PROJECT ADMINISTRATION DATA SHEET

[XX] ORIGINAL [ ] REVISION NO. ______

Project No. E-20-G08 (R6179-0A0) GTRC/GIT DATE 8 / 6 / 86

Project Director: Quentin L. Robnett School/Lab Civil Engineering

Sponsor: USDA - Forest Service

Type Agreement: P.O. No. 40-43ZP-6-834

Award Period: From 7/1/86 To 10/31/86 (Performance) 10/31/86 (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$ 2,000	$ 2,000
Funded:	$ 2,000	$ 2,000

Cost Sharing Amount: $ N/A Cost Sharing No: N/A

Title: Resilient Testing of Granular Materials

ADMINISTRATIVE DATA OCA Contact Earnestine P. Smith ext. 4820

1) Sponsor Technical Contact:

(Same as Admin./Contact)

2) Sponsor Admin/Contractual Matters:

Charles F. Hoffman
Purchasing Agent
USDA-Forest Service
Room 716-Eng.-Inside Delivery
1720 Peachtree Road, N.W.
Atlanta, Georgia 30367

Defense Priority Rating: N/A Military Security Classification: N/A

(or) Company/Industrial Proprietary: N/A

RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval — Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with None Proposed.

COMMENTS:

AUG 1986 RECEIVED SUPPORT SERVICES OCA

COPIES TO: SPONSOR'S I. D. NO. 02.109.001.87.001

Project Director	Procurement/GTRI Supply Services	GTRC
Research Administrative Network	Research Security Services	Library
Research Property Management	Reports Coordinator (OCA)	Project File
Accounting	Research Communications (2)	Other A. Jones

FORM OCA 65:285

GEORGIA INSTITUTE OF TECHNOLOGY | OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 12/29/86

Project No. E-20-G08 ~~School~~/Lab CE

Includes Subproject No.(s) N/A

Project Director(s) Q. L. Robnett GTRC / ~~GIT~~

Sponsor USDA-Forest Service

Title Resilient Testing of Granular Materials

Effective Completion Date: 10/31/86 (Performance) ____ (Reports)

Grant/Contract Closeout Actions Remaining:

- [ ] None
- [X] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ____

Continues Project No. ____ Continued by Project No. ____

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Project File
Other Ina Lashley
Angela Jones
Russ Embry

FORM OCA 69.285

FINAL REPORT

LABORATORY STUDY OF THE RESILIENT MODULUS OF SELECTED GRANULAR MATERIALS USED ON FOREST SERVICE HAUL ROADS

Dr. Quentin L. Robnett

Submitted to

U.S. Forest Service
1720 Peachtree Road, N.W.
Atlanta, Georgia 30367

November 1986

GEORGIA INSTITUTE OF TECHNOLOGY
A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA
SCHOOL OF CIVIL ENGINEERING
ATLANTA, GEORGIA 30332

1986

SCEGIT-86-120

FINAL REPORT

LABORATORY STUDY OF THE RESILIENT MODULUS OF SELECTED GRANULAR MATERIALS USED ON FOREST SERVICE HAUL ROADS

Report
Prepared By

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School of Civil Engineering
Georgia Institute of Technology

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INTRODUCTION

The structural response of a granular surfaced pavement is influenced by the behavior of the underlying subgrade as well as the behavior and characteristics of the granular material used in the paving layer.

Previously (1983-1984) Georgia Tech has evaluated the resilient behavior of a number of subgrade soil materials typical of forest haul roads.

Information however, is needed concerning the resilient behavior of typical granular materials used as the paving layer or surfacing on forest haul roads.

MATERIALS

Bulk samples of 11 different granular materials were collected by U.S. Forest Service personnel from various locations in the southeastern part of the United States. Compaction tests (AASHTO T-99 or ASTM D-698) were conducted by outside laboratories and the results provided along with the bulk samples. These bulk samples were then shipped to Dr. Robnett, School of Civil Engineering, Georgia Institute of Technology.

