FINAL REPORT

ILLINOIS METHOD FOR THE DESIGN OF DENSE-GRADED EMULSION BASE MIXES

by

C. S. Hughes
Senior Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

Virginia Highway and Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

June 1981

VHTRC 81-R53

BITUMINOUS RESEARCH ADVISORY COMMITTEE

R. L. ALWOOD, Chairman, District Materials Engineer, VDH&T

A. D. BARNHART, District Materials Engineer, VDH&T

P. F. CECCHINI, District Engineer, VDH&T

J. L. CORLEY, Assistant District Engineer — Construction, VDH&T

W. R. DAVIDSON, Assistant Maintenance Engineer, VDH&T

W. A. DENNISON, District Materials Engineer, VDH&T

C. E. ECHOLS, Asst. Prof. of Civil Engineering, U. Va.

R. V. FIELDING, Materials Engineer, VDH&T

C. S. HUGHES III, Highway Research Senior Scientist, VH&TRC

A. B. JOHNSON, Assistant Construction Engineer, VDH&T

J. T. LOVE, Materials Engineer, Materials Division, VDH&T

H. E. MARSHALL, District Engineer, FHWA

C. G. MCALLISTER, Chief Chemist, Materials Division, VDH&T

R. S. THOMAS, Bituminous Engineer — Maintenance Div., VDH&T

R. D. WALKER, Chairman, Dept. of Civil Engineering, VPI & SU

SUMMARY

This study evaluated the practicality of using a basic test method developed at the University of Illinois. The report describes the use of the Illinois equation for predicting trial asphalt content, compares the results obtained with two CSS emulsions, and gives the results of resilient modulus tests. Also described is a cure and soak procedure that can be used to expedite designs by the Illinois method.

3602

FINAL REPORT

ILLINOIS METHOD FOR THE DESIGN OF DENSE-GRADED EMULSION BASE MIXES

by

C. S. Hughes
Senior Research Scientist

INTRODUCTION

Virginia, along with many other states, is increasing its use of asphalt emulsion mixes. The Maintenance Division of the Department of Highways and Transportation has used emulsion surface mixes for several years, with the mixes being produced in either a portable pugmill mixer or a traveling plant, and some districts have tried emulsion base courses.

Although the design of emulsion mixes can be developed on the basis of guess and experience, it is only logical that a mix design procedure should be developed to give general direction in the selection of aggregate gradation, asphalt type and content, and desirable moisture content for mixes to be placed on secondary and low-traffic primary roads.

Of the several design procedures available, the Illinois method appears to be the most feasible for adoption in Virginia because –

1. it relies on the Marshall design procedure, which is used statewide for the design of hot mixes;

2. it is one of the most thorough and definitive of the methods available; and

3. since it is being evaluated by several other agencies, including The Asphalt Institute, comparison of evaluations from various agencies will be possible.(1,2,3)

PURPOSE AND SCOPE

The purpose of this investigation was to determine the feasibility of the Department's adopting the Illinois procedure for designing asphalt emulsion mixes. It was limited to the design of dense-graded emulsion base mixes using cationic emulsions, since these mixes are likely to be in greatest demand.

Of course, the final determination of the value of the design procedure is the performance of the mixes in the field. However, this determination cannot be made until the design procedure is put into practice and mixes designed under it are put into service.

APPROACH

While it was recognized that of the available procedures the Illinois method appeared to best suit the needs of the Virginia Department of Highways and Transportation, there were several concerns, including the following.

1. The necessity of using a different compactive effort than is used in the design of hot mixes.
2. The practicality of using an equation based on a wet sieve gradation for determining the trial emulsion content.
3. The practicality of the curing time, in which 7 days are required to obtain the optimum emulsion content.

These three elements of the design procedure were emphasized in the investigation.

MATERIALS

Aggregates

Four aggregates were used: crusher-run limestone, crusher-run granite, a recycled surface course of predominately gravel, and a pit-run sand.

The dry and wet gradations, including sand equivalent values, are shown in Table 1. The sand equivalent test was run on all aggregates simply for completeness. The only aggregates with a value close to the recommended minimum of 25 was the pit sand with a value of 37. The gradations met the tentatively recommended Illinois guidelines, which are quite broad. From experience with the sand, it was anticipated that 5% hydrated lime would have to be added to improve the gradation, and this was done for the analyses.

The gradations are shown in Table 1, where the dry gradation is from the standard test method in Virginia. The Illinois procedure uses an equation based on the washed (wet) gradation to predict a trial residual asphalt content.

Table 1

Gradations of Aggregate, Percentage Passing

	Limestone		Granite		Recycle		Sand*	
Sieve Size	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1"	100.0	100.0	100.0	100.0				
3/4"	94.4	91.6	99.0	100.0	100.0	100.0	100.0	
1/2"	71.4	72.3	83.5	86.3	92.0	93.8	98.6	100.0
3/8"	60.3	67.1	70.2	69.4	80.2	85.7	97.6	99.5
#4	45.3	46.4	41.0	42.1	47.5	57.3	96.2	98.4
#8	25.8	26.2	22.9	22.5	27.3	34.8	94.0	97.0
#30	7.9	8.5	10.0	10.1	7.3	9.2	72.4	74.5
#50	4.8	5.9	7.5	7.4	3.0	3.9	27.6	34.0
#100	3.1	4.4	5.2	5.1	1.0	1.4	5.6	16.3
#200	2.2	3.6	3.3	3.3	0.9	0.6	4.9	15.3
Sand Eq.	61		70		99		37	

*With 5% hydrated lime

Emulsions

Two emulsions were used, both CSS-1h, one supplied by the Central Oil Company and the other by Chevron U.S.A., Incorporated. However, before the study could be completed it was obvious that the supply of the Chevron emulsion was going to be depleted. The laboratory that had furnished this material had closed, so the second supply of the Chevron emulsion was provided by another laboratory. Because the properties of these two emulsions were not the same, as shown in Table 2, some duplication of testing was necessary to establish a correlation between the two.

Table 2

Properties of Emulsion
CSS-1h Type

	Central Oil	Chevron #1	Chevron #2
Viscosity, Saybolt Furol at 77°F.	21	32	46
Distillation residue, percent	61.9	65.1	65.7
Penetration at 77°F.	169*	84	73
Ductility	40+	40+	40+
Bitumen Sol., percent	99.9	98.4	99.3

*Did not meet specifications

MODIFIED PROCEDURE

The procedure for establishing the optimum moisture content at compaction and the emulsion contents generally followed the Illinois method.(3) However, the experimental procedure for establishing the trial emulsion content deviated from this method as follows:

1. A 200-g. sample of aggregate was dampened and mixed for 30 seconds.

2. Emulsion was added to achieve about 100%** coating of the aggregate.

This amount of emulsion was then used as the trial emulsion content. The Illinois method was followed from this point, except that 50-blow Marshalls were used to bring the emulsion design procedure in line with the hot mix design used in Virginia.

To facilitate soaking, specimens were jacked out of the molds and placed in 1/2 in* of water. This provided the same depth of water on the specimen as recommended by the Illinois method.

