - used the same aggregates, Arizona Types IIIb and IVb, and the same asphalts and AR-8000 for the cold mix and an AR-4000 for the hot mix which, when extracted from the hot mix, has essentially the same penetration and viscosity (stiffness) as the AR-8000. Phase II, however, investigated the compaction characteristics of Kneading Compaction and the Hveem stability procedure in contrast to the Marshall method reported in Phase I. Phase II also reports the results of accelerated laboratory specimen cure in an effort to obtain density and voids values similar to the high density and low voids obtainable from cold mix placed in the field.

Kneading compaction appears to produce specimens of higher density and lower voids than does the Marshall. However, both methods are inadequate, as written, to obtain the density and voids values which are comparable to the high density and low voids which are possible from a 3" to 4" mat of cold mix placed in the field.

These data indicate that an appropriate laboratory specimen cure method is more important than the method of compaction. This will be the subject of Phase II.

The most important need the asphalt emulsion industry currently faces, with respect to cold mix base and surface courses, is the need for well documented and thoroughly tested field installations where data on density, voids and the development of specification stability with time can be acquired and disseminated. These data and only these data will validate the development of a laboratory design method and acceptable design criteria.

### Introduction

This is a summary of a study conducted for ArmaK by Western Technologies, Inc. of Phoenix, Arizona that is a continuation of previous work that showed cold mixed paving mixtures can be substituted on a 1 to 1 thickness basis for conventional hot mixed asphalt concrete.

This work is intended to show the effects of aggregate gradation, compaction method, curing method, and anti-strip treatments on laboratory properties of mixtures using emulsified asphalt and asphalt cement binders. Properties measured include:

- Density-voids
- Stability
- Resilient Modulus
- Tensile Strength

### Materials

2.1 Aggregates were crushed river gravel from Salt River siliceous deposits in Phoenix, Arizona. Gradations were dense and open conforming to The Asphalt Institute Types IV-b and III-b as shown on Figure 1.

2.2 Asphalt cement binder was a California AR-4000. emulsified asphalt binders were formulated solvent-free from a California AR-8000 base stock to approach CSS-1 and CMS-2 properties. Anti-strip agent, when used, was ArmaK Redicote 82-S.

2.3 Binder contents were 4.7 and 4.9 percent by weight of mixture for open and dense gradations

### Specimen Preparation

3.1 Asphalt cement mixtures were compacted at 230F (110C) by kneading compactor (25 tamps at 250 psi followed by 150 tamps at 500 psi).

3.2 emulsified asphalt mixtures were aerated to optimum compaction fluids content then received 25 tamps of a kneading compactor at 250 psi followed by static double plunger loading to 40,000 pounds (177.9 kN). Following compaction, specimens were cured in the mold for 18 hours at room temperature. After removal from molds, specimens were subjected to 12-15 in Hg (40.5 - 50.6 kPa) vacuum desiccation to constant weight. Other curing methods will be discussed later in this report.

#### 4.0 Data matrix

4.1 Variables considered in the study are shown on Figure 2. Data were analyzed by conventional analysis of variance.

#### 5.0 Tests and Measurements

5.1 The following tests were made as part of the larger study but not all will be discussed at this time.

- Density-voids
- Resilient modulus after 18 hour cure
- Resilient modulus after full cure
- Indirect tensile strength
- Hveem stability
- Marshall stability
- Effects of California Moisture Vapor Susceptibility conditioning (NvS)

#### 6.0 Effect of Binder Type

6.1 Data matrix for this experiment is shown on Figure 3. All mixtures for this experiment used type III-b (open) aggregate gradation. Binders include:

- CSS-1: Emulsified asphalt
- CSS-1M: Emulsified asphalt modified with an anti-strip additive
- CMS-2: Emulsified asphalt
- AR-4000: Asphalt cement

- AR-4000M: Asphalt cement modified with an anti-strip additive

## 6.2 Density

6.2.1 Cell means are plotted on Figure 4. Hot mixes show statistically higher densities than cold mixes using emulsified asphalt binders. This is consistent with findings of past work and suggests higher voids may be a result of water that remains in the mixture during compaction.

6.2.2 Since many mixture design criteria and other laboratory mixture characteristics that predict field performance are highly sensitive to density, two questions with regard to mixtures using emulsified asphalt binders must be addressed. The first concerns moisture removal during field mixing and placement and the second concerns development of laboratory compaction methods that will accurately simulate field mixtures. Projects are planned to study both situations and will be reported when results are available and analyzed.