A listing of materials supplied, a general description of each, and the general location from which each sample came are as follow:

Name	Source Location	General Description
New York Pit	Mississippi	Clay-gravel
Cotton Pit	Mississippi	Clay-gravel
Crushed Iron Ore	Texas-Currie's Pit	Crushed material
Crushed Sandstone	Texas-Triple S Pit	Crushed material
FDR-59	Road 59, Florida	Light brown silty fine sand with crushed limerock
FDR-90	Road 90, Florida	Tan silty fine sand with crushed limerock
FDR-309	Road 309, Florida	Gray with brown slightly clayey silty fine sand
FDR-348	Road 348, Florida	Brownish-gray clayey fine sand

G-1A	Grovestone Gravel Co.	Crushed creek gravel
G-2A	Enka, N.C.	Crushed gneiss
G-3A	Mableton, Tenn.	Crushed limestone

LABORATORY PROCEDURE

For each bulk sample, a large triaxial specimen, 6 inches in diameter by 13 inches high was carefully prepared in the laboratory to a compacted density and moisture content as close as practical to values from the AASHTO T-99 (or ASTM D-698) compaction test data supplied with each sample.

Moisture was carefully blended with the aggregate mixture and the mixture was then allowed to set for at least 24 hours prior to sample production.

The density and moisture values from AASHTO T-99 and actual compacted values for each test specimen can be found in Table 1 through Table 12 (duplicate specimens were made for the Cotton Pit clay gravel).

Each of the triaxial specimens was prepared on the triaxial base plate, inside a membrane-lined mold. Compaction was accomplished with a vibratory hammer placed on the top of a steel compaction base plate. A total of 5 layers was compacted to prepare each triaxial specimen.

After preparation, each specimen, setting on the triaxial base, was placed in the load frame, Figure 1, the mold removed, and the triaxial cell assembled. The repeated-load applicator was adjusted to the top of the triaxial cell and the externally mounted LVDT's (used to monitor axial displacement during application of the repeated load) were zeroed, Figure 1.

Approximately 100 load applications (0.2 sec. duration, repetition rate = 20 per minute) for each stress ratio of $(\sigma_1 - \sigma_3)/\sigma_3$ equal to 20/10, 30/10, 28/7, 20/5, and 12/3 were applied for conditioning. Then the confining pressure was set at 3 psi and about 10 load applications were applied for $(\sigma_1 - \sigma_3)$ values (deviator stress) of 6, 9, 12, and 15. For each N=10 loads, a resilient deformation was monitored with the LVDT's and recorded on a strip chart. Then the confining pressure was set equal to 5 and specific $(\sigma_1 - \sigma_3)$ values of 10, 15, 20, and 25 were applied in sequence (N=10 for each). Other $(\sigma_1 - \sigma_3)/\sigma_3$ ratios were then applied. The total stress ratio sequence used was as follows:

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Number of Loads
6/3	10
9/3	10
12/3	10
15/3	10
10/5	10
15/5	10
20/5	10
25/5	10
14/7	10
21/7	10
28/7	10
35/7	10
20/10	10
30/10	10
40/10	10
50/10	10

The previous stress ratio sequence was followed for each specimen until excessive permanent deformation occurred and it became impossible to further monitor the resilient or elastic deformation or until the last stress ratio was applied.

DATA ANALYSIS AND PRESENTATION

The elastic or resilient deformation for each repeatedly applied stress ratio was converted to a resilient strain by dividing by the specimen height (13 inches).

Thus, for each stress ratio, an average resilient strain, ε_r, was determined. By dividing this ε_r-value into the associated repeated deviator stress, $\sigma_1 - \sigma_3$, a resilient modulus, E_r was calculated, i.e.,

$$E_r = \frac{(\sigma_1 - \sigma_3)}{\varepsilon_r}$$

The average resilient strain, ε_r, and resilient modulus, E_r, for each of the stress ratios are summarized in Tables 1 through 12 for the 11 bulk samples (duplicate specimen for Cotton Pit clay gravel).

The data from each of these tables was also converted to a graphical form by plotting $\log E_r$ vs. $\log \theta$, where $\theta = \sigma_1 + 2\sigma_3$ for the triaxial test.

These graphical presentations are depicted in Figures 2 through 12.