*For S.I. equivalents of conventional units used, see notations on page 25.

**The Illinois method uses a visual coating of 50% as satisfactory. In the modified procedure, it was felt that 100% coating was easier to judge and would provide a convenient level at which to define the trial emulsion content.

Problems were encountered in determining the moisture content, because in the Marshall tests the heads of the testing apparatus squeezed water out of the specimens while testing. It is suggested that in lieu of making weight determinations on the failed specimens, the specimens be weighed prior to testing for both dry and soaked conditions, and that this value be used for the value "H" cited in reference 3.

As will be discussed later, accelerated dry and soaked curing procedures were developed after the initial design evaluation had been completed.

RESULTS

The design charts for the four aggregates and two emulsions are shown in Figures 1-8, and the data are discussed under the succeeding subheads.

Trial Asphalt Contents

In addition to the use of the Illinois equation and the experimental procedure for establishing the trial emulsion content, the CKE procedure[3] as recommended in The Asphalt Institute method was also investigated.

The Illinois equation for calculating the trial residual asphalt content is

$$R = 0.00138AB + 6.358 \log_{10} C - 4.655,$$

where

R = trial residual asphalt content by weight of dry aggregate, W%;

A = percentage retained on #4 sieve;*

B = percentage passing #4 and retained on #200 sieve;* and

C = percentage passing #200 sieve;*

*Obtained by washed (wet) gradation.

3608

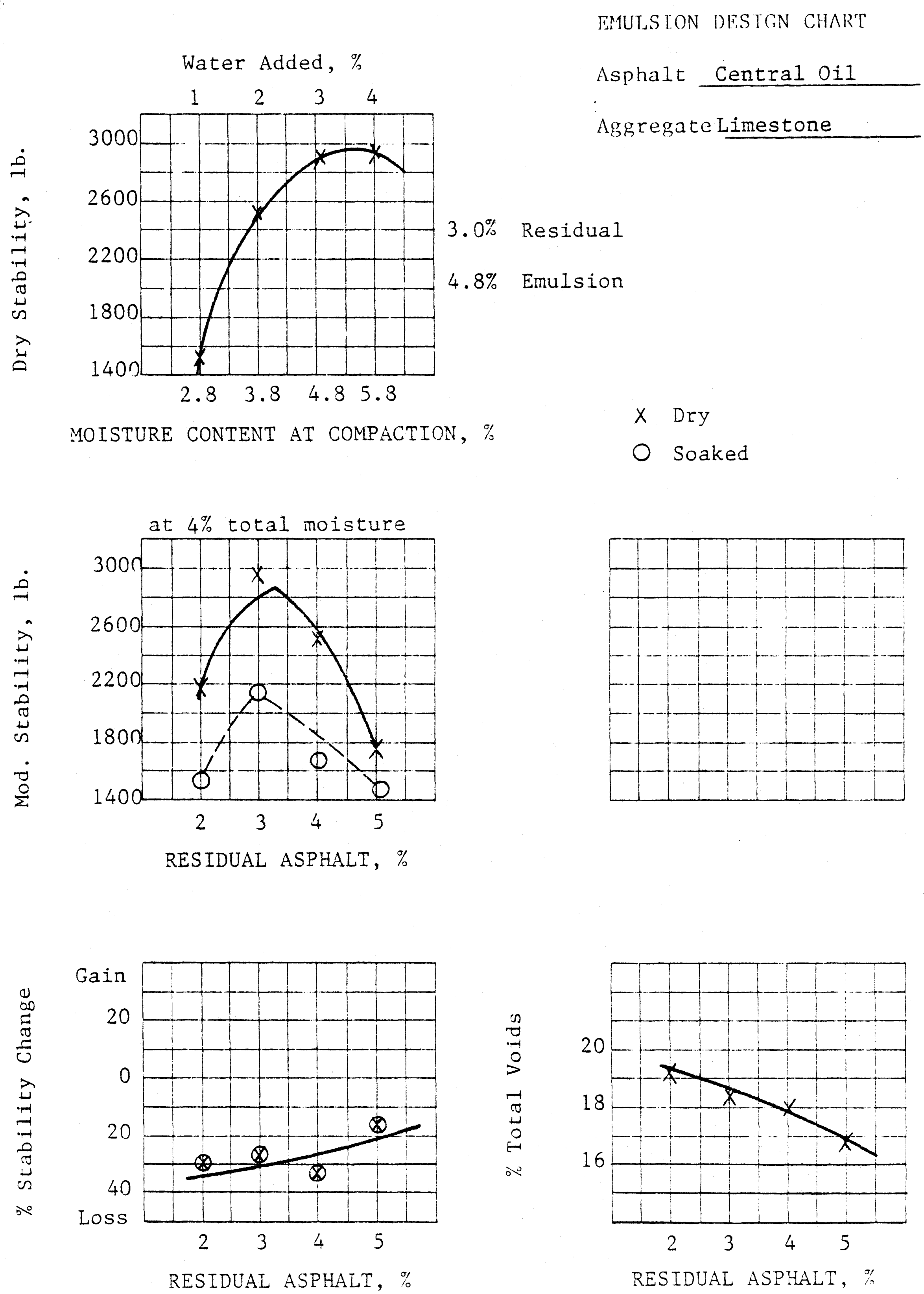

Figure 1. Mix design for limestone aggregate with Central Oil emulsion.