## 6.3 Resilient Modulus

6.3.1 Resilient modulus for hot mixes using asphalt cement averaged 648,000 psi (4.5 GPa) with no significant effects due to the anti-strip modifier. After 18 hours cure, mixtures using emulsified asphalt averaged 117,000 psi (0.8 GPa) with no significant difference due to emulsified asphalt type or anti-strip modifier. However, after full cure, mixtures using emulsified asphalt averaged 745,000 psi (5.1 GPa) which is significantly higher than mixtures using asphalt cement. (See Table 1 and Figure 5)

## 6.4 Tensile Strength

6.4.1 Cell means are plotted on Figure 6. Conventional AR-4000 mixtures showed a significantly higher tensile strength than mixtures using CMS-2 emulsified asphalt but there is no statistical difference between mixtures using asphalt cement and CSS-1 emulsified asphalt.

## 6.5 Hveem Stability

6.5.1 Stability measurements were made before and after exposure to the California Moisture Vapor Susceptibility (MVS) test (Caltrans Method 307). The method, essentially, exposes a specimen to 100 percent relative humidity for 75 hours at 140F (60C) prior to stability testing. Caltrans stability requirements are as follows:

	Asphalt Concrete			Asphalt Base	
	A	B	C	A	B
Stability (mm)	37	35	30	37	35
MVS	30	25	20	30	25

6.5.2 As should be expected from density data, stability varies with density. Data for treated and untreated binders are shown on Figure 7. Note that none of the untreated mixtures meet the criteria for Class A asphalt concrete or base. Both AR-4000 mixtures qualify for Class B and the CSS-1 mixture qualifies for Class C.

6.5.3 An interesting observation can be made, however, if percent retained stability is calculated based on measurement of stability before and after MVS exposure. Ranked averages are as follows:

<u>Binder</u>	% Retained Stability
AR-4000M	102.3
CSS-1M	102.2
AR-4000	91.6
CSS-1	81.4
CMS-2	80.0

There is statistical significance between binders at the 95 percent confidence level but not at the 99 percent level. Mixtures using modified binders show higher retained stability than untreated binders and there is no significant difference in retained stability between mixtures using AR-4000, AR-4000M, or CSS-1M. It is of further interest to note that, for all binders, retained Marshall stability is higher after MVS exposure than dry (before exposure) testing.

## 7.0 Effect of Gradation

7.1 Data matrix for this experiment is shown on Figure 8. The experiment used both gradations and CSS-1 and CSS-1M (modified with an anti-strip additive)

### 7.2 Density

7.2.1 There was no statistical effect due to binder type but, as should be expected, the dense mixtures show higher densities by approximately one lb. per cu. ft.

### 7.3 Resilient Modulus

7.3.1 After 18 hours cure, the CSS-1 type III mixture showed the lowest resilient modulus (94,000 psi (0.6 GPa)) with no significant difference between the remaining three (127,000 psi (0.9 GPa)). After full cure, statistical ranking is as follows:

<u>Mixture</u>		Resilient modulus ( $10^6$ psi)
CSS-1M	(IV)	1.32
CSS-1	(IV)	1.00
CSS-1M	(III)	0.78
CSS-1	(III)	0.76

### 7.4 Tensile Strength

7.4.1 There is no significant effect due to binder modification but type IV gradations show higher tensile strengths than type III (147.8 psi (1.0 MPa) vs 108.0 (0.7 MPa)).

### 7.5 Hveem Stability

7.5.1 When analyzed on a percent retained stability basis after MVS there is no statistical effect due to gradation or binder modification.



## 8.0 Effect of Antistrip Treatment

8.1 Data matrix for the experiment is shown on Figure 9. This experiment used type III gradation and both treated and untreated AR-4000 and CSS-1 binders.

### 8.2 Hveem Stability

8.2.1 When analyzed on a percent retained stability basis after MVS there is no statistical effect due to base asphalt or anti-strip treatment.

## 9.0 Effect of Compaction Method

9.1 This section is somewhat subjective in as much as data obtained in this study (25 tamps with a kneading compactor at 250 psi followed by a 140,000 pound (177.9 kN) static double plunger load) are compared with 75 blow Marshall data from a different study based on materials from the same sources. Data matrix is shown on Figure 10.