As can be noted in these figures, some scatter of data exists. Linear regression was used to fit a curve through the data. This regression equation, developed with transformed data (i.e., linear regression performed on the log values) gives a linear relation on the log-log plot which has an equation form of:

$$E_r = K\ \theta^n$$

where: E_r = resilient modulus, psi
θ = bulk stress, = $\sigma_1 + 2\sigma_3$
k = regression constant
n = regression exponent (a constant)

The equation for each of the regression lines is shown in Figures 2 through 12.

CONCLUDING REMARKS

For comparison, the typical range of E_r-values plotted against θ for granular materials is depicted on Figure 13. Generally, the upper part of the range is typical of highly compacted, dense angular crushed aggregates whereas the lower part of the range is more typical of sandy materials and granular materials with large amounts of finer fraction (sand, silt, clay) present.

Also for comparison, the E_r vs. θ relationship for a typical silty clay soil has been plotted on Figure 13.

No specific comparisons or behavior response of the 11 bulk samples will be discussed within this report since only testing and presentation of results were requested.

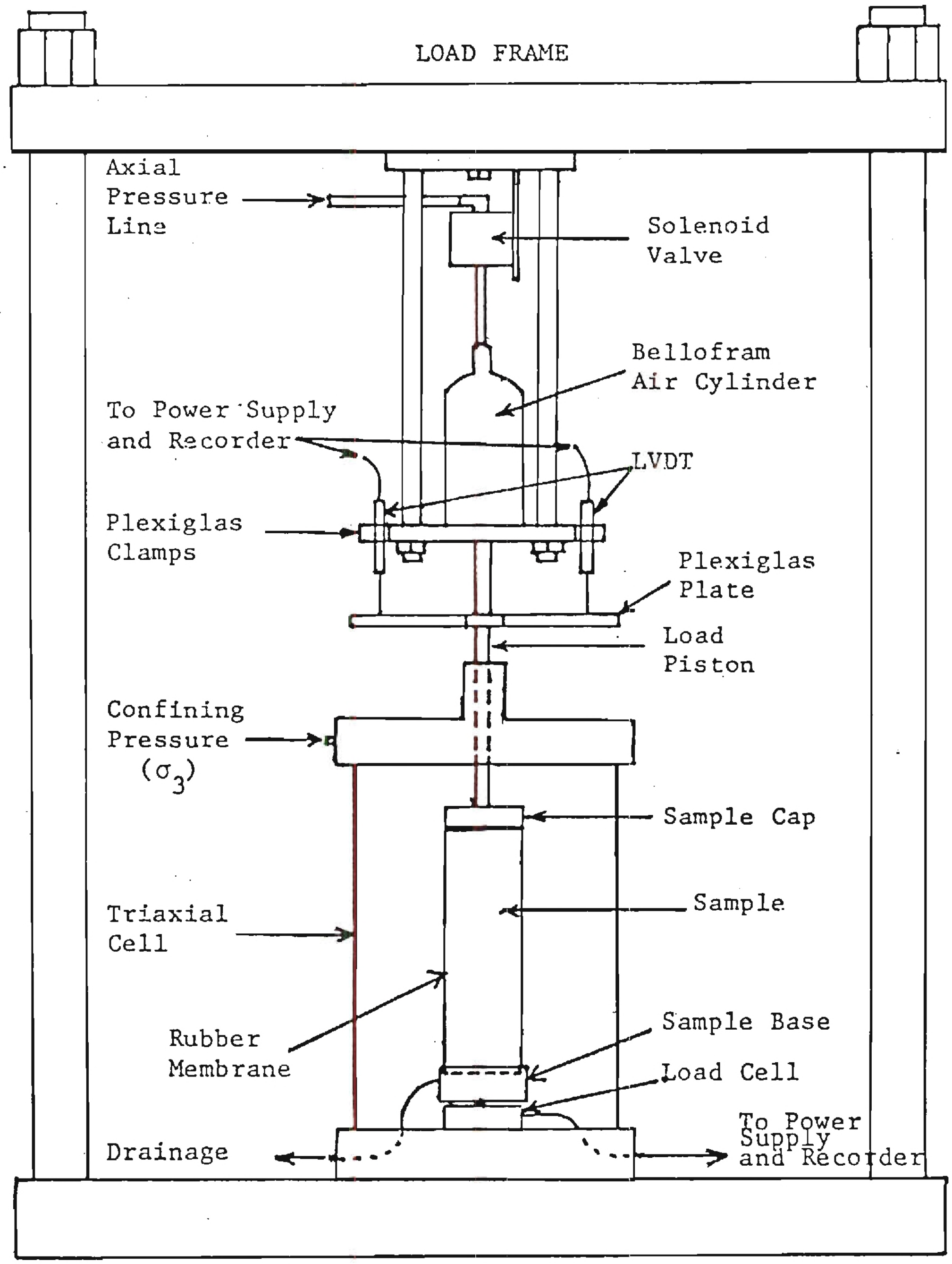

Figure 1. Schematic Diagram of Repeated Load Triaxial Testing Equipment.