3609

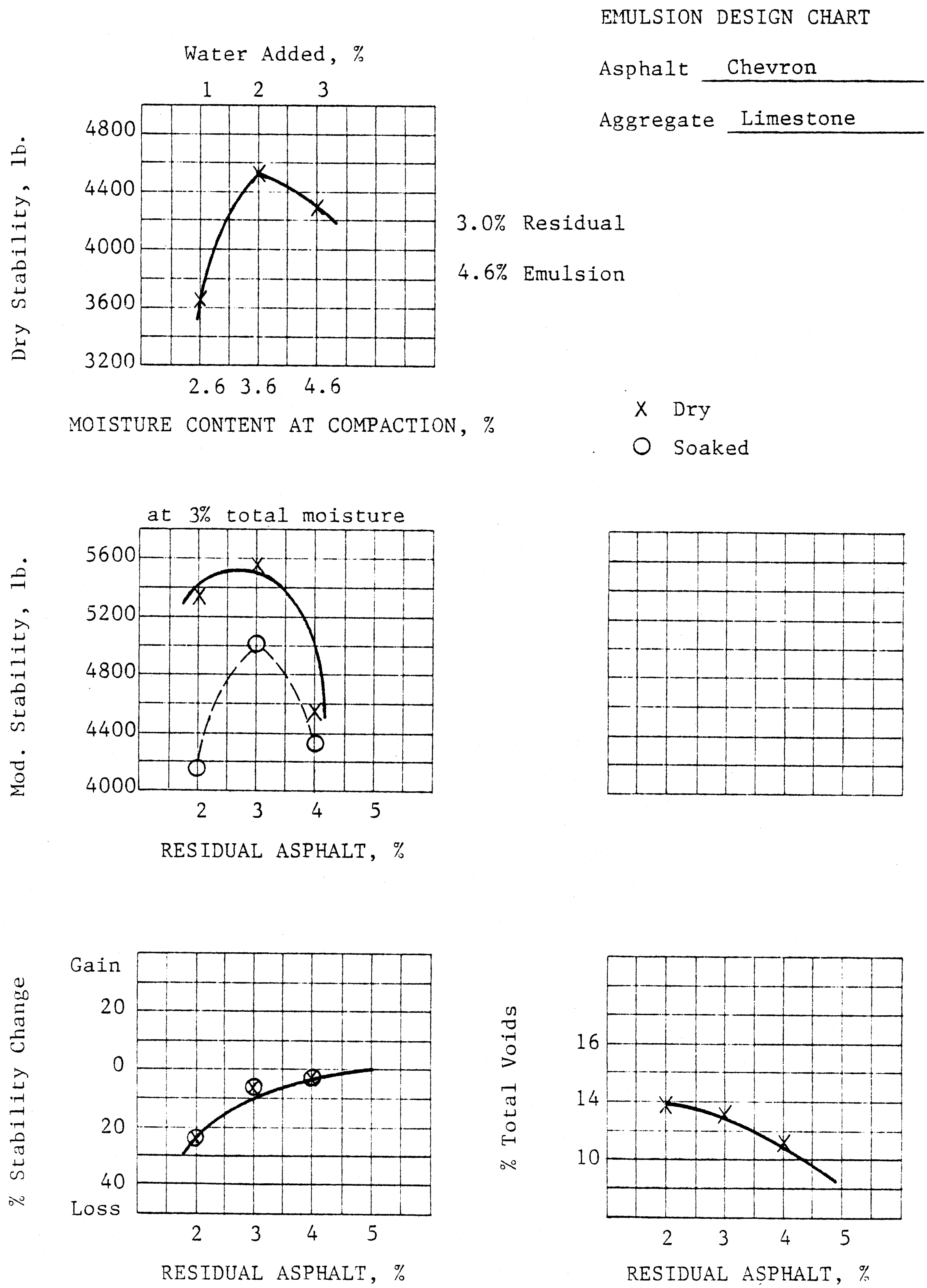

Figure 2. Mix design for limestone aggregates with Chevron emulsions.

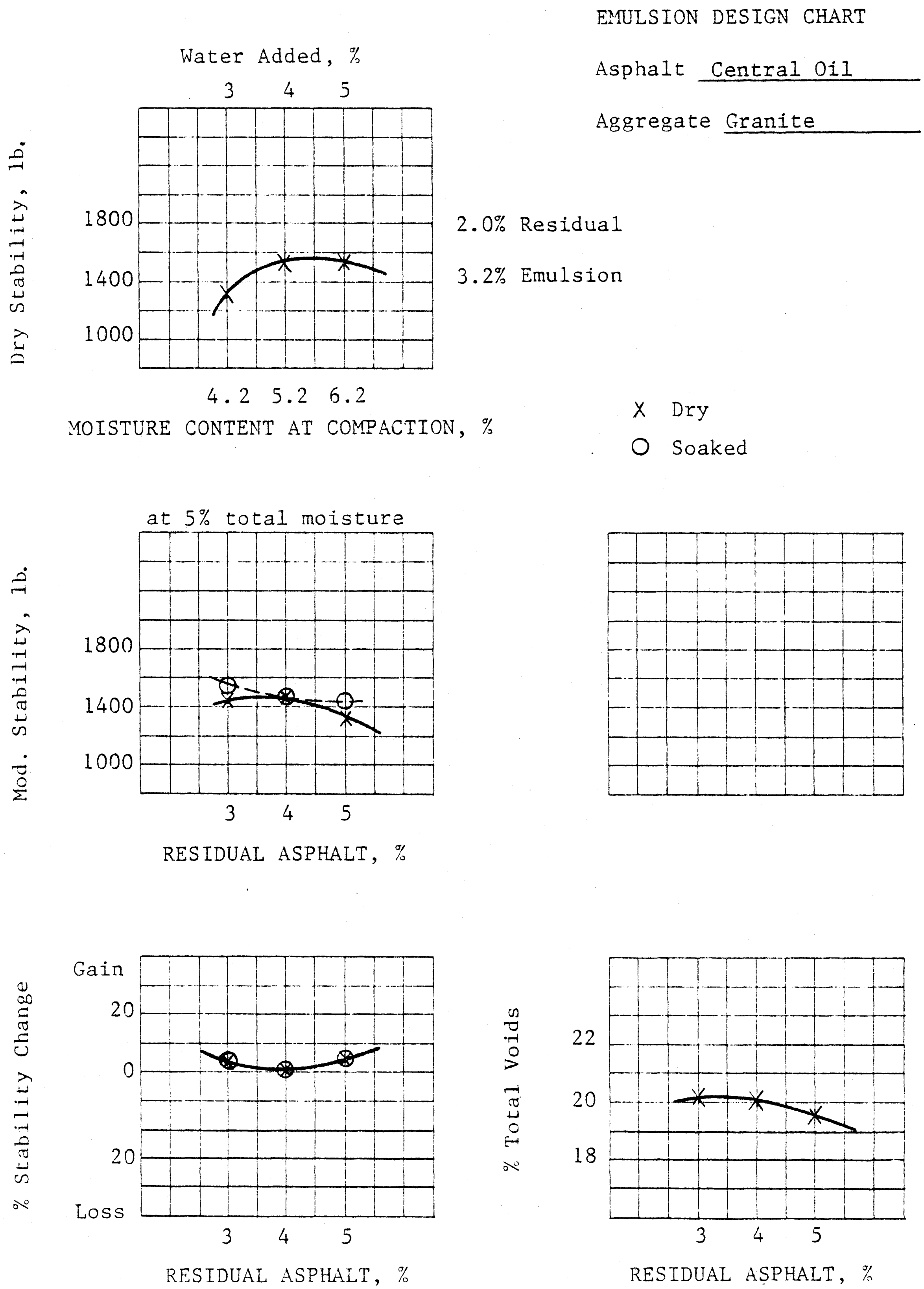

Figure 3. Mix design for granite aggregates with Central Oil emulsions.