### 9.2 Density

9.2.1 There is no statistical effect due to gradation type. Density by the modified Hveem method was significantly higher than that produced by the Marshall method (143.0 pcf vs 139.7).

### 9.3 Resilient Modulus

9.3.1 There is no statistical effect due to gradation or compaction method.

### 9.4 Tensile Strength

9.4.1 There is apparently no significant effect due to compaction method but dense graded (type IV) gradations with Hveem compaction may produce slight higher tensile strengths.

## 10.0 Effect of Cure Method

10.1 In an effort to reduce time from compaction to testing and recognizing that retained water (lack of cure) has an adverse effect on mixture properties measured in the laboratory, three methods of cure were studied.

- A. 18 hours in compaction mold at room temperature followed by vacuum desiccation at 12-15 in. Hg (40.5 - 50.6 kPa) to constant weight. This is the method used to develop data previously discussed and will be referred to as the WTI method.
- B. Three day cure in compaction mold at room temperature followed by vacuum desiccation at 10-20 mm Hg (1.3 - 2.5 kPa) for 3 days to constant weight. This method is referred to as the Chevron method.

- C. 24 hours in compaction mold at room temperature followed by 72 hours at 120F (48.9C) with the specimen placed on a geotextile fabric wick. This method is referred to as the modified Monismith or Rapid method.

10.2 Results of this study show no effect of cure method on density but the method does have an effect on resilient modulus, tensile strength, and Hveem stability.

### 10.3 Resilient Modulus

10.3.1 Data for the experiment is shown on Figure 12. There is no significant difference between the WTI and Rapid methods with a mean of 761,000 psi (5.2 GPa). Both produce a higher modulus than the Chevron method with 388,000 psi (2.7 CPa).

### 10.4 Tensile Strength

10.4.1 Data for the experiment is shown on Figure 13. Trends in tensile strength follow resilient modulus with no significant difference between the WTI and Rapid methods with a mean of 108 psi (0.7 MPa) and both produce higher tensile strength than the Chevron method with 66 psi (0.5 MPa).

### 10.5 Hveem Stability

10.5.1 Data for the experiment are shown on Figure 14. The Chevron and Rapid methods produce the same stability (25) and both are significantly lower than the WTI method (29).

## 11.0 Conclusions and Recommendations

11.1 This study, that used kneading compaction, points up some of the same concerns and suggests some of the same conclusions that were made in the first study that used Marshall compaction. First, is the question of applicability of using conventional hot-mix procedures for the laboratory evaluation of mixtures using emulsified asphalt. Procedures for hot-mix design (Hveem and Marshall) have been shown to produce laboratory mixtures that fairly accurately simulate characteristics of these mixtures after exposure to some traffic. This, and the previous study strongly suggest this may not be the case for mixtures using emulsified asphalt binders.

Data from these studies indicate that conventional laboratory compaction methods and procedures do not produce realistic densities and, hence, show unrealistic low stability when measured in the laboratory. It is recommended that field studies be initiated to determine what field density is produced by construction and later traffic compaction and that laboratory procedures be modified accordingly. Suggested modifications include study of additional double plunger compaction after curing to remove water or preparing specimens for stability testing and density-voids analysis by using residue (or base asphalt) rather than the emulsified asphalt binder.

11.2 The second conclusion that was also made in the first study is that cured emulsified asphalt mixtures show higher resilient moduli at 75F (24C) than mixtures using conventional asphalt cement binders. The cause of this is not known at this time but it has been

attributed to modification of asphalt properties by the emulsifier. Further study is recommended to investigate this at higher and lower temperatures, say, 140F (60C) and 0 F (-18C).

11.3 This study showed that curing of laboratory specimens can be accelerated by storing 72 hours at 120 F (49C) with the specimen placed on a geotextile fabric wick.

### Addendum

#### Laboratory Specimen Cure Methods

- 1) 72 hour air cure, out of mold.
- 2) 24 hour air cure, in mold without weight; 48 hour air cure, out of mold.
- 3) 24 hour air cure, in mold with 3,000 g load; 48 hour air cure, out of mold.
- 4) 72 hour in mold, 120F. without weight. 24 hour out of mold, 120F.
- 5) 72 hour in mold 120F. with 3,000 g load; 24 hour out of mold 120F.