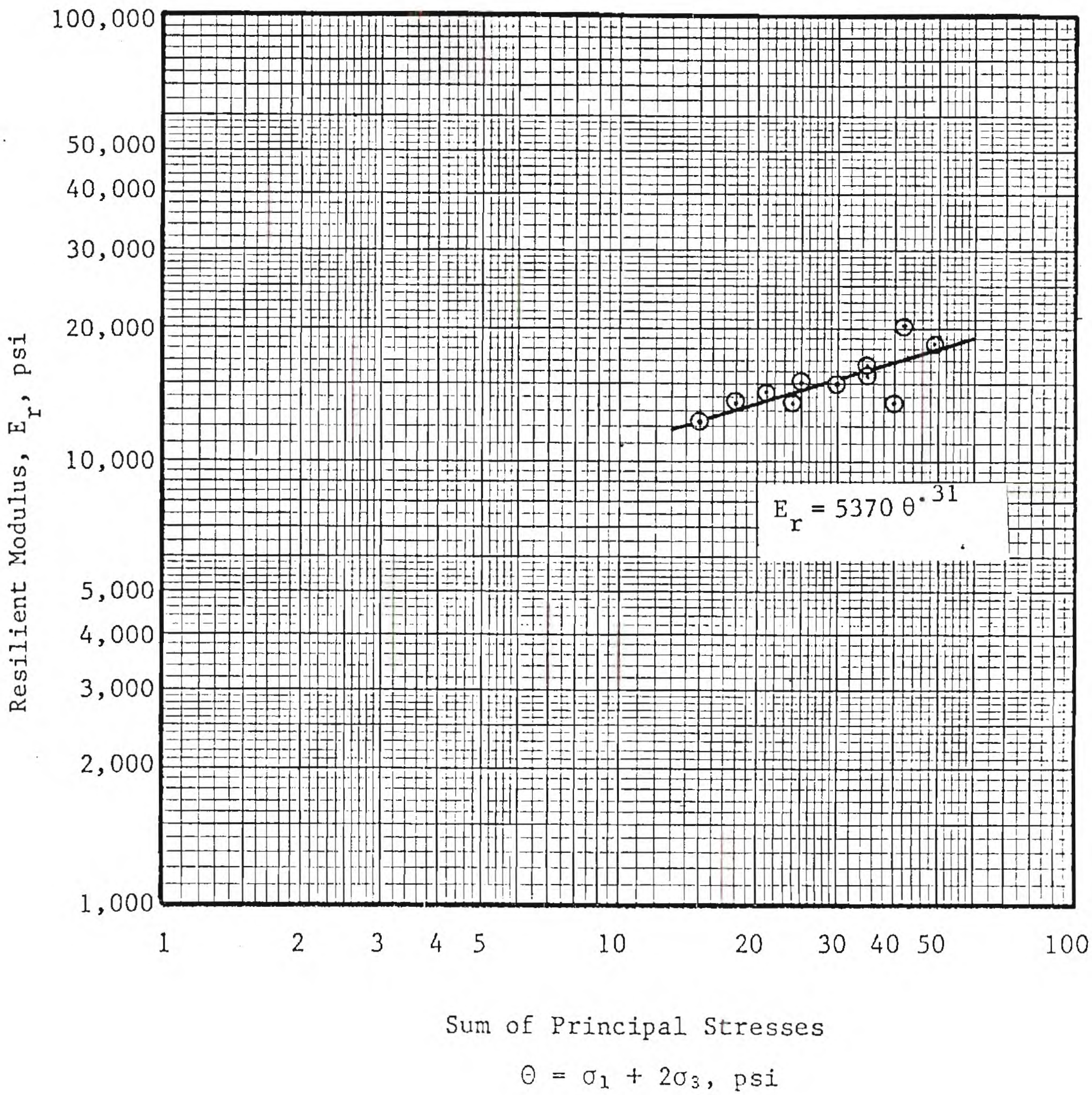

Figure 2. Resilient Modulus vs Applied Stress State for New York Pit Sample (Clay Gravel).