3611

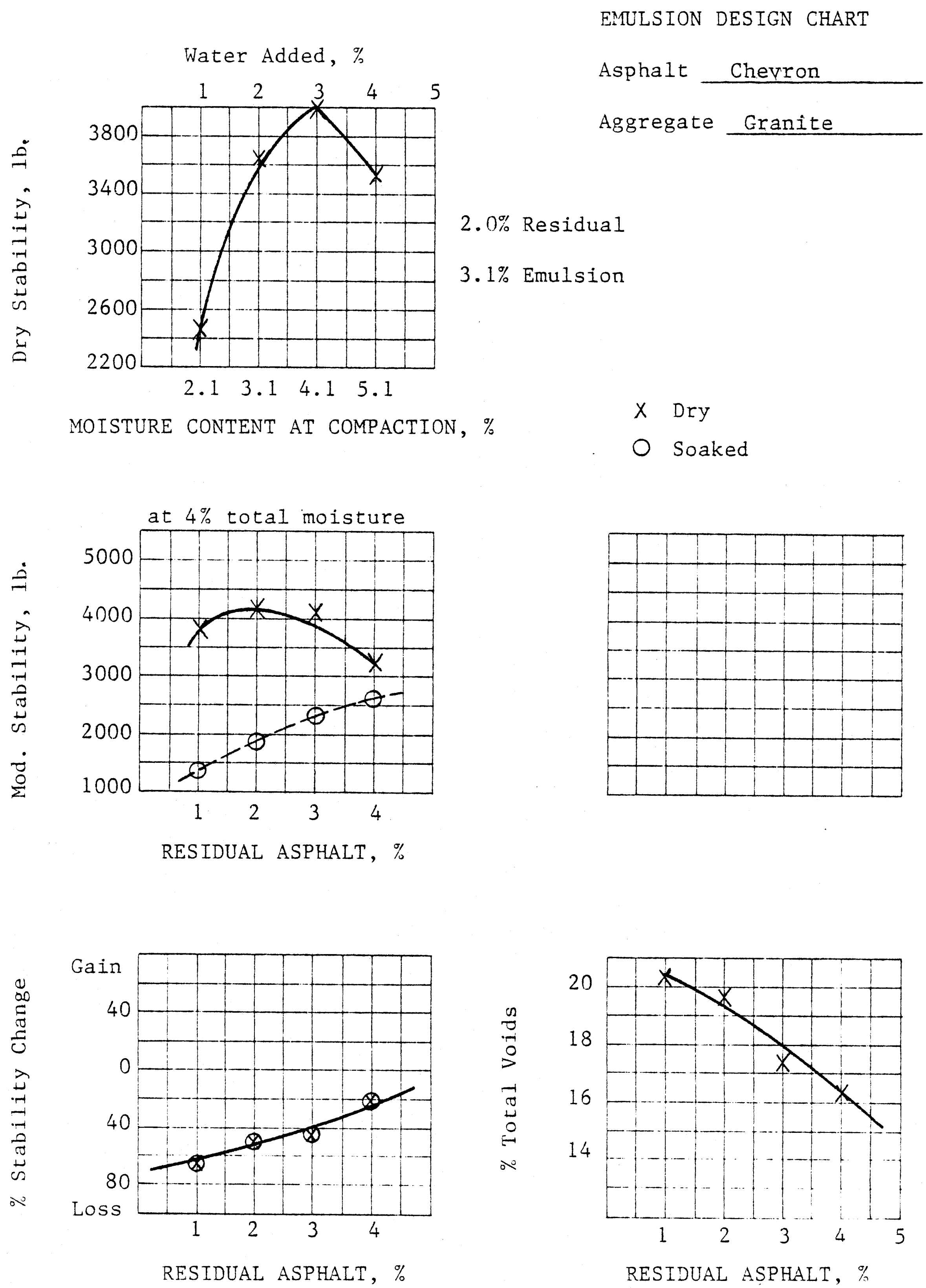

Figure 4. Mix design for granite aggregates with Chevron emulsions.

3612

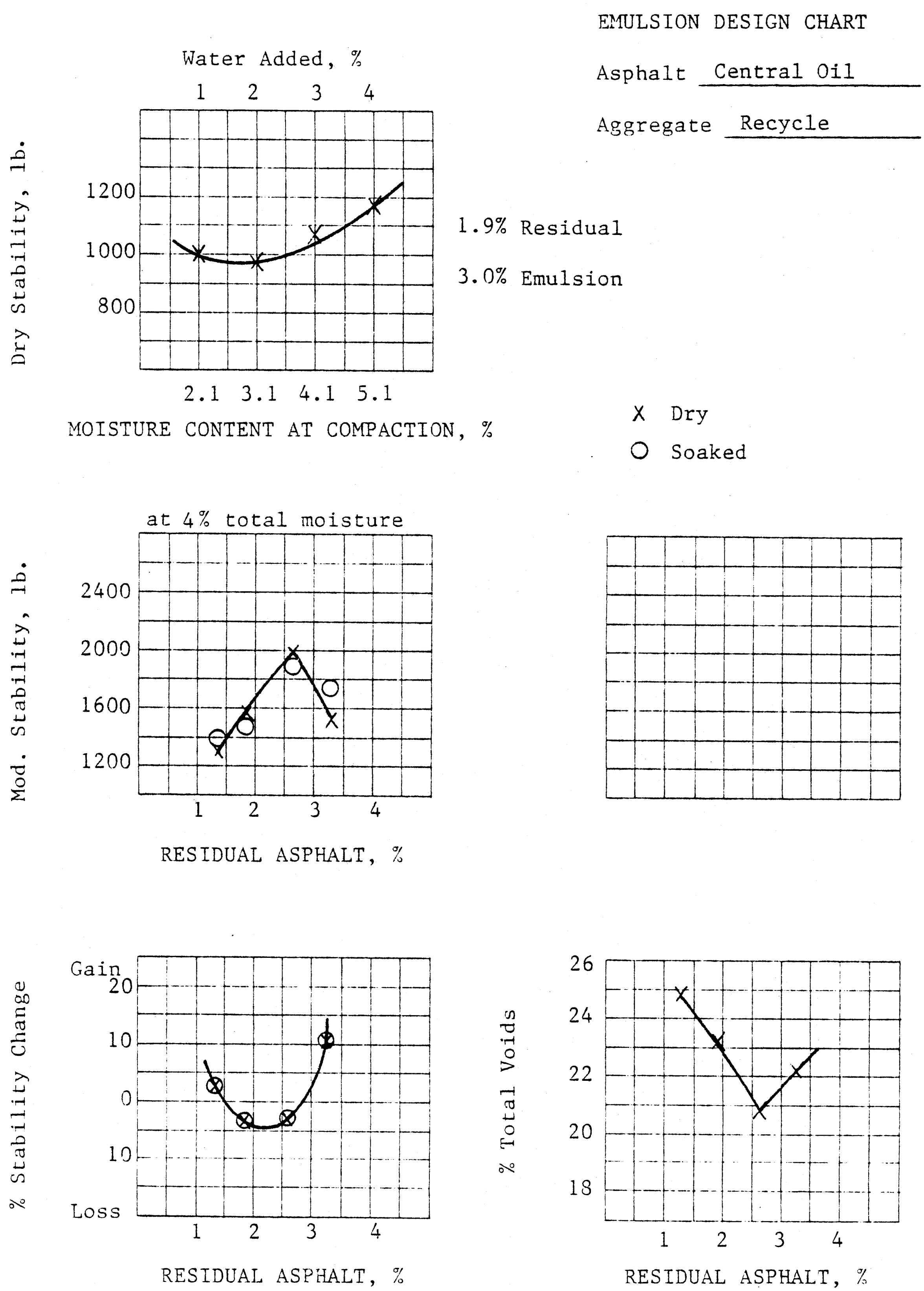

Figure 5. Mix design for recycled aggregates with Central Oil emulsions.