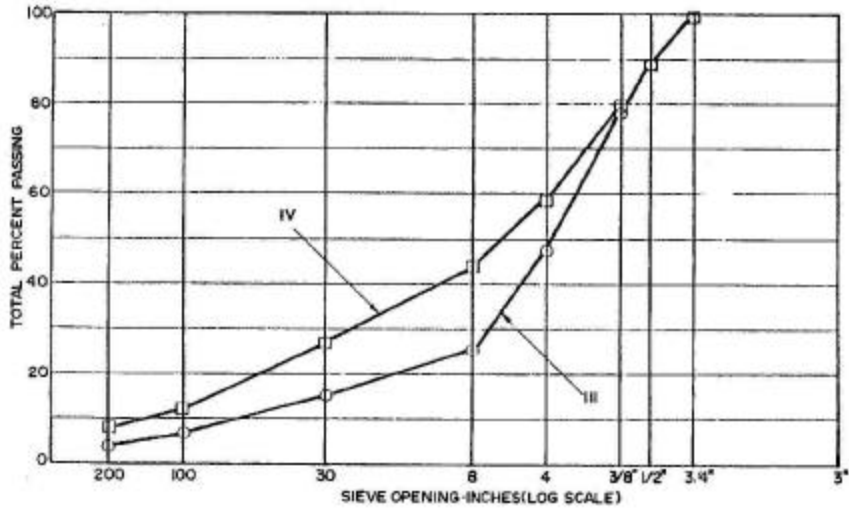
#### Average Values

Cure Method	Bulk Specific Gravity	Density	Maximum Theoretical Specific Gravity	% Air Voids	Marshall Stability	Flow
1	2.15	134	2.46	11.8	3264	17
2	2.18	136	2.46	10.4	3040	19
3	2.14	133	2.46	12.1	2980	20
4	2.26	139	2.46	8.1	3473	13
5	2.26	139	2.46	6.3	3411	13