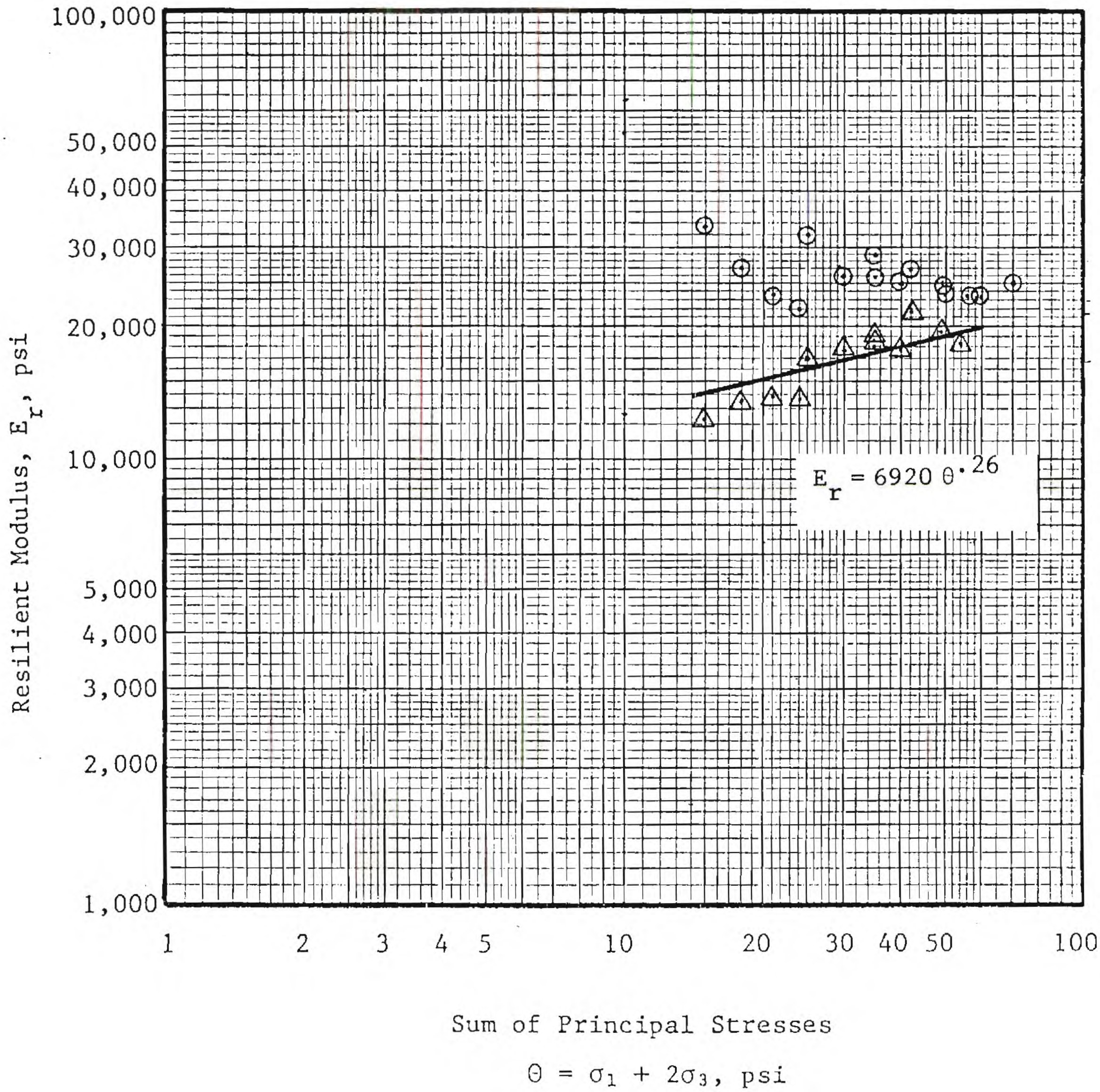

Figure 3. Resilient Modulus vs Applied Stress State for Cotton Pit Sample (Clay Gravel).