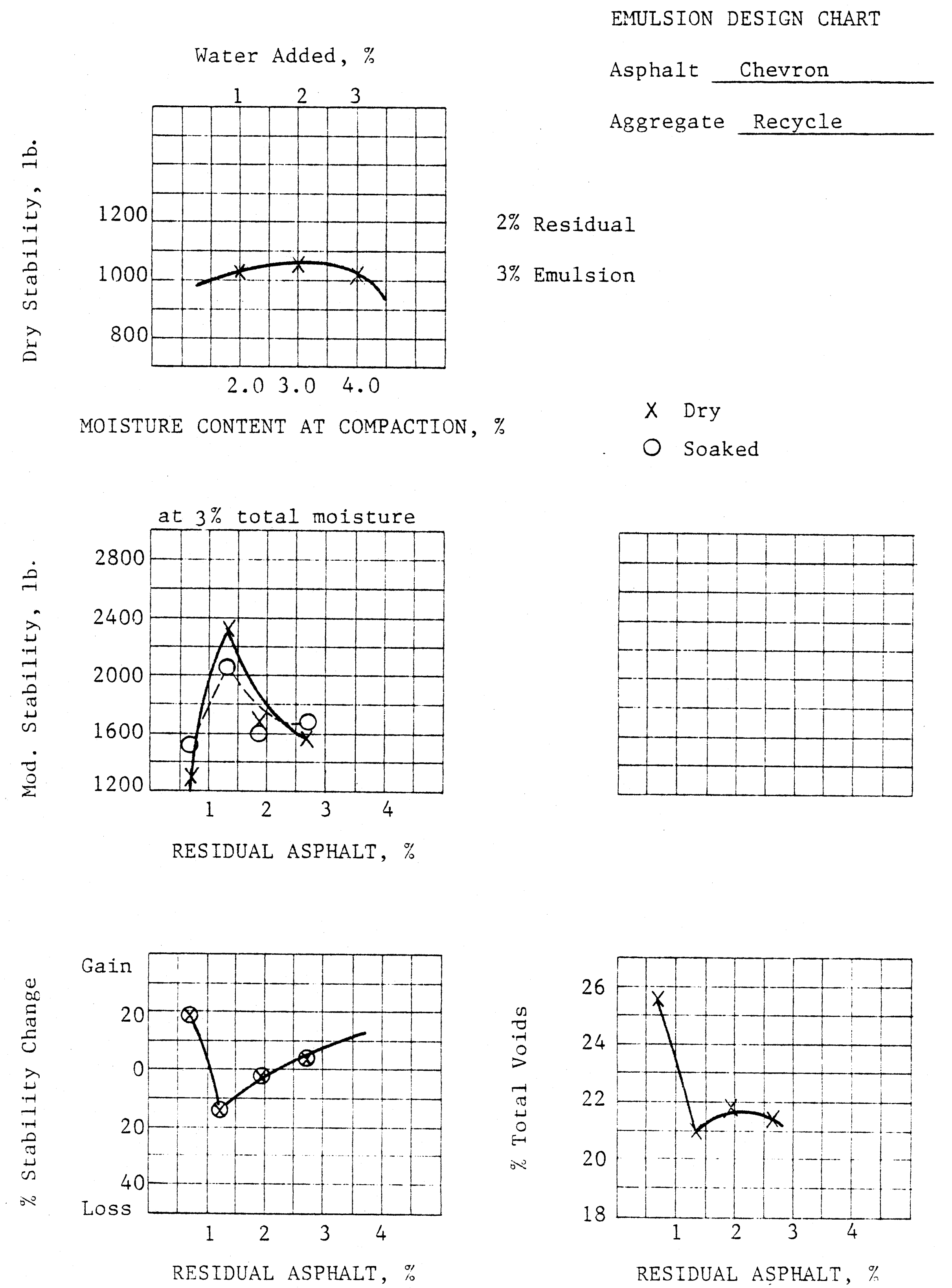

Figure 6. Mix design for recycled aggregates with Chevron emulsions.