● ASPHALT CEMENT	648,000psi
● EMULSIFIED ASPHALTS	
18 HOUR	117,000
FULL CURE	745,000

TABLE I RESILIENT MODULUS

AGGREGATE GRADING CHART



GRADATION

BINDER

	EMULSION			HOT MIX	
	CSS-1	CSS-1 MOD	CMS-2	AR-4000	AR-4000 MOD
III-b	— — —	— — —	— — —	— — —	— — —
IV-b	— — —	— — —			

FIGURE 2. EXPERIMENTAL TEST MATRIX

BINDER TYPE,  $M_1$

	EMULSION			HOT MIX	
	CSS-1	CSS-1 MOD	CMS-2	AR-4000	AR-4000 MOD
III-b	— — —	— — —	— — —	— — —	— — —

FIG. 3 DATA MATRIX, EFFECT OF BINDER

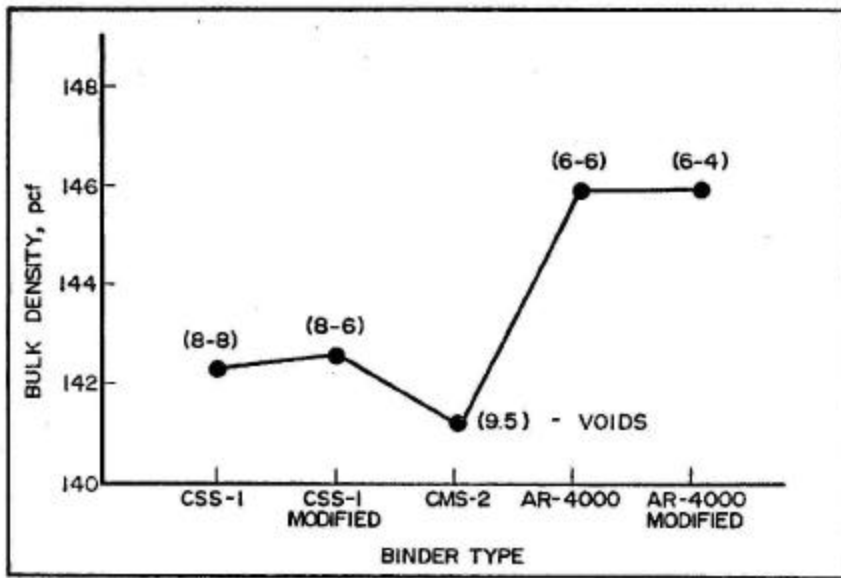


FIG. 4 BULK DENSITY

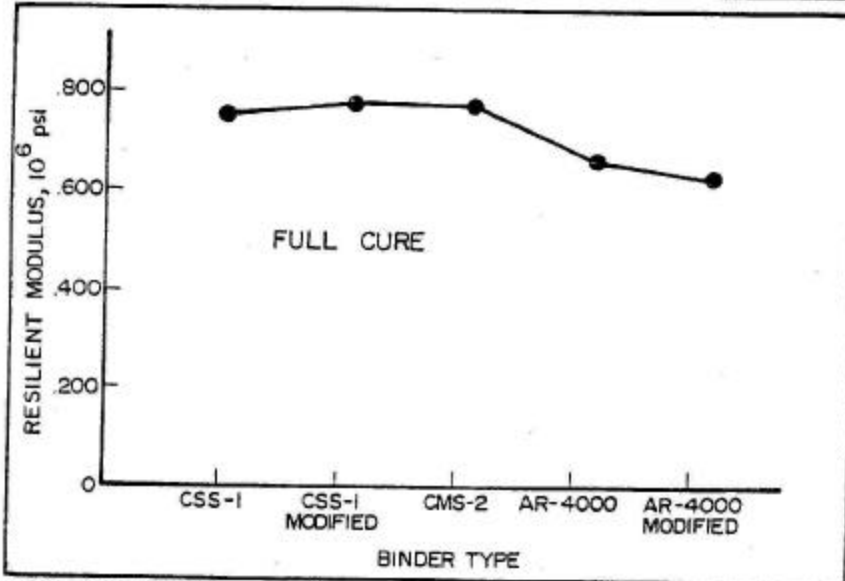
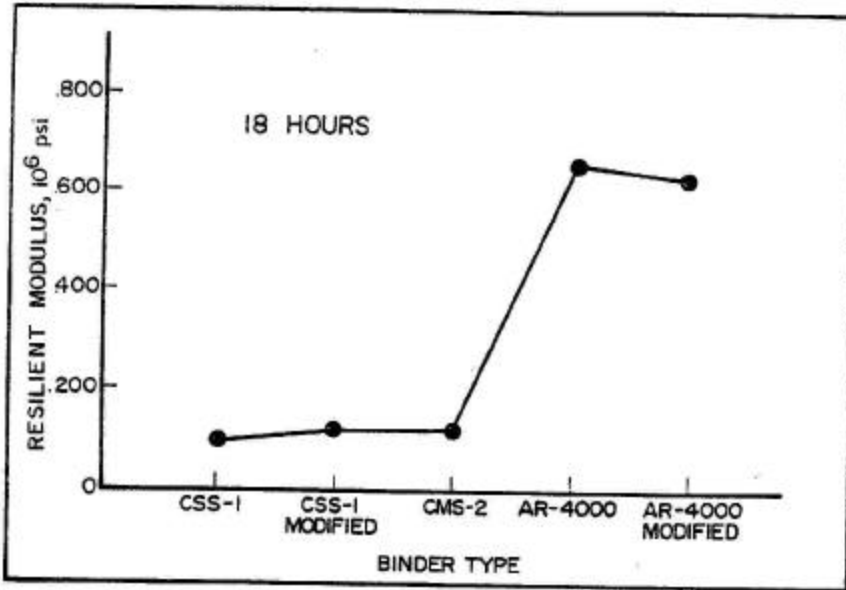