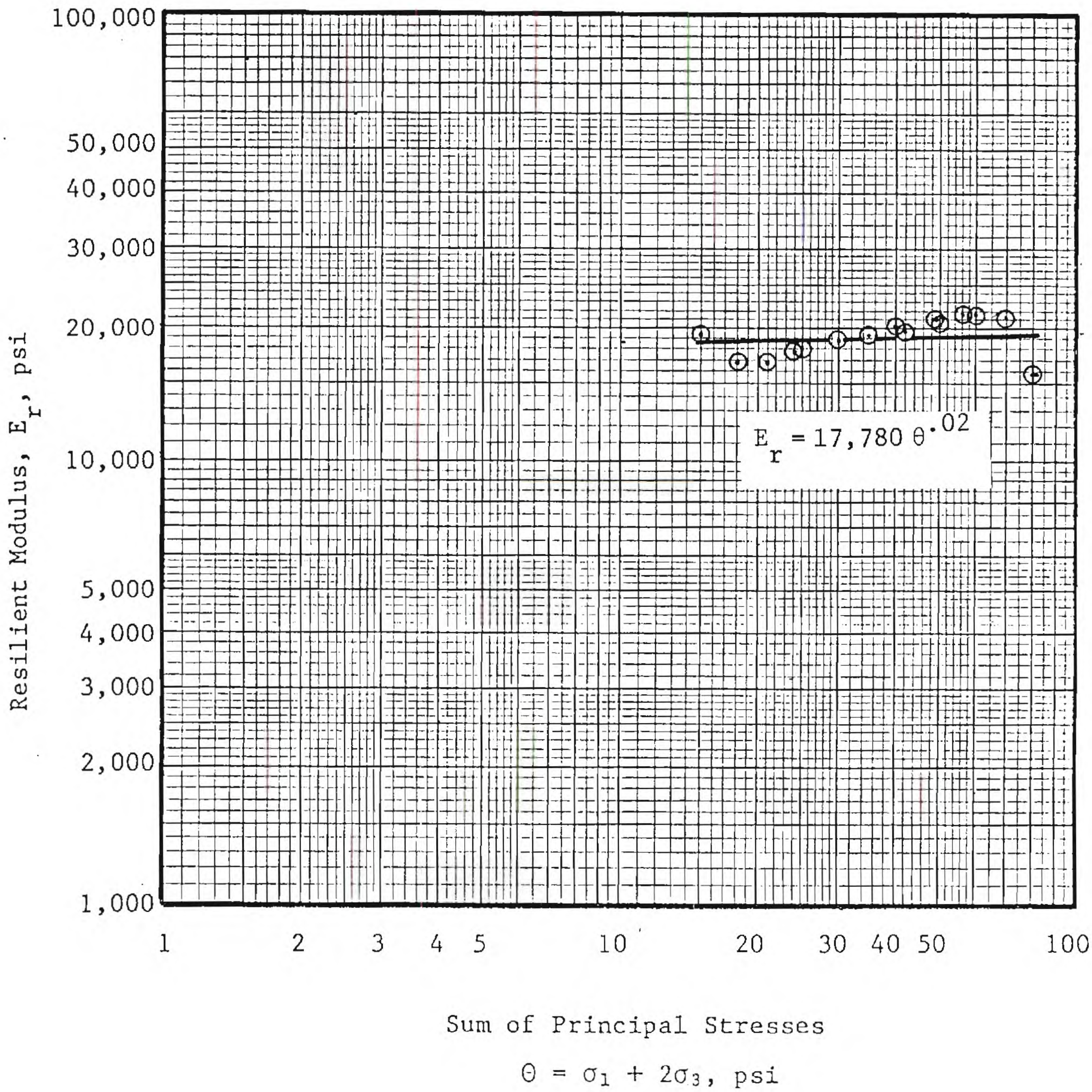

Figure 4. Resilient Modulus vs Applied Stress State for Iron Ore Sample (Crushed Material).