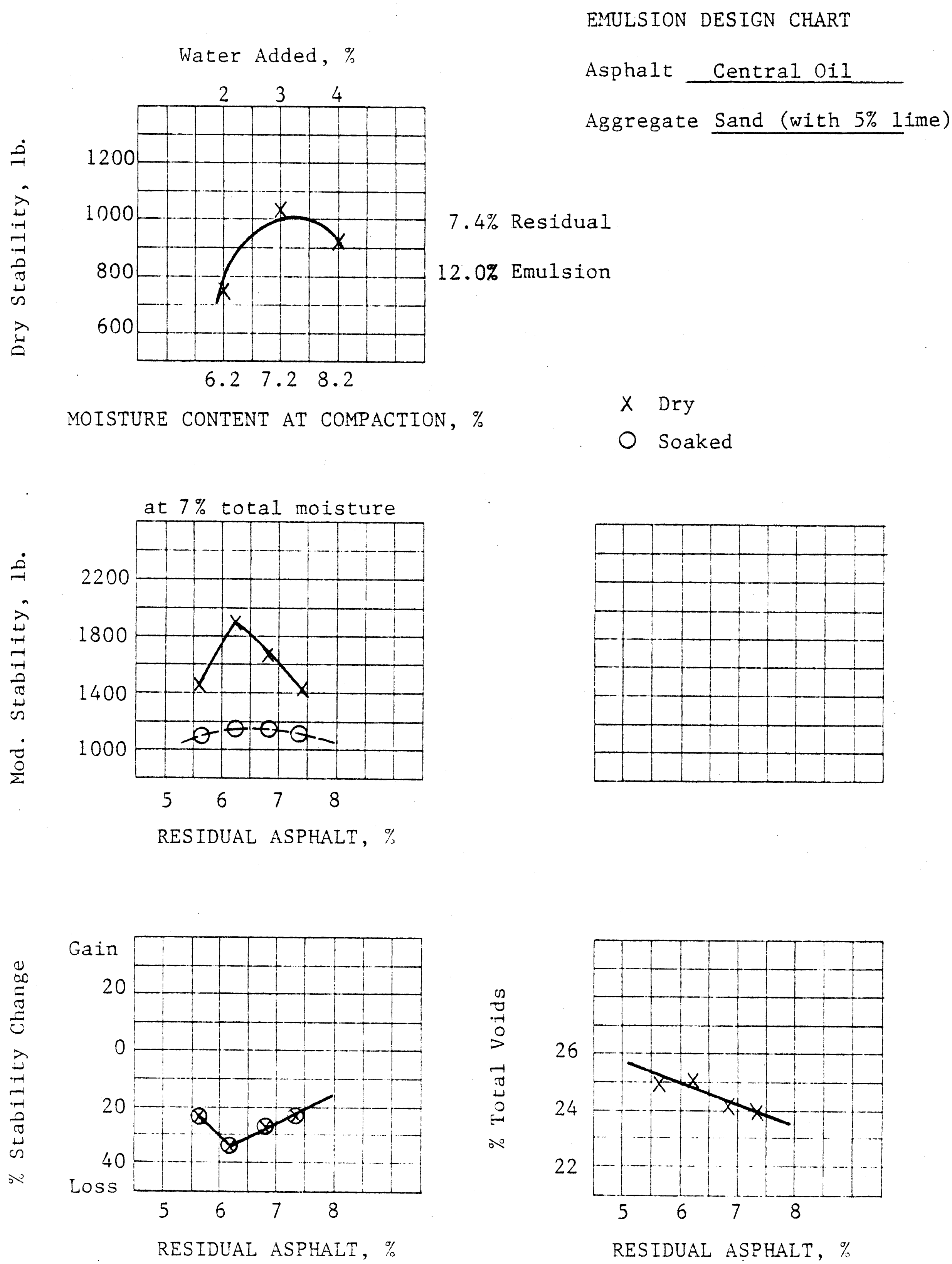

Figure 7. Mix design for sand with Central Oil emulsions.

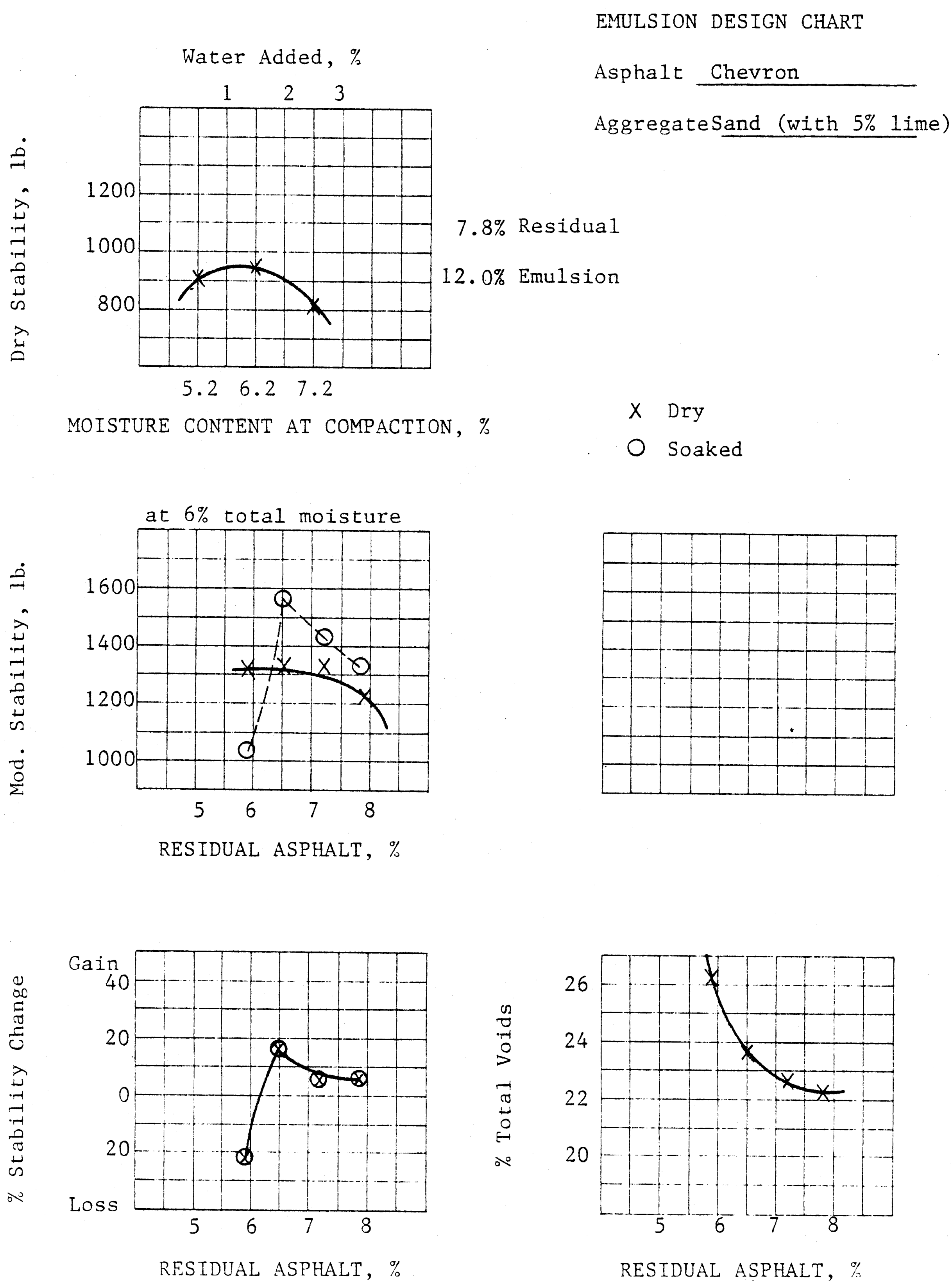

Figure 8. Mix design for sand with Chevron emulsions.

The trial asphalt contents are shown in Table 3 using the Virginia experimental procedure, the CKE procedure and the Illinois equation with both dry and wet gradations. The Virginia data are shown in both emulsion and residual form for ease of comparison.

Table 3

Trial Asphalt Contents, Percent

	Emulsion			Residual			
	Virginia		CKE	Virginia		Illinois	
Aggregate	Cent. Oil	Chevron		Cent. Oil	Chevron	Dry	Wet
Limestone	4.8	4.6	3.6	3.0	3.0	1.9	2.0
Granite	3.2	3.1	3.8	2.0	2.0	1.7	1.7
Recycle	3.0	3.0	-	1.9	2.0	-1.6	-2.7
Sand	12.0	12.0	7.6	7.4	7.8	0.2	3.1

From the data in Table 3 it appears that both the CKE method and the Illinois formula do a reasonable job of estimating the trial asphalt contents of the limestone and granite mixes when compared to the Virginia experimental method used in this study. For these crushed stone gradations there was not much difference between the wet and dry analyses, thus there were no practical differences in the estimated residual asphalt contents. The Illinois equation estimated slightly less asphalt than the Virginia experimental method. Neither the CKE nor the Illinois equation was useful in estimating the asphalt content for the recycled aggregate. Both of these estimated much lower asphalt contents than those estimated by the Virginia experimental method. The Illinois equation estimated negative residual asphalt contents because of the low percentage passing the No. 200 sieve; less than 1% produces a negative value in the equation. In the CKE tests, the kerosene washed some of the asphalt off the aggregate so the test was terminated. For the sand both the CKE method and the Illinois equation predict too low an emulsion content for either procedure to be workable.

It would appear that as a first attempt to establish a trial asphalt content in Virginia, the most easily adaptable procedure would consist of the Illinois method with a dry gradation. This would not require any change in Virginia's gradation procedure and would be a reasonable starting point. It should be recognized, however, that this procedure will very likely not be useful for recycled aggregate or fine, particularly one-sized, sands. For any mixes not made with virgin crushed aggregate, the experimental approach used in this study is suggested.