FIG. 5 RESILIENT MODULUS

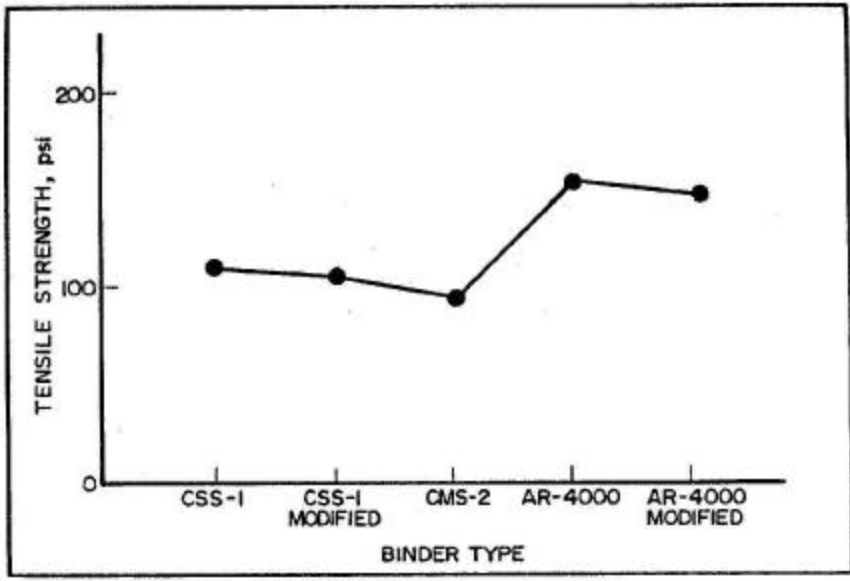
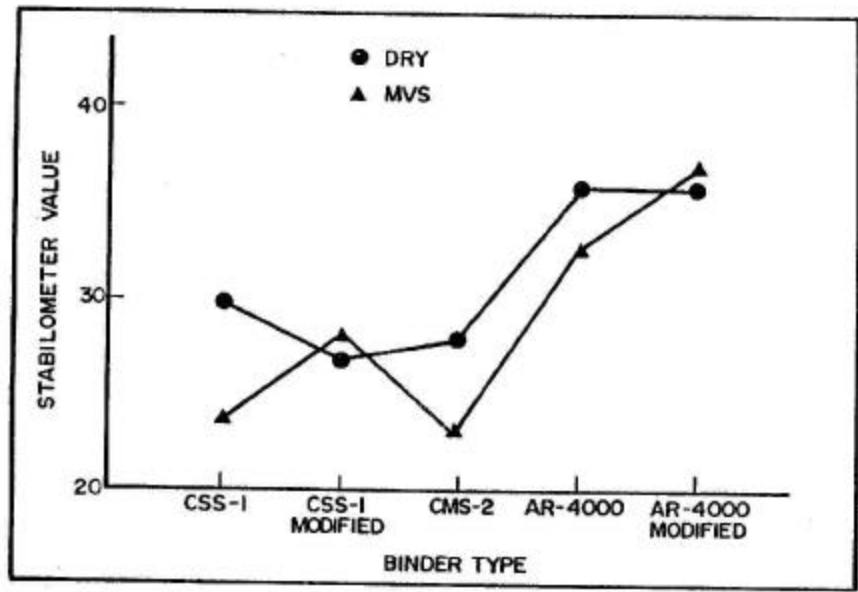