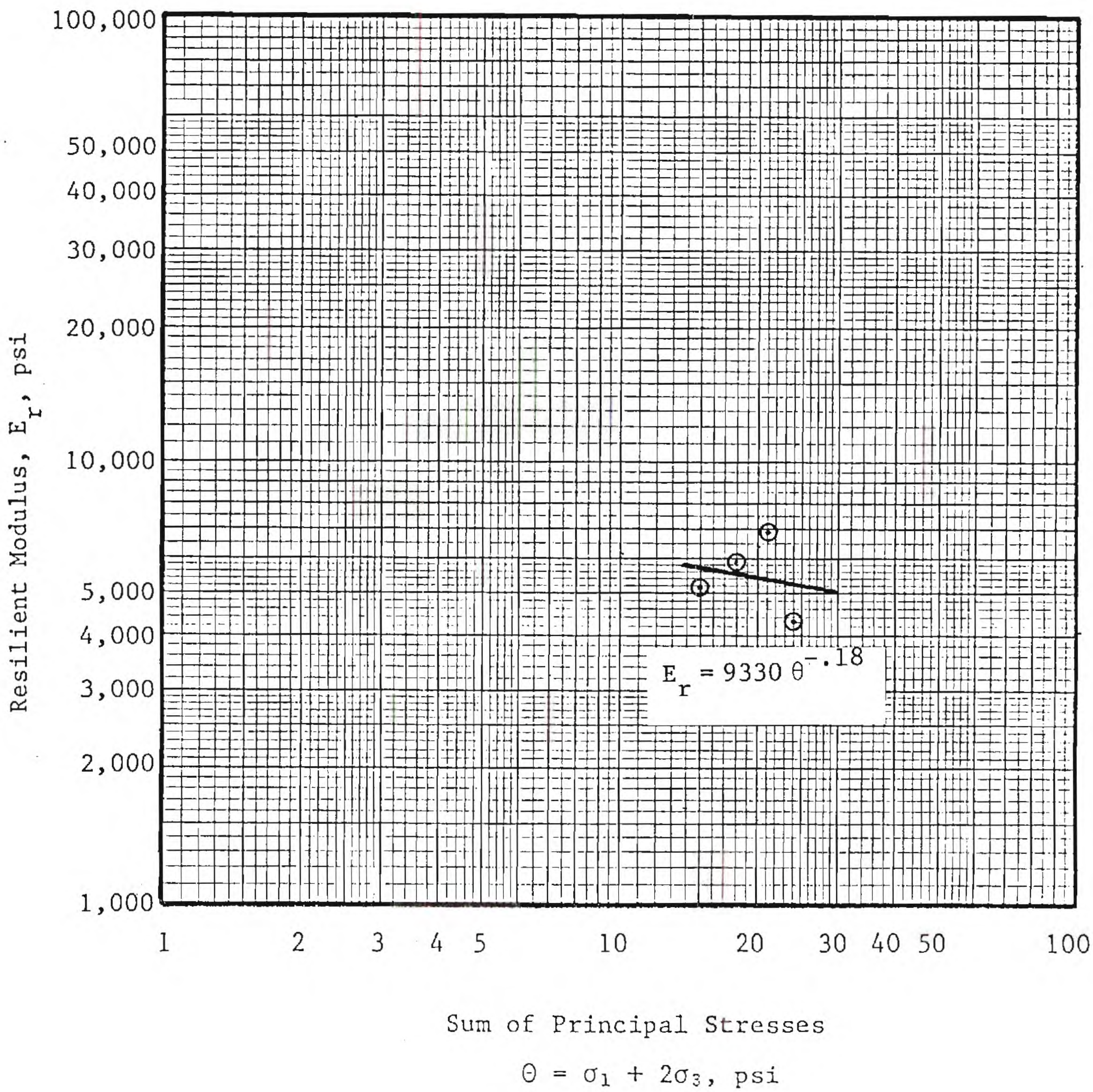

Figure 5. Resilient Modulus vs Applied Stress State for Crushed Sandstone Sample.

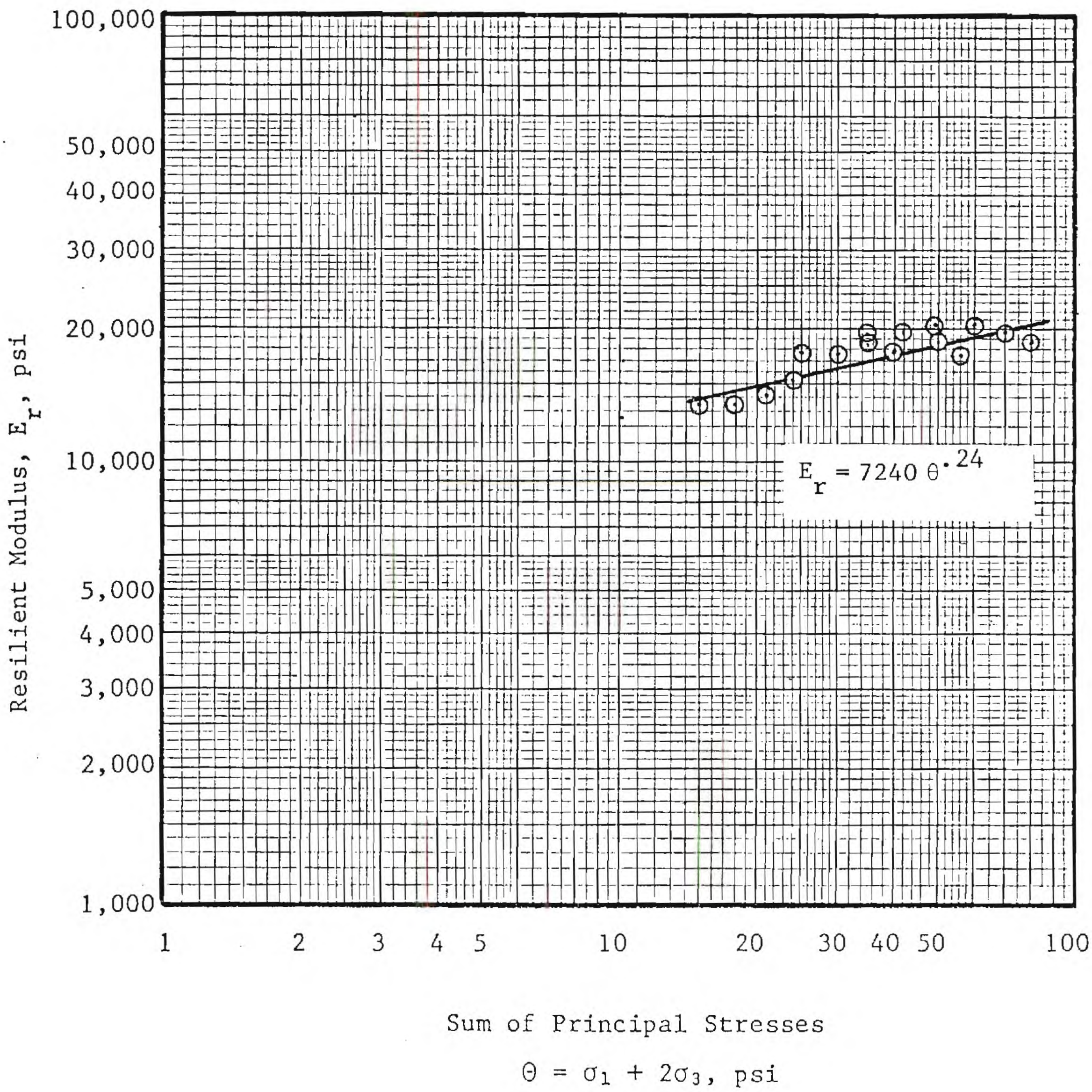

Figure 6. Resilient Modulus vs Applied Stress State for FDR-59 Sample (Light Brown Silty Fine Sand with Crushed Limerock).