As would be expected, the trial asphalt contents vary considerably from aggregate to aggregate but, as the results from the Virginia experimental method indicate, there is little or no difference between the two emulsions for a given aggregate.

Moisture Content at Compaction

The graphs at the upper left of the design charts give the dry stability vs. percent moisture content at compaction, including the percent water added. To the right of these graphs are the trial residual and emulsion contents used. In nearly every case, a peak dry stability was reached for the moisture at compaction. In the few cases where a peak stability was not obtained, it was noted that the mixes were too wet and that continued wetting would not help.

Of interest in these data is the fact that both the level of dry stability and moisture content at compaction vary for the two emulsions. Generally, the Central Oil emulsion required 1% more moisture than the Chevron emulsion to produce the peak stability. Also, for the crushed stone mixes the peak dry stability was higher for the Chevron emulsion than for the Central Oil emulsion, and this result was probably strongly influenced by the penetration of the residual asphalt, which was higher for the Central Oil emulsion as shown in Table 2.

Choosing the optimum moisture content at compaction was not difficult. Using the stability vs. moisture content at compaction curve and visual observation of the consistency of the mix the selection of the total moisture to be used with varying residual asphalts became routine.

Dry and Soaked Stabilities vs. Residual Asphalt

Plotted on the middle graphs in the design charts is the relationship between dry and soaked stabilities and residual asphalt, and at the top of each graph is the total moisture used for the mixes.

The dry stability results for the crushed stone mixes varied considerably between emulsions, with the Chevron producing the highest stability. The mix with the recycled aggregate had about the same stability with both emulsions, and the stabilities for the sand mix were slightly higher with Central Oil emulsion. These findings indicate a strong aggregate-asphalt interaction.

Surprisingly, in four of the eight asphalt-aggregate combinations the soaked stabilities approached or exceeded the dry stabilities.

The graph at the bottom left-hand corner of the design charts indicates the percent change in stability. The changes for the granite-Central Oil, recycled-Central Oil, recycled-Chevron, and sand-Chevron mixes ranged from slight losses to appreciable gains. The explanation of the change for the recycled aggregates probably is that the original asphalt coating combined with the emulsion to produce a low water susceptibility. The stability changes are apparently inversely related to the percent total voids shown on the graph in the lower right of the design chart. Carrying this reasoning one step further, it would seem that improvements in gradations, while maybe not economical, could result in mixes less sensitive to attack by water. The voids in the crushed stone mixes were generally lower than in the recycled aggregate and sand mixes, but still in the 10% to 20% range.

Mixture Design Criteria

The design criteria given in reference 3 were easily met, with the exception of the maximum percent total voids, which was given as 8%. In every case the voids exceeded this value. The finding of greater voids in this study is partially due to the lower compactive effort (50 blows) than that recommended in the Illinois procedure (75 blows).

The percent absorbed moisture value was not obtained because of the previously noted difficulty in determining an accurate weight of the failed specimen as called for in the procedure. This problem could be overcome by weighing both dry and soaked specimens just prior to testing rather than after testing.

Optimum Asphalt Content

Based on the maximum soaked stabilities, the optimum residual asphalt contents are given in Table 4. It is interesting to note that these optimum asphalt contents are not greatly different from those obtained by the Virginia experimental trial asphalt content procedure.

Table 4

Optimum Residual Asphalt in Percent
Based on Max. Soaked Stability

Aggregate	Central Oil	Chevron
Limestone	3.0	3.0
Granite	3.0	4.0
Recycle	2.5	1.5
Sand	6.5	6.5

Accelerated Curing and Soaking

Because the seven-day period of dry curing and soaking appears to be excessive for a practical design procedure, the modified procedure outlined below was developed.

1. Cure six specimens in the mold in an oven at 140°F for 16 hours.

2. Remove the specimens from the oven and let stand until they reach room temperature.

3. Remove specimens from mold and test 3 of them normally.

4. Vacuum saturate the 3 remaining specimens for 5 minutes, turn off the vacuum, and let them stand in water for 2 hours.

5. Remove specimens from water, dry the surface, and test normally.

The results from this accelerated curing procedure are compared to those from the Illinois curing procedure in Table 5.

Table 5

Comparison of Illinois and Accelerated Curing and Soaking

	Stability in lb.							
	Dry				Soaked			
Aggregate	Central Oil		Chevron		Central Oil		Chevron	
	Ill.	Accel.	Ill.	Accel.	Ill.	Accel.	Ill.	Accel.
Limestone	2,980	2,809	5,525	5,392	2,150	2,257	5,100	4,810
Granite	1,415	1,540	4,114	4,196	1,413	1,371	1,947	1,843
Recycle	1,986	1,661	2,316	1,951	1,908	1,666	2,004	1,420
Sand	1,865	1,473	1,320	1,744	1,399	1,458	1,573	1,279

The correlations for these results were very good as can be seen in Figure 9. The correlation coefficient, r, was .982 for the combined dry and soaked results. The percent variance explained (r^2) is thus 96%, which indicates a very good correlation. The linear regression equation has a slope of .99 and an intercept of only 158 lb. For all practical purposes, this indicates a 1 to 1 relationship.

Comparison of Emulsion Shipments

As mentioned previously, it was apparent that the initial supply of Chevron emulsion would not be sufficient to make mixes for the entire project. When this became apparent, the Chevron lab that had formulated the original emulsion had closed, and the second supply was obtained from another lab. It was considered prudent to run a correlation between the two emulsions, not just through a comparison of their physical properties as shown in Table 2, but also through the mix design procedure. The accelerated curing and soaking procedure was used on all mixes. Data from the correlation are shown in Table 6. The linear regression analysis produced a correlation coefficient of .938 for an r^2 (variance explained) of 88%. The difference between average stabilities for Chevron #1 and #2 is only 74 lb., which indicates no difference was found between the mixes made with the two emulsions.

Table 6

Comparison of Mixes Made With Chevron Emulsions

Aggregate	Stability in lb.			
	Dry		Soaked	
	Chevron #1	Chevron #2	Chevron #1	Chevron #2
Limestone	5,392	4,627	4,810	4,025
Granite	4,196	4,184	1,843	2,953
Recycle	1,951	2,018	1,420	1,581
Sand	1,744	1,991	1,279	1,376

Although not calculated here, the percent changes of Chevron soaked to dry specimens compare favorably with those found in the initial mix design using the Illinois curing and soaking procedure.