FIG. 6 TENSILE STRENGTH





GRADATION,  $G_j$

EMULSION TYPE, T

	EMULSION	
	CSS-1	CSS-1 MOD
III-b	— — —	— — —
IV-b	— — —	— — —

FIG. 8 DATA MATRIX, EFFECT OF GRADATION

MOISTURE RESISTANCE TREATMENT,  $T_i$

BINDER,  $B_j$

	CSS-1	AR-4000
UNTREATED	— — —	— — —
MODIFIED	— — —	— — —

FIG. 9 DATA MATRIX ANTI-STRIP TREATMENT

GRADATION,  $G_j$

COMPACTION TYPE,  $C_i$

	KNEADING	MARSHALL
III-b	— — —	— — —
IV-b	— — —	— — —

FIG. 10 DATA MATRIX, COMPARISON OF COMPACTION METHODS

EMULSION,  $E_j$

CURE METHOD,  $C_i$

	WTI	CHEVRON	RAPID
CSS-1	— — —	— — —	— — —
CMS-2	— — —	— — —	— — —

FIG. 11 DATA MATRIX FOR EFFECT OF CURE METHOD

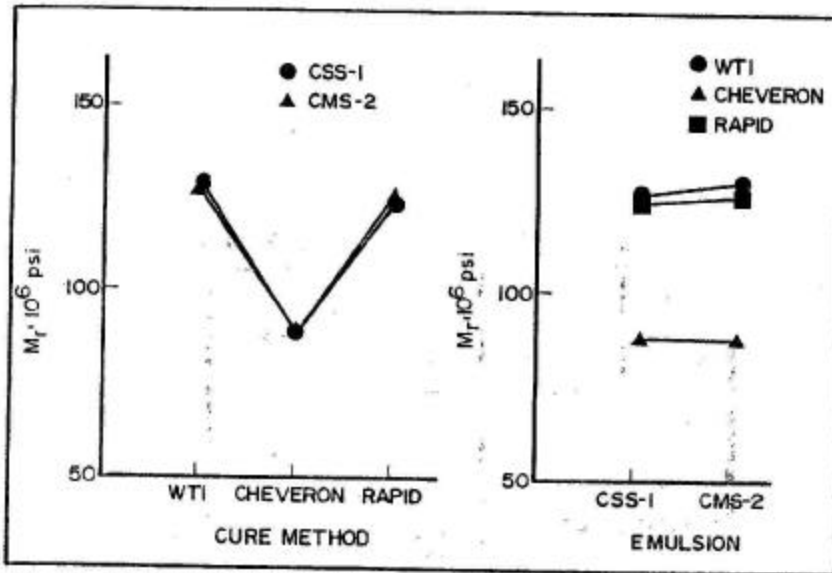


FIG. 12 RESILIENT MODULUS

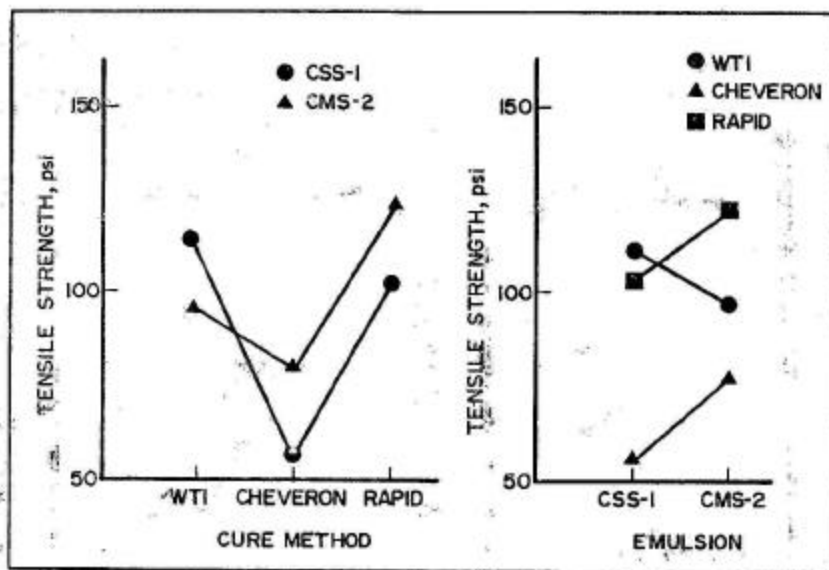


FIG. 13 TENSILE STRENGTH

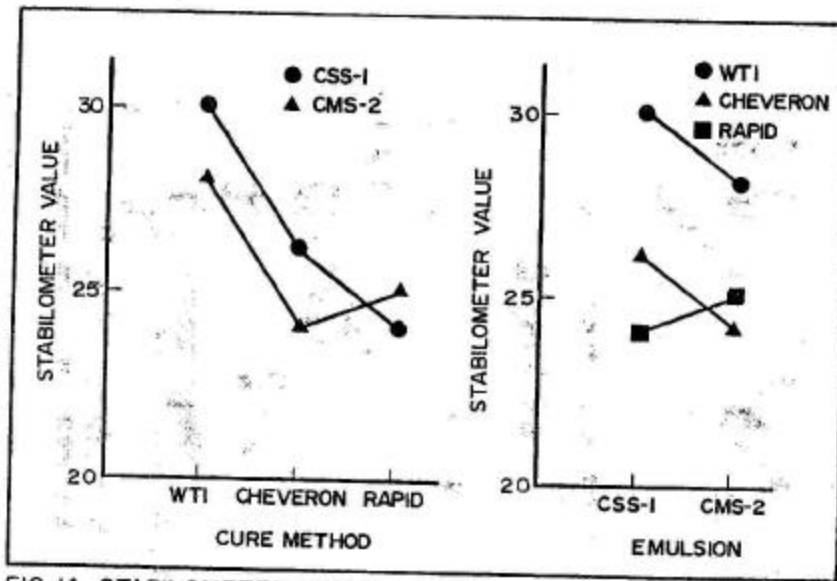


FIG. 14 STABILOMETER VALUE