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Resilient Modulus Test Reproducibility Study

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7. AUTHOR(S)
Svetich, Ralph R.; Mann, Gary W.; Doty, Robert N.; Sherman, George B.

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Sacramento, California 95819

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This report describes a study of the test results when similar soil samples were tested with different resilient modulus testing machines. Three agencies on the West Coast (including the Transportation Laboratory) participated in the study.

The report briefly describes the resilient modulus testing machine and how its results have been used by researchers. The results are then shown in graphical and tabular form with general comments made on the test results. The study also included using the resilient modulus data received from the agencies in an actual design of a full-depth AC pavement. A comparison was made of the different design thicknesses (associated with this resilient modulus data) required for a 10 year pavement design life based upon fatigue analysis.

17. KEYWORDS
Resilient modulus, resilient modulus test equipment, correlation

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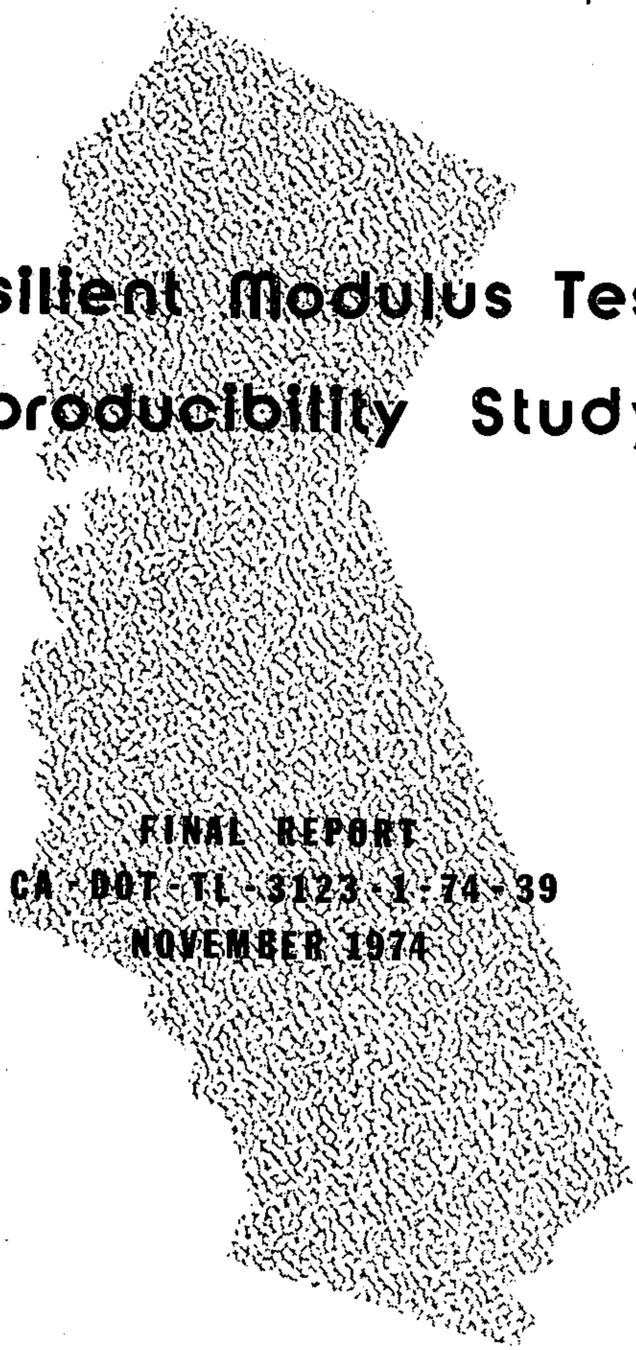
TRANSPORTATION LABORATORY
RESEARCH REPORT



Resilient Modulus Test Reproducibility Study

FINAL REPORT
CA-DOT-TL-3123-1-74-39
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CALIFORNIA DEPARTMENT OF TRANSPORTATION

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STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
TRANSPORTATION LABORATORY

November 1974

TL No. 643123

Mr. R. J. Datel
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

RESILIENT MODULUS TEST
REPRODUCIBILITY STUDY

Study made by . . . . Pavement Section

Under the Supervision of . . . . George B. Sherman

Principal Investigator . . . . Robert N. Doty

Co-Investigators . . . . Ralph R. Svetich and Gary W. Mann

Report prepared by . . . . Ralph R. Svetich

Very truly yours,

JOHN L. BEATON
Chief Engineer, Transportation Laboratory

Attachment

ACKNOWLEDGEMENTS

The authors wish to thank the agencies who participated in this study for the time and effort they expended in running the resilient modulus tests. This includes the University of California's Institute of Transportation and Traffic Engineering, wherein the testing was completed under the supervision of Professor Carl L. Monismith and the Oregon State Highway Division, wherein the testing was completed under the supervision of Mr. James E. Wilson.

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INTRODUCTION

Use of the resilient modulus test for characterization of structural section component materials is rapidly gaining acceptance by research engineers developing and refining rational pavement design theories incorporating elastic layer theory. However, the repeatability and reproducibility of tests of this characteristic have not been determined. Thus, a study to compare the results when a subgrade material was tested by different agencies using their resilient modulus testing machines was considered necessary in conjunction with other on-going FHWA financed research.

Six different agencies on the West Coast (including the Transportation Laboratory) agreed to test a material using their own resilient modulus testing machines. The material selected was the basement soil from the California Department of Transportation's full-depth AC project on Route 101 in Willits, California. Transportation Laboratory personnel collected, split, and sent this split material (representing similar soil) to the five other agencies involved in the study. Two agencies, in addition to the Transportation Laboratory, were able to complete their testing of this material. The test results from these agencies will be discussed in this report.

CONCLUSIONS AND RECOMMENDATIONS

Based upon the limited data that was received for this comparative study, it is recommended that, due to apparent procedural differences in testing and measuring the resilient modulus by the participating agencies, a more definitive method of testing and measuring the resilient modulus be established. Any further development of the method of testing should be followed by further cooperative studies to determine precision prior to the use of this test for structural section design.

IMPLEMENTATION

This test should not be adopted as a standard test method for use in asphalt concrete pavement design at this time.

DISCUSSION OF THE RESILIENT MODULUS TESTING MACHINE

The resilient modulus testing machine which was used by the California Transportation Laboratory for this study is a repeated pulse axial load testing device(1) (see Figure 1). The soil sample to be tested is placed in a chamber where a confining air pressure can be applied to the sample. As an axial load (haversine in shape) is applied, the radial and axial deformation of the sample are measured by means of linear variable

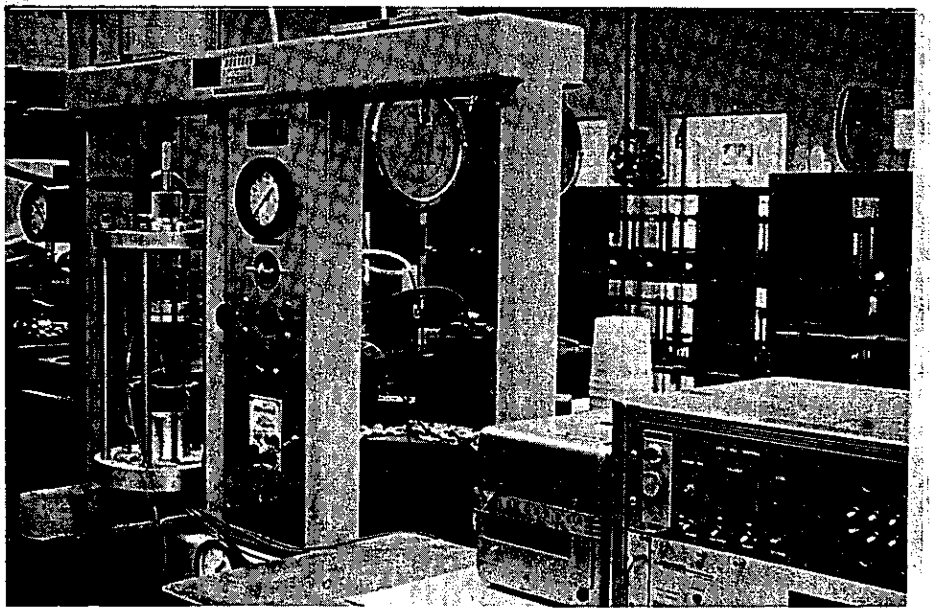


Figure 1 Resilient Modulus Test Equipment.

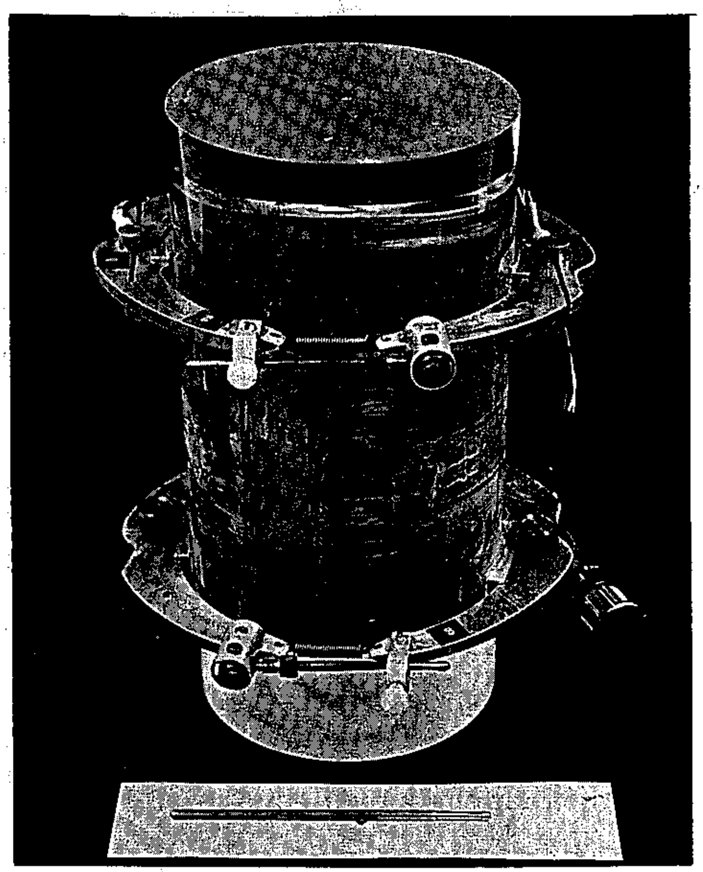


Figure 2 LVDT's in Place for Strain Measurements.

differential transformers (LVDT's) which are attached to the sample by means of clamps (for radial readings) and LVDT's placed between these clamps for axial readings (see Figure 2). The movement of the LVDT's is then transmitted through a signal conditioner to a strip recorder. The time of loading can be varied but most researchers use 0.1 second duration loads at 3 second intervals to simulate traffic conditions. (The 0.1 second interval was used for this study.)

The determination of the resilient modulus consists of calculating the ratio of the repeated dynamic axial deviator stress (σ_d) to the recovered axial strain (as measured by the LVDT's). As this modulus can be determined over a wide range of confining pressures, researchers believe that this test better simulates the actual condition of the soil in the field under a traffic-type load. These resilient modulus values have been incorporated into computer programs, such as the "Chevron Five Layer Elastic Theory Program," which are used in conjunction with asphalt concrete stiffness values to determine theoretical stresses, strains, and deflections in AC pavements. This information can therefore be used for pavement structural section design.

When the procedures described in Appendix A of "Design Considerations for Asphalt Pavements" by Monismith et al,(2) are followed, it takes about 10 hours to prepare and test a sandy or silty soil sample. To calibrate and zero the LVDT's prior to the actual testing requires the use of an additional man for about one hour.

DESCRIPTION OF SOIL TESTED

The soil used for this study was the subgrade soil from the California Department of Transportation's full-depth AC pavement project on US 101 in the City of Willits, California - Contract No. 01-111804. For this project, the old asphalt concrete and some of the subgrade soil were removed. The subgrade compaction specification for this contract was as follows:

> "The subgrade shall be thoroughly compacted to form a firm, stable base before placing the asphalt concrete."(3)

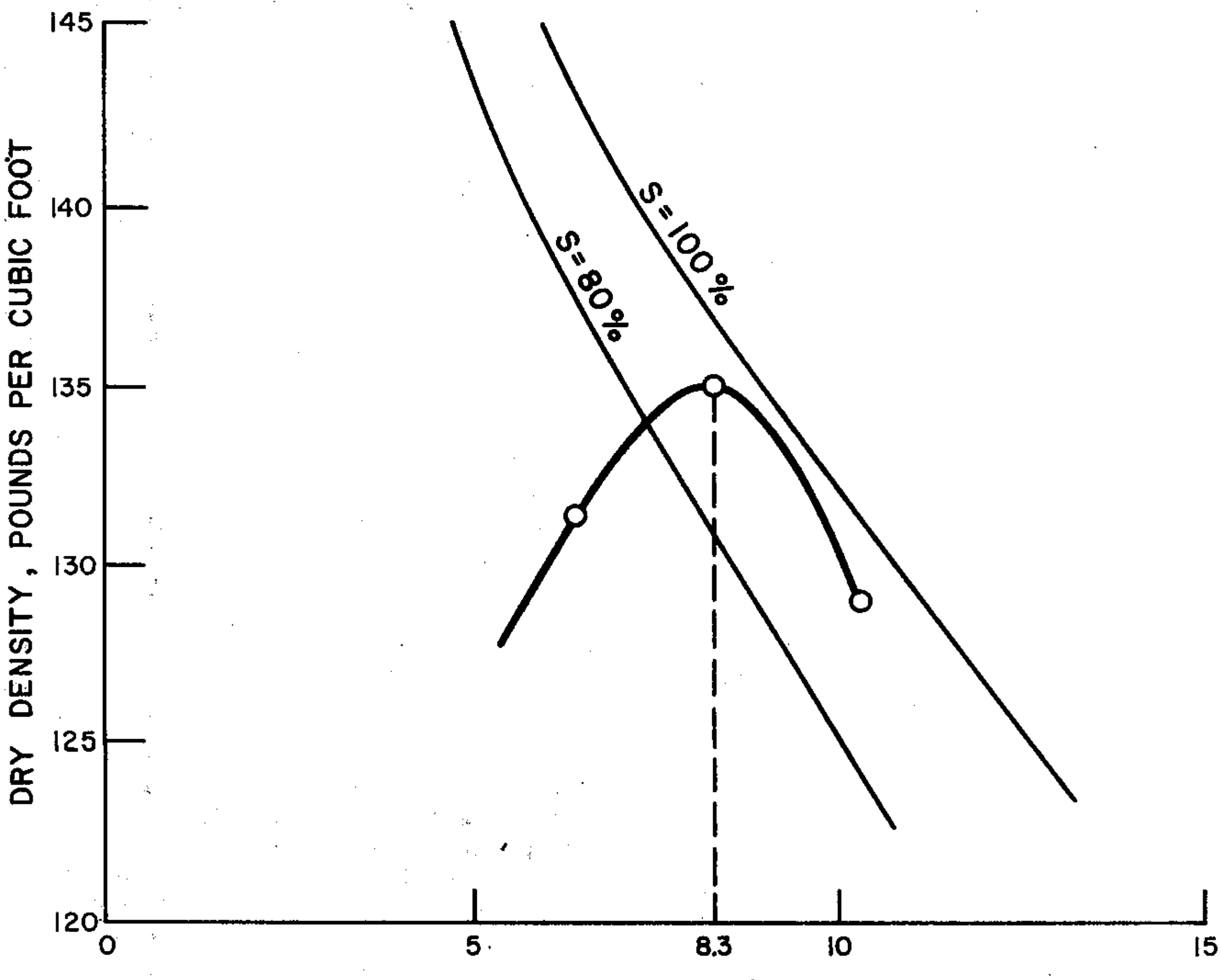
Therefore, as there would be no field control of the moisture and density of the subgrade soil, it was decided to determine a moisture-density curve for the subgrade soil and use this information as a basis for the selection of the moisture contents to be used for the test specimens. Figure 3 shows the moisture-density curve for the Willits subgrade soil. Based upon this data, it was decided to test the soil at moisture contents of 6, 8 and 10 percent in an attempt to encompass the in-place conditions. One of the agencies originally intending to

Figure 3

MOISTURE - DENSITY CURVE *

SUBGRADE SOIL-WILLITS, CALIF.

Sp. Gr. = 2.693



* Test Method No. Calif. 216

participate in this study objected to the selection of these high, dry densities, contending that they could not achieve the densities because the California Impact results gave appreciably higher results than the Standard Proctor or AASHTO tests and, as a result, were misleading. Even though a Transportation Laboratory study has shown the California Impact test to give results about 5-10% higher than the Proctor or AASTHO tests, it was decided to use the original moisture contents and dry densities because the main intent of the study was to determine the reproducibility of the resilient modulus test. Also, some of the other agencies had already started their testing and had encountered no problems, that we were aware of, in achieving the desired densities.

TEST RESULTS AND DISCUSSION

The three agencies who completed all the tests required for the project were the University of California, the Transportation Laboratory of the California Department of Transportation, and the Oregon State Highway Division. Since only three agencies completed the study, a statistical analysis of the data were considered inappropriate. Therefore, the results of this study have been presented in graphical and tabular form with general comments about the data.

In an effort to obtain test procedure uniformity, instructions were sent to each agency regarding sample preparation and the testing sequence to be used (Appendix A). Figure 3 and Table 1 were also sent showing the subgrade material properties, gradings, and the moisture-density curve for the soil to be used for this study. Tables 2-4 show the complete test results from each agency for the preselected moisture contents and corresponding densities. As these tables show, each agency performed the tests using different stress ratios for the various confining pressures. This further compounded the problem as far as attempting to analyze the data.

Another area that could have contributed to the wide range of values between the agencies was the procedure used to measure axial strain. Two of the three agencies involved in this study (California Transportation Laboratory and ITTE) placed the LVDT's used to measure the axial strain between clamps attached directly to the soil sample (Figure 2), while the Oregon State Highway Division placed their strain measuring equipment outside the triaxial cell cover plate and measured the movement of the loading piston. As can be seen by examining Tables 2-4, the Oregon data differed considerably from that obtained by the other two agencies.

Table 1

Material Properties

R-value	- 60
Liquid Limit	- 24
Plastic Limit	- 21
Plasticity Index	- 3
Unified Soil Classification System - Gravelly, Silty Sand; (SM)	
Specific Gravity	- 2.693

Grading Analysis

Sieve Size	As Received	As Sent to the Participating Labs*
2	100	
1-1/2	99	
1	97	
3/4	94	100
1/2	89	95
3/8	86	92
#4	74	79
8	67	71
16	61	65
30	56	60
50	49	52
100	38	40
200	31	33
5 Micron	12	13
1 Micron	5	5

Moisture Content (%)	Desired Dry Density (pcf)
6.0	130.0
8.0	135.0
10.0	130.3

*As per letter sent to participating labs (Appendix A) only material passing #4 Sieve was to be used for M_R tests.

Table 2

COMPARISON OF RESILIENT MODULUS RESULTS

Water Content 6%

Agency			Univ. of Calif.		Calif.Trans.Lab.		Oregon S.H.D.			
Moisture Content			6.0	6.0	5.6	5.7	5.9	5.9	6.2	6.1
Dry Density			129.8	129.5	130.0	130.0	129.7	129.6	130.4	130.0
σ_3	σ_d	θ	M_Rx1000 PSI		M_Rx1000 PSI		M_Rx1000 PSI			
1	2.2	5.2			111	80				
	3	6			121	72.5				
	4	7			122.5	80				
	5	8			123.5	77				
3	1	10					29	29	27	58
	2	11					27	24	29	41
	3	12	98.9	47.4	106	92.9	29	25	26	34
	4	13					29	26	25	33
	5	14	114.5	72.5			29	25	27	30
	6	15			101.7	92.3				
	7.5	16.5					30	27	27	29
	9	18			96	87.5				
	10	19					30	27	31	30
	12	21			91	83				
	15	24			85	79.5				
	5	14*	97.7	124.3						
	3	12*	104.4	130.5						
5	5	20	114.5	91.6	95.6	98.8				
	7.5	22.5	108.7	118.6						
	10	25			75.4	100				

*Decreasing Stress Sequence

$\theta = \sigma_d + 3\sigma_3$

Table 2 (cont.)

COMPARISON OF RESILIENT MODULUS RESULTS

Water Content 6%

Agency			Univ. of Calif.		Calif.Trans.Lab.		Oregon S.H.D.			
Moisture Content			6.0	6.0	5.6	5.7				
Dry Density			129.8	129.5	130.0	130.0				
σ_3	σ_d	θ	M_Rx1000 PSI		M_Rx1000 PSI		M_Rx1000 PSI			
5	15	30			71.4	86.3				
	20	35			60.4	83.4				
	25	40			53.2	75.6				
	7.5	22.5*	108.7	118.6						
	5	20	108.7	108.7						
7.5	7.5	30	101.2	116.0	80.7	101				
	10	32.5	103.6	133.8						
	15	37.5			69.3	86.4				
	22.5	45			61.1	75.9				
	30	52.5			52.4	70.6				
	37.5	60			50.8	55.0				
	10	32.5*	103.6	126.1						
	7.5	30*	107.0	130.5						
10	10	40	107.4	139.2	61.3	95.5				
	15	45	101.2	130.5						
	20	50	84.9	111.2	60.0	72.6				
	30	60			53.3	63.0				
	40	70			51.6	61.5				
	50	80			49.4	56.5				
	15	45*	96.6	109.7						

*Decreasing Stress Sequence

$\theta = \sigma_d + 3\sigma_3$

Table 2 (cont.)

COMPARISON OF RESILIENT MODULUS RESULTS

Water Content 6%

Agency			Univ. of Calif.		Calif.Trans.Lab.		Oregon S.H.D.			
Moisture Content			6.0	6.0	5.6	5.7				
Dry Density			129.8	129.5	130.0	130.0				
σ_3	σ_d	θ	M_Rx1000 PSI		M_Rx1000 PSI		M_Rx1000 PSI			
10	10	40*	102.3	139.2						
15	15	60			71.7	79.6				
	30	75			53.8	62.2				
	45	90			53.6	59.2				
	60	105			52.4	62.3				
	75	120			53.5	60.1				
20	20	80			78.4	69.0				
	40	100			56.7	57.1				
	60	120			57.1	70.3				
	80	140			58	66.3				

*Decreasing Stress Sequence

$\theta = \sigma_d + 3\sigma_3$

Table 3

COMPARISON OF RESILIENT MODULUS RESULTS

Water Content 8%

Agency			Univ. of Calif.		Calif.Trans.Lab.		Oregon S.H.D.			
Moisture Content			8.0	8.0	8.0	8.0	8.3	8.3	7.9	8.2
Dry Density			134.9	134.9	135.0	135.0	134.1	133.8	134.0	133.1
σ_3	σ_d	θ	M_Rx1000 PSI		M_Rx1000 PSI		M_Rx1000 PSI			
1	2	5			80	86				
	3	6			86	93.1				
	4	7			80	79.6				
	5	8			83	90				
3	1	10					167	24	31	36
	2	11					50	23	28	37
	3	12	104.4	102.3	84.9	93.1	42	28	23	38
	4	13					40	23	24	31
	5	14	107.4	111.5			42	25	21	33
	6	15			79.7	95.4				
	7.5	16.5					38	22	26	35
	9	18			76.6	93.9				
	10	19					35	23	24	36
	12	21			63.7	82.8				
	15	24			67.3	72.7				
	5	14*	116.0	108.7						
	3	12*	121.4	118.6						
5	5	20	129.9	111.5	95.6	103.5				
	7.5	22.5	117.6	108.7						
	10	25			87.3	89.2				

*Decreasing Stress Sequence

$\theta = \sigma_d + 3\sigma_3$

Table 3 (cont.)

COMPARISON OF RESILIENT MODULUS RESULTS

Water Content 8%

Agency			Univ. of Calif.		Calif.Trans.Lab.		Oregon S.H.D.			
Moisture Content			8.0	8.0	8.0	8.0				
Dry Density			134.9	134.9	135.0	135.0				
σ_3	σ_d	θ	M_Rx1000 PSI		M_Rx1000 PSI		M_Rx1000 PSI			
5	15	30			67.3	76.4				
	20	35			51.3	63.9				
	25	40			36.4	56.4				
	7.5	22.5	137.4	110.6						
	5	20*	135.9	108.7						
7.5	7.5	30	100.0	104.4	60.6	99.8				
	10	32.5	122.5	103.6						
	15	37.5			49.0	78.6				
	22.5	45			42.9	63.7				
	30	52.5			39.8	56.4				
	37.5	60			40.0	45.8				
	10	32.5*	127.9	108.7						
	7.5	30*	130.5	108.7						
10	10	40	127.9	111.5	63.8	98.7				
	15	45	116.5	105.2						
	20	50	177.6	99.4	52.0	65.0				
	30	60			41.5	50.0				
	40	70			43.1	44.7				
	50	80			39.5	41.3				
	15	45*	171.7	116.0						

*Decreasing Stress Sequence

$\theta = \sigma_d + 3\sigma_3$

Table 3 (cont.)

COMPARISON OF RESILIENT MODULUS RESULTS

Water Content 8%

Agency			Univ. of Calif.		Calif.Trans.Lab.		Oregon S.H.D.			
Moisture Content			8.0	8.0	8.0	8.0				
Dry Density			134.9	134.9	135.0	135.0				
σ_3	σ_d	θ	M_Rx1000 PSI		M_Rx1000 PSI		M_Rx1000 PSI			
10	10	40*	140.3	124.3						
15	15	60			48.8	88				
	30	75			41.5	51.5				
	45	90			39.8	44.4				
	60	105			40.3	44.2				
	75	120			38.6	45.2				
20	20	80			49.8	69.9				
	40	100			37.4	46.8				
	60	120			37.3	45.6				
	80	140			38.4	44.9				

*Decreasing Stress Sequence

$\theta = \sigma_d + 3\sigma_3$

Table 4

COMPARISON OF RESILIENT MODULUS RESULTS

Water Content 10%

Agency:			Univ. of Calif.		Calif. Trans. Lab.			Oregon S.H.D.			
Moisture Content:			10.0	10.0	9.0	9.3	10.7	9.7	9.4	10.4	9.95
Dry Density:			130.3	130.0	130.3	130.3	130.3	130.2	130.6	129.1	129.9
σ_3	σ_d	θ	M_Rx1000 PSI		M_Rx1000 PSI			M_Rx1000 PSI			
1	2	5			61.0	55.2	22.0				
	3	6			59.7	48.4	19.6				
	4	7			54.9	43.7	15.7				
	5	8			55.7	38.6	12.0				
3	1	10						43	17	13	25
	2	11						27	15	12	22
	3	12	66.9	69.6	67.2	47.8	18.3	25	17	10	23
	4	13						21	16	10	21
	5	14	63.0	70.1				20	15	10	21
	6	15			55.5	41.4	13.6				
	7.5	16.5						21	16	10	20
	9	18			47.6	37.4	11.1				
	10	19						20	24	11	18
	12	21			41.0	40.1	10.5				
	15	24			38.5	36.5	10.5				
	5	14*	75.6	79.1							
	3	12*	69.6	69.6							
5	5	20	60.0	63.0	55.9	59.1	14.8				
	7.5	22.5	56.0	57.5							
	10	25			34.7	48.3	11.4				

*Decreasing Stress Sequence

$\theta = \sigma_d + 3\sigma_3$

Table 4 (cont.)

COMPARISON OF RESILIENT MODULUS RESULTS

Water Content 10%

Agency			Univ of Calif.		Calif. Trans. Lab			Oregon S.H.D.			
Moisture Content			10.0	10.0	9.0	9.3	10.7				
Dry Density			130.3	130.0	130.3	130.3	130.3				
σ_3	σ_d	θ	M_Rx1000 PSI		M_Rx1000 PSI			M_Rx1000 PSI			
5	15	300			30.2	34.2	10.8				
	20	35			26.5	29.6	11.3				
	25	40			23.6	19.4	12.2				
	7.5	22.5*	63.2	68.7							
	5	20*	64.4	75.6							
7.5	7.5	30	61.5	64.6	37.8	42.0	13.5				
	10	32.5	56.3	60.8							
	15	37.5			34.9	28.5	10.8				
	22.5	45			25.3	23.2	11.7				
	30	52.5			26.0	22.5	13.0				
	37.5	60			23.0	22.3	14.4				
	10	32.5*	63.2	65.6							
	7.5	30*	69.4	65.2							
10	10	40	66.9	71.0	48.9	35.1	13.4				
	15	45	52.7	54.3							
	20	50	49.3	51.1	28.4	23.6	12.6				
	30	60			24.2	21.6	13.9				
	40	70			25.8	22.4	15.3				
	50	80			25.9	23.0	17.1				
	15	45*	53.2	60.7							

*Decreasing Stress Sequence
$\theta = \sigma_d + 3\sigma_3$

Table 4 (cont.)

COMPARISON OF RESILIENT MODULUS RESULTS

Water Content 10%

Agency			Univ of Calif.		Calif. Trans. Lab			Oregon S.H.D.			
Moisture Content			10.0	10.0	9.0	9.3	10.7				
Dry Density			130.3	130.0	130.3	130.3	130.3				
σ_3	σ_d	θ	M_Rx1000 PSI		M_Rx1000 PSI			M_Rx1000 PSI			
10	10	40*	60.0	69.6							
15	15	60			41.7	26.5					
	30	75			28.2	21.2					
	45	90			26.4	22.6					
	60	105			28.1	24.3					
	75	120			28.5	24.5					
20	20	80			40.7	25.9					
	40	100			29.7	22.3					
	60	120			27.8	23.8					
	80	140			31.3	26.8					

*Decreasing Stress Sequence

$\theta = \sigma_d + 3\sigma_3$

At the Transportation Laboratory, a problem was encountered during the first test at the 10% moisture content when the sample failed in shear at the higher stress levels. Upon checking the moisture content, it was found that the moisture content was 10.7%, which would put it at or near the saturation limit. Therefore, it was decided to reduce the water content somewhat and, as a result, the two tests for the 10% moisture content turned out to be closer to 9%. The results for the 10.7% moisture content were substantially lower than the 9% contents (see Figure 4).

Figures 5-7 contain the test results plotted on a log-log scale. The points plotted are the average values of the repeated tests run at each desired moisture content and density except for the Oregon SHD data, where one result varied considerably from the other three.

The lines shown on Figures 5-7 are not statistical best-fit lines, but rather are visual best-fit lines that were intended to represent the trend of the test results for the different agencies. The lines shown for the University of California test results were their recommended best-fit lines.

It was originally intended to run an analysis of variance on the test results that would include both the repeatability for each agency and the reproducibility among the agencies. However, due to the different test procedures used by each agency, this analysis was not considered appropriate. The only comments that can be made about the repeatability of the test is that, by inspection of Tables 2-4, the results usually repeat within 20% of each other. There are some notable exceptions, however, and no statistical inferences about repeatability can be made from this study.

Generally, the data shown on Figures 5-7 show the following trends:

(1) The University of California's data shows the highest results, and except for the water content at 10% data, can be taken to be stress independent (no change in resilient modulus with corresponding changes in stress).

(2) The California Transportation Laboratory's data shows that at lower values of θ (sum of the principal stresses) the M_R values are essentially stress independent; in the intermediate range for θ, the M_R values decrease as θ increases; and at the higher range of θ, the M_R values are again stress independent, but at a much lower value than for the lower range of θ.

(3) The Oregon State Highway Division's resilient moduli are much lower than that determined by the other two agencies. Generally, it can again be said that the data is stress independent.

Figure 4

RESILIENT MODULUS CORRELATION STUDY
WATER CONTENT = 10%

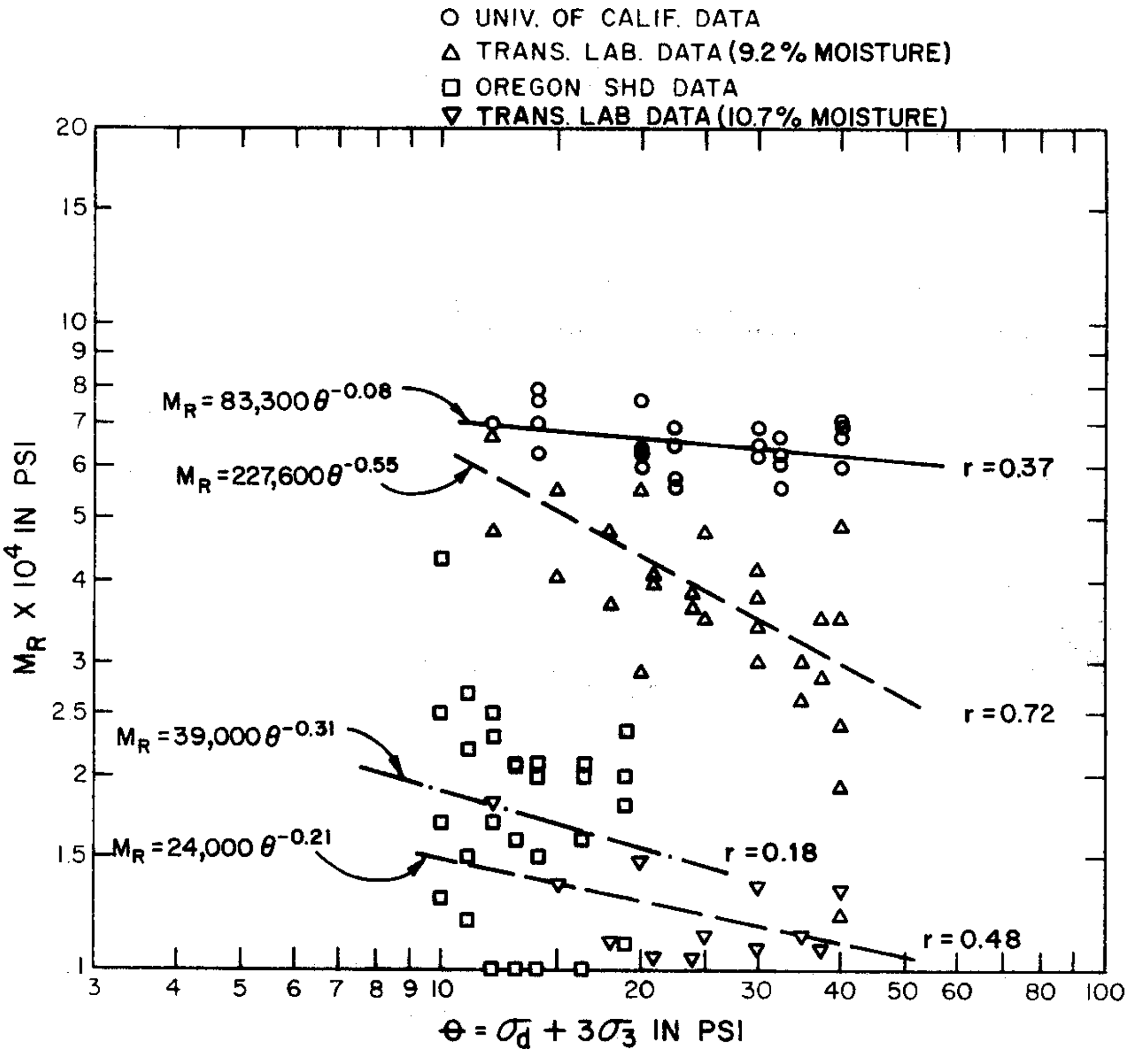


Figure 5

RESILIENT MODULUS CORRELATION STUDY
WATER CONTENT = 6 %

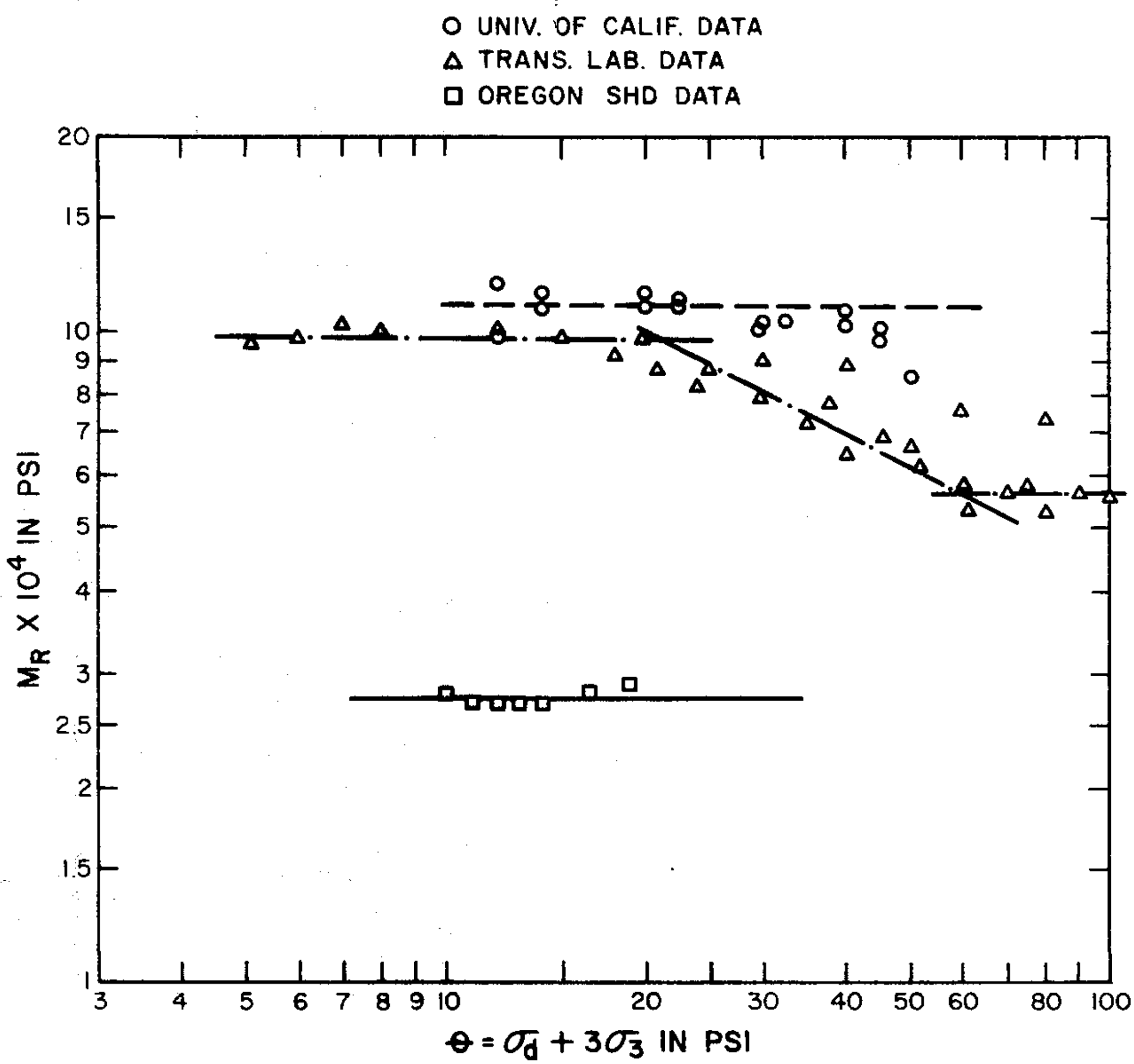


Figure 6

RESILIENT MODULUS CORRELATION STUDY
WATER CONTENT = 8 %

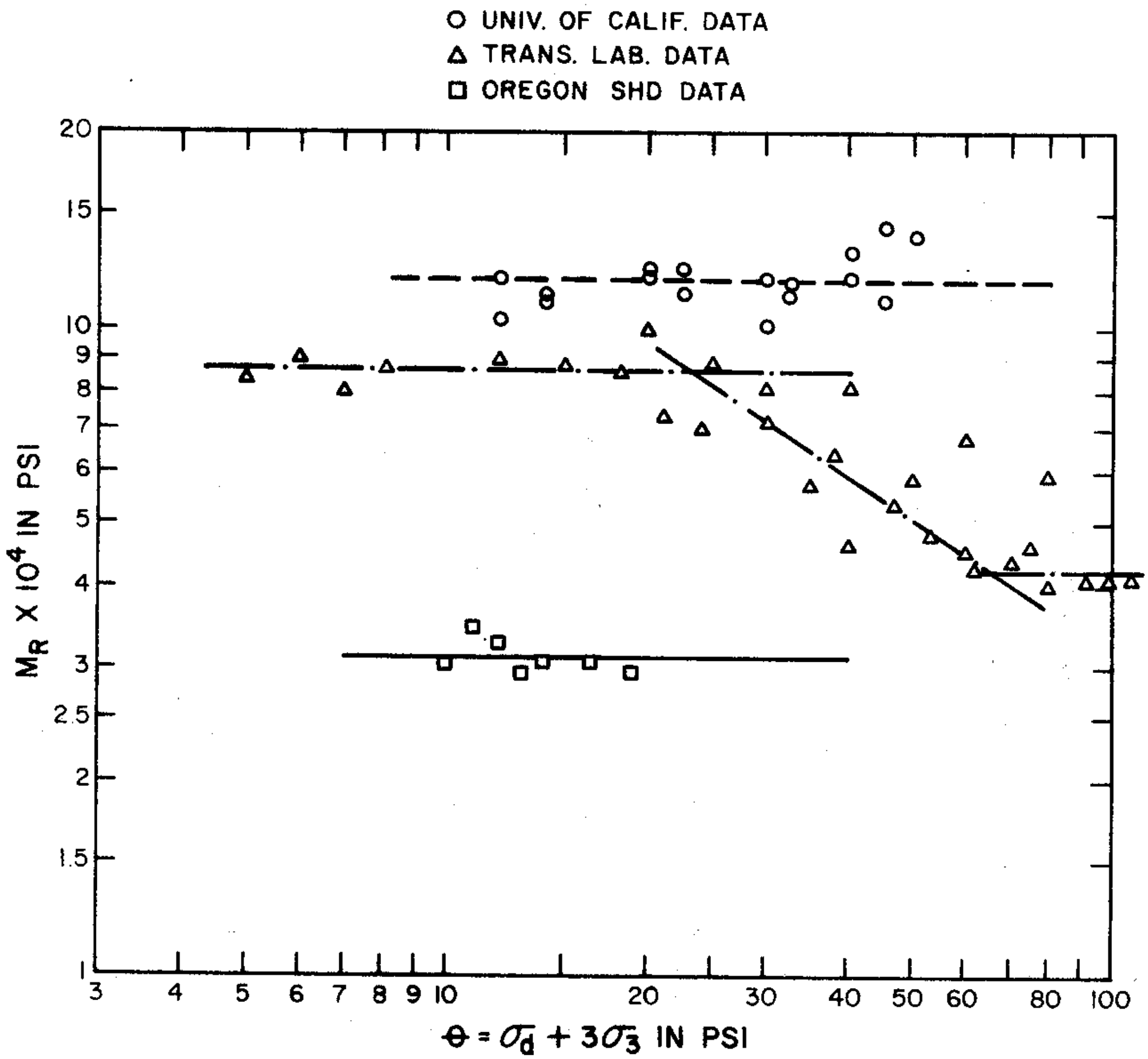
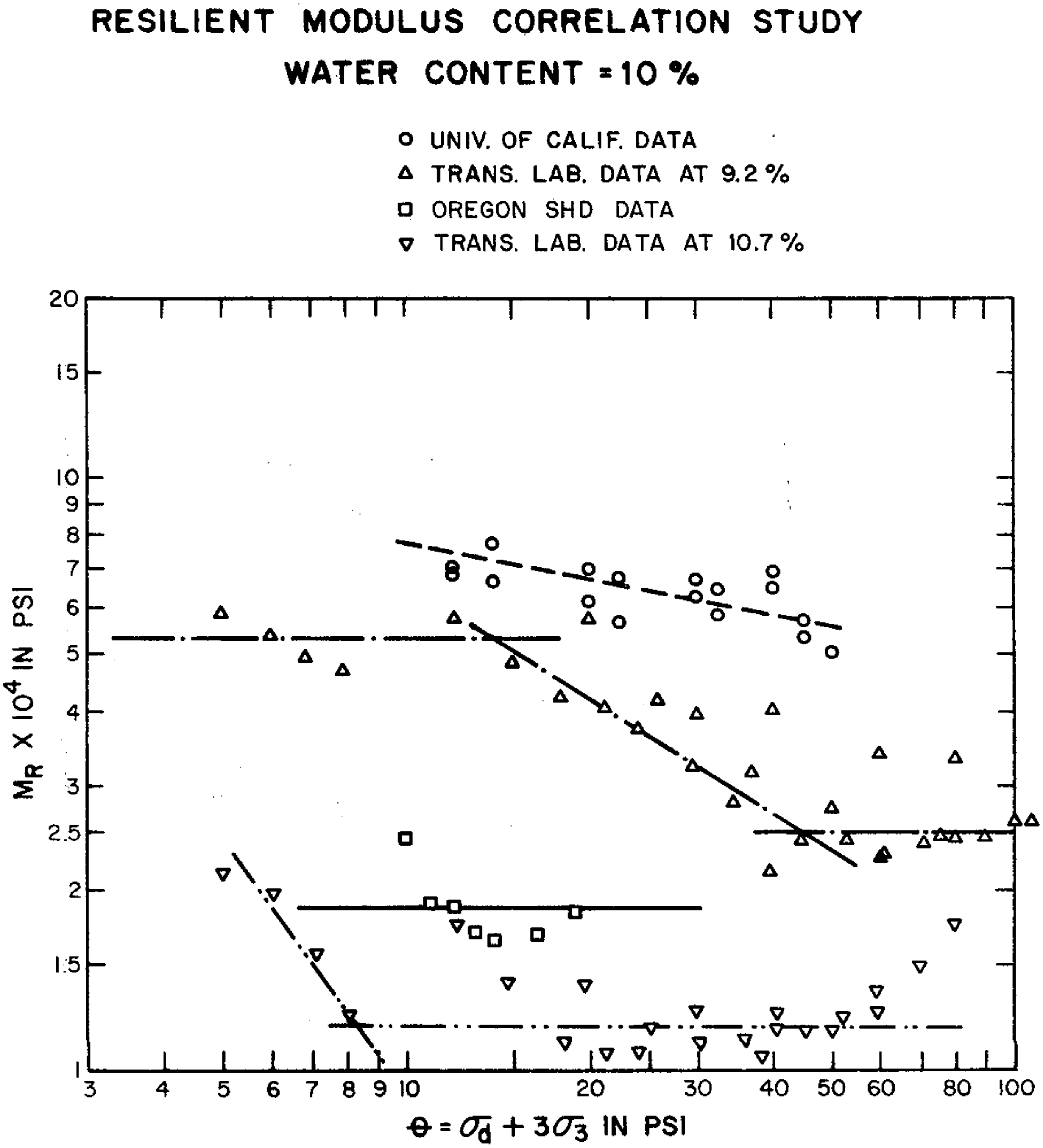


Figure 7



RESILIENT MODULUS CORRELATION STUDY
WATER CONTENT = 10 %
○ UNIV. OF CALIF. DATA
△ TRANS. LAB. DATA AT 9.2 %
□ OREGON SHD DATA
▽ TRANS. LAB. DATA AT 10.7 %
M_R X 10^4 IN PSI
20
15
10
9
8
7
6
5
4
3
2.5
2
1.5
1
3 4 5 6 7 8 9 10 20 30 40 50 60 80 100
$\Theta = \sigma_d + 3\sigma_3$ IN PSI

As Figures 5-7 appeared to be inconclusive, it was decided to look at the data in a slightly different manner. For this analysis, only that resilient modulus data between the θ ranges of 10 to 40 psi (the expected ranges in most subgrade soils) were used. All the data for the three agencies were included in a regression analysis for each moisture content in order to determine if the data in this range was similar. Figures 8-10 show the plots of each data point, and the corresponding equations for the best-fit lines with their correlation coefficients. Once again, there does not appear to be much of an agreement among the three agencies' results, other than the fact that the equation for the best-fit lines generally have negative slopes. Also, the relative displacement between the Oregon State Highway Division's data and the California Transportation Laboratory's data is readily apparent. The best-fit lines for both agencies fall in almost parallel lines for all three moisture contents. This would tend to support the belief that there is a measurement reading difference between the agencies that affects the magnitude of the resilient modulus. No hypothesis is offered for the difference between the results of the regression analysis for ITTE's data and the other participating agencies.

PAVEMENT DESIGN USING THE RESILIENT MODULUS DATA

Since the variations of the resilient modulus test data appeared to be quite large, it was decided to use each agency's results for a pavement design in an attempt to evaluate the significance of the differences. The design method used was the fatigue life analysis as developed at the University of California(4). This method involves three separate computer programs to arrive at the fatigue life of an asphalt concrete pavement. Since one of the computer programs requires resilient modulus data, this procedure was used to evaluate the differences in resilient modulus reported by the three agencies.

Program 1 of the analysis was used to determine the variation of the traffic-weighted mean stiffness of the AC with respect to depth of the AC, time duration of loading, and months of the year. Initially, only one run of this program was needed to determine the stiffnesses throughout the year, based on the 12-inch AC thickness actually used for the Route 101 Willits project and a time-of-loading of 0.10 second (which approximates the effect of a truck traveling 20 mph).

Program 2 of the analysis incorporates the stiffnesses from Program 1 and resilient modulus vs. deviator stress data to determine the strain on the underside of the AC. For input

Figure 8

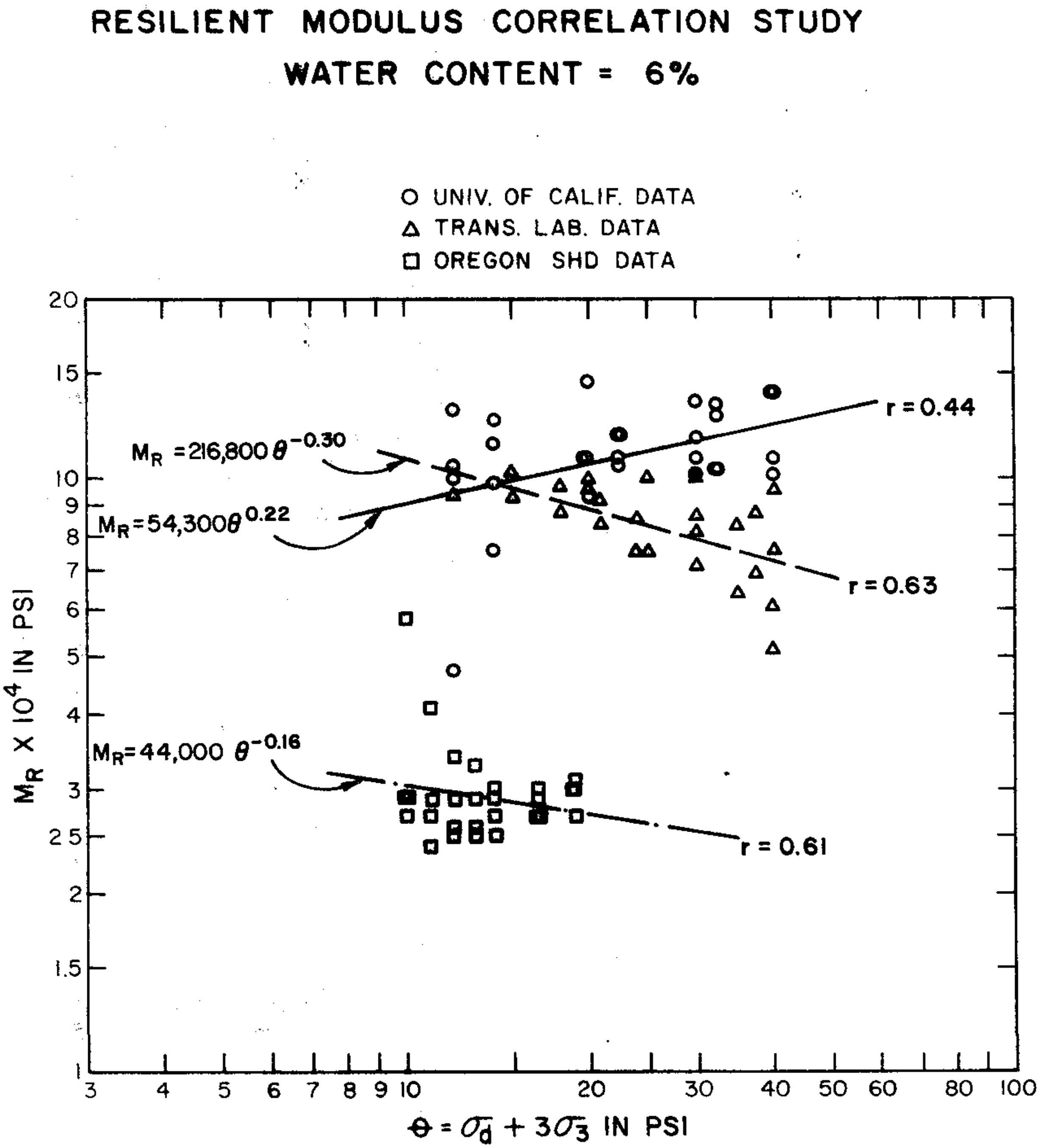

RESILIENT MODULUS CORRELATION STUDY
WATER CONTENT = 6%
O UNIV. OF CALIF. DATA
Δ TRANS. LAB. DATA
□ OREGON SHD DATA
M_R = 216,800 θ^-0.30
M_R = 54,300 θ^0.22
M_R = 44,000 θ^-0.16
r = 0.44
r = 0.63
r = 0.61
M_R X 10^4 IN PSI
20
15
10
9
8
7
6
5
4
3
2.5
2
1.5
1
3
4
5
6
7
8
9
10
20
30
40
50
60
80
100
θ = σ_d + 3σ_3 IN PSI

Figure 9

RESILIENT MODULUS CORRELATION STUDY
WATER CONTENT = 8%

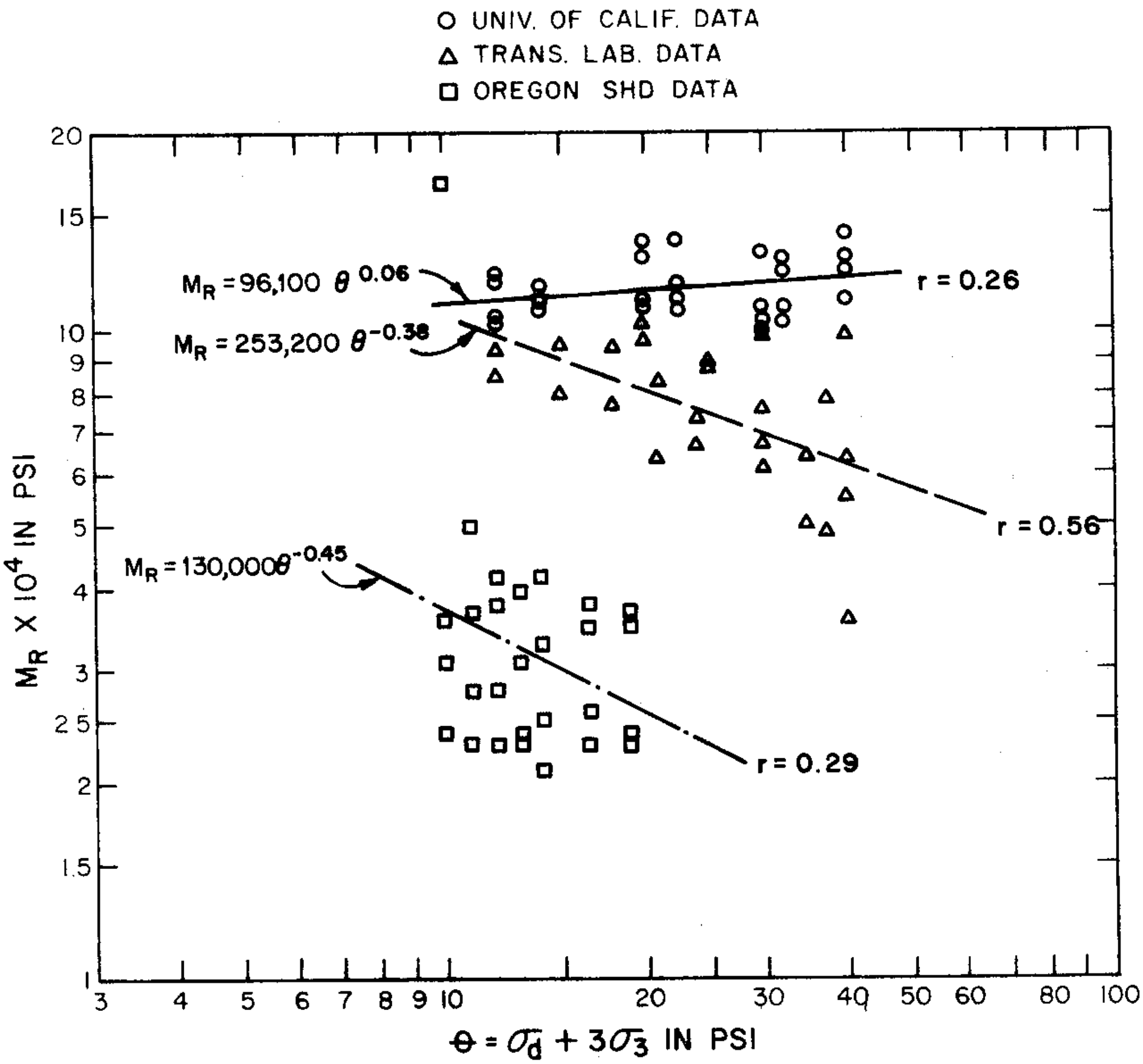
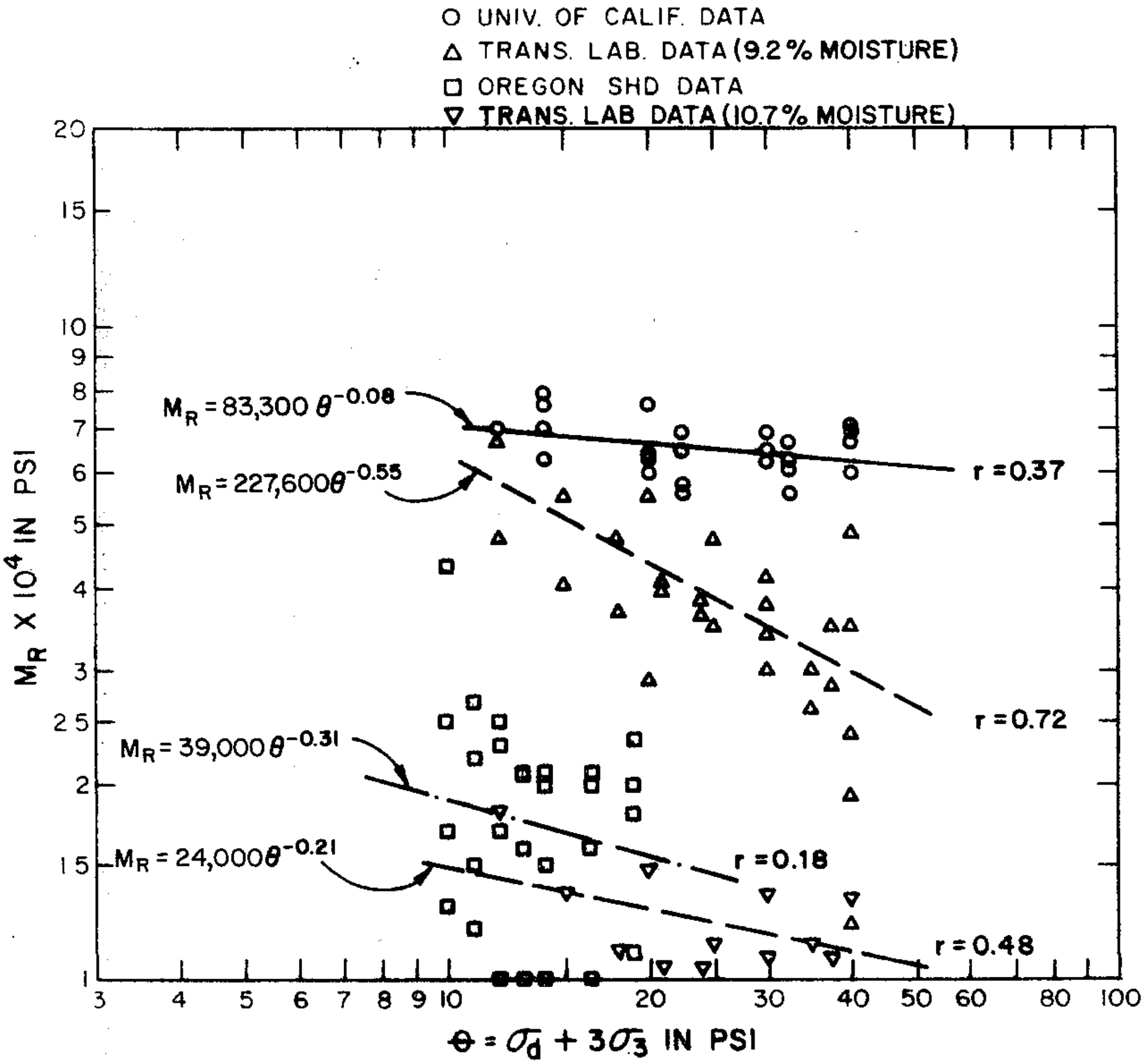


Figure 10

RESILIENT MODULUS CORRELATION STUDY
WATER CONTENT = 10%



into this program, it was decided to use the resilient modulus vs. deviator stress data for the water content of 10% (dry density = 130 pcf) for the following reasons:

(1) this would be near the 95 percent relative compaction that normally would be required of subgrade material,

(2) selecting the 10 percent water content would allow for some moisture build-up, and

(3) it also would tend to give conservative results.

The input used for the different agencies was selected from Table 5 as follows:

TABLE 5

INPUT DATA

Agency	Deviator Stress vs.	Resilient Modulus
ITTE	Constant	M_R = 70,000 psi
Cal. Trans Lab @ 9.3%	σ_d = 3,	M_R = 48,000
	σ_d = 6,	M_R = 41,000
	σ_d = 9,	M_R = 37,000
Oregon SHD (avg. all tests)	σ_d = 1,	M_R = 25,000
	σ_d = 2,	M_R = 19,000
	σ_d = 4,	M_R = 17,000

The above input was then used in the design of the AC pavement. The design method used is described in Appendix G of reference(4). Using the charts and tables described in this procedure, Program 3 can be used to determine the theoretical fatigue life of the pavement. As the pavement at Willits was designed for a 10-year life, this was the "target" fatigue life for this study. If the calculated fatigue life from Program 3 differed from the 10-year design, new input for Programs 1 and 2 would be required, including a different AC thickness, until the "target" fatigue life, as determined by Program 3, was achieved.

Table 6 shows a comparison of design depths using various design methods. Two R-values (25 and 60) were used since District 01 used the R-value of 25 when designing the pavement at Willits, while the R-value of 60 was the value determined from the in-place material at the Transportation Laboratory's test site where all the subgrade material used for this study was taken. The truck traffic and truck growth factor were obtained from

TABLE 6

Comparison of Design Depths Using Various Design Methods

Design Life - 10 yrs.

Traffic Index - 9.5

	R-value 25	R-value 60
Asphalt Institute (MS-1)	0.95'	0.55'
Cities & Counties Method (Calif. H.D.)	1.01'	0.60'

Resilient Modulus & Chev. 5-Layer Method

Truck Traffic - 789 per day*

Growth Factor - 3% per year*

Agency	Design Depth	Fatigue Life
Caltrans Lab	12"	10.8 yrs.
ITTE	12"	39.0 yrs.
ITTE	8"	9.8 yrs.
Oregon S.H.D.	12"	3.3 yrs.
" S.H.D.	18"	19.3 yrs.
" S.H.D.	16"	12.2 yrs.

*Data obtained from District 1 Urban Planning Office.

the District 01 Urban Planning Office. As can be seen from Table 6, using the Chevron 5-layer method, the AC thicknesses required to provide a fatigue life of 10 years ranged from 8 inches using the ITTE's resilient modulus data to about 15 inches using the Oregon State Highway Division's data.

This shows that if the three agencies had actually designed the Willits pavement using their resilient modulus data there could have been a 67% difference in asphalt concrete cost, depending on which agency's data were used. No inference is intended regarding which of the three sets of data are preferable. It should be noted, however, that use of the Translab data results in a design life that closely approximates the 10 year design life used by the District when selecting the 12-inch AC thickness actually used for the Willits job.

CONCLUDING REMARKS

This study was conducted to determine the repeatability and/or reproducibility of the resilient modulus test. To interpret the data submitted by the three participating agencies, the study was taken one step further in that a full depth asphalt concrete pavement was designed using the resilient modulus data submitted by each agency, in order to compare the difference in final design thickness which would have resulted from these resilient modulus tests.

While statistical testing to determine the precision of the test could not be made, the figures, tables, and design thicknesses included in this report tend to indicate that there was considerable variation among the test results of the three agencies. Since the test was not conducted using the same procedures by each agency, this could be a major reason for the large variation among the results. It is therefore recommended that if this test is to gain wide acceptance, a single, definitive test method to determine AC resilient modulus must be developed and religiously adhered to by user agencies. A study of test repeatability should then be conducted. Test reproducibility is of a lesser importance in that the test will be used for design work only, and, as such, probably will not be performed by multiple laboratories within any given agency. It is felt this is the only way to reduce the testing variation among the different agencies who have a resilient modulus testing machine.

REFERENCES

1. Hicks, Russell G., "Factors Influencing the Resilient Properties of Granular Materials," PhD Thesis, University of California, Berkeley, May 1970.

2. Monismith, C. L., McLean, D. B., "Design Considerations for Asphalt Pavements," Report No. TE 71-8, University of California, Berkeley, December 1971.

3. Special Provisions, Contract No. 01-111804, State of California, Department of Public Works, Division of Highways, April 1971.

4. Monismith, C. L., Epps, J. A., Kasianchuk, D. A., and McLean, D. B., "Design Considerations for Asphalt Pavements," Report No. TE 70-5, University of California, Berkeley, December 1970.

APPENDIX A

(Same letter sent to people shown on attached list)

STATE OF CALIFORNIA—BUSINESS AND TRANSPORTATION AGENCY RONALD REAGAN, Governor

DEPARTMENT OF TRANSPORTATION

DIVISION OF HIGHWAYS
TRANSPORTATION LABORATORY
5900 FOLSOM BLVD., SACRAMENTO 95819

The purpose of this letter is to outline the procedure to be used in the Resilient Modulus Correlation Study, in which you have agreed to participate. A thirty-gallon barrel of material sampled from the subgrade of our full-depth AC research project at Willits, California, is being sent to your testing facility. We have also enclosed with this letter a copy of Report No. TE 71-8 by C. L. Monismith and D. B. McLean, in which Appendix A will serve as an exact procedure for sample preparation and testing.

The sample should be split so that only that portion passing the No. 4 sieve is tested. We have tested the material and have ascertained the optimum moisture and density as shown in Table I* Also, we have shown the 80 and 100% saturation lines. Even though the optimum density lies between the 80 and 100% saturation lines; due to the high percentage of fines (33% passing the #200 sieve), we feel that the desired density can best be achieved by static compaction. Other material properties are given in Table II.** The number of layers should be set at four and the following static loading procedure utilized: 1) approximately one minute to bring each layer to its designated volume, 2) holding that load level for another minute, and 3) then slowly releasing the load over a period of about a minute to minimize any rebound characteristics of the soil.

At least three samples should be compacted and tested at water contents of 6, 8, and 10 percent to provide a statistical base for equipment correlation. Determination of mean, standard deviation, and analysis of variance is presently planned for

*Shown as Figure 3 in this report.

**Shown as Table 1 in this report.

the test results; however, if there are any special statistical methods or procedures which you think should be included in the evaluation, please let us know.

The data is scheduled to be gathered in March so that the evaluation can be made and distributed by May. If there are any questions or comments, please contact us.

Very truly yours,

JOHN L. BEATON, P.E.
Materials and Research Engineer

By

George B. Sherman, P.E.
Assistant Materials and
Research Engineer - Pavement

WB:EA

Enclosures