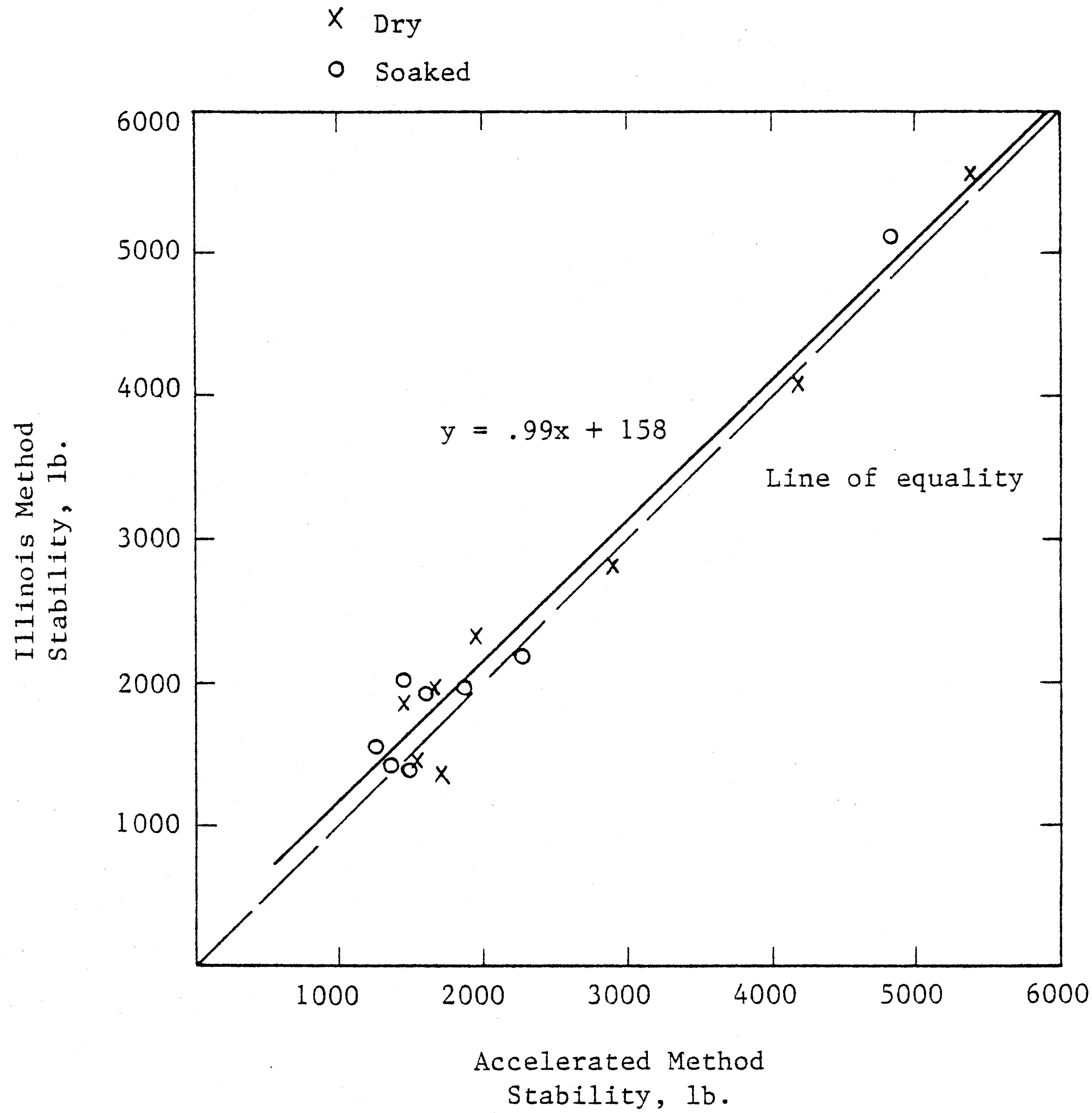

Figure 9. Correlation of Illinois and accelerated cured and soaked specimens.

Resilient Modulus

To obtain some basic information on resilient modulus values, tests were run on one set of samples using Central Oil and Chevron #2 emulsions with each of the four aggregates. Three specimens were made for each emulsion-aggregate combination, cured and soaked with the accelerated procedure, and tested on a Mark II testing device. The average results are shown in Table 7.

Table 7

Resilient Modulus Results, psi (Accelerated Curing and Soaking)

	Central Oil			Chevron		
Aggregate	Dry	Soaked	% Change	Dry	Soaked	% Change
Limestone	100,000	48,000	-52	178,000	89,000	-50
Granite	27,000	33,000	+22	57,000	25,000	-56
Recycle	42,000	40,000	-5	71,000	46,000	-35
Sand	44,000	28,000	-36	87,000	40,000	-54

As with the stability tests, there was a considerable difference between the moduli for the same aggregate but different emulsions. However, for this test the Chevron emulsion produced consistently higher resilient moduli in the dry condition than did the Central Oil. For the soaked condition, the Central Oil emulsion mixes were less adversely affected than the Chevron emulsions. A comparison of the percent change results from the resilient modulus test to those of the stability test indicated that the former were more affected by soaking than the latter.

CONCLUSIONS

1. The Illinois equation for determining the trial asphalt content using a dry gradation can provide a reasonable starting point for mixes made with virgin crushed aggregate.

2. For recycled aggregate and fine, one-size sands, the experimental approach described in this study appears more suitable.

3. The CKE test for estimating the trial asphalt content is more time consuming than the Illinois equation, and does not appear to provide a better starting point than the equation.

4. Trial asphalt contents vary considerably from aggregate to aggregate, as expected, but not between the two emulsions used.

5. Generally, the Central Oil emulsion required 1% more moisture to produce the optimum moisture at compaction than did the Chevron.

6. Appreciable differences in stabilities were found between emulsions for some aggregates.

7. For four of the eight asphalt-aggregate combinations, the soaked stabilities approached or exceeded the dry stabilities.

8. Soaked stabilities are inversely related to percent total voids.

9. The mixes investigated in this study generally met the design criteria from the Illinois recommendation, with the exception of voids. Part of this discrepancy resulted from the use of a 50-blow compactive effort as opposed to the 75-blow effort used in the Illinois method. The coarse and one-size gradation of the aggregates used also contributed to the higher voids found in this study.

10. Optimum asphalt contents based on maximum soaked stabilities compared favorably with trial asphalt contents arrived at by the Virginia experimental approach.

11. The curing and soaking procedure given by the Illinois method is too lengthy to be practical.

12. Results from the accelerated curing and soaking method developed in this study agree well with those of the Illinois procedure, and the accelerated procedure requires less than 24 hours as opposed to 7 days for the Illinois procedure.

13. Although the two emulsions from the Chevron supplier were produced in separate labs, the mixture results were quite close.

14. Resilient modulus results varied considerably between emulsions.

15. The resilient modulus results appear to be more severely affected by soaking than do the results from the stability tests.

REFERENCES

1. Darter, M. I., et al., Development of Emulsified Asphalt-Aggregate Cold Mix Design Procedure, Illinois Cooperative Highway Research Program, February 1978.

2. _______, Factors Affecting the Structural Response of Emulsified Asphalt-Aggregate Mixtures, Illinois Cooperative Highway Research Program, March 1978.

3. A Basic Asphalt Emulsion Manual, The Asphalt Institute, MS-19, March 1979.

S.I. CONVERSION FACTORS

1 inch = 2.54 cm

^{o}F = 9/5 (C^{o}) + 32

1 pound = 0.45 kg

1 psi = 6.9 kPa

3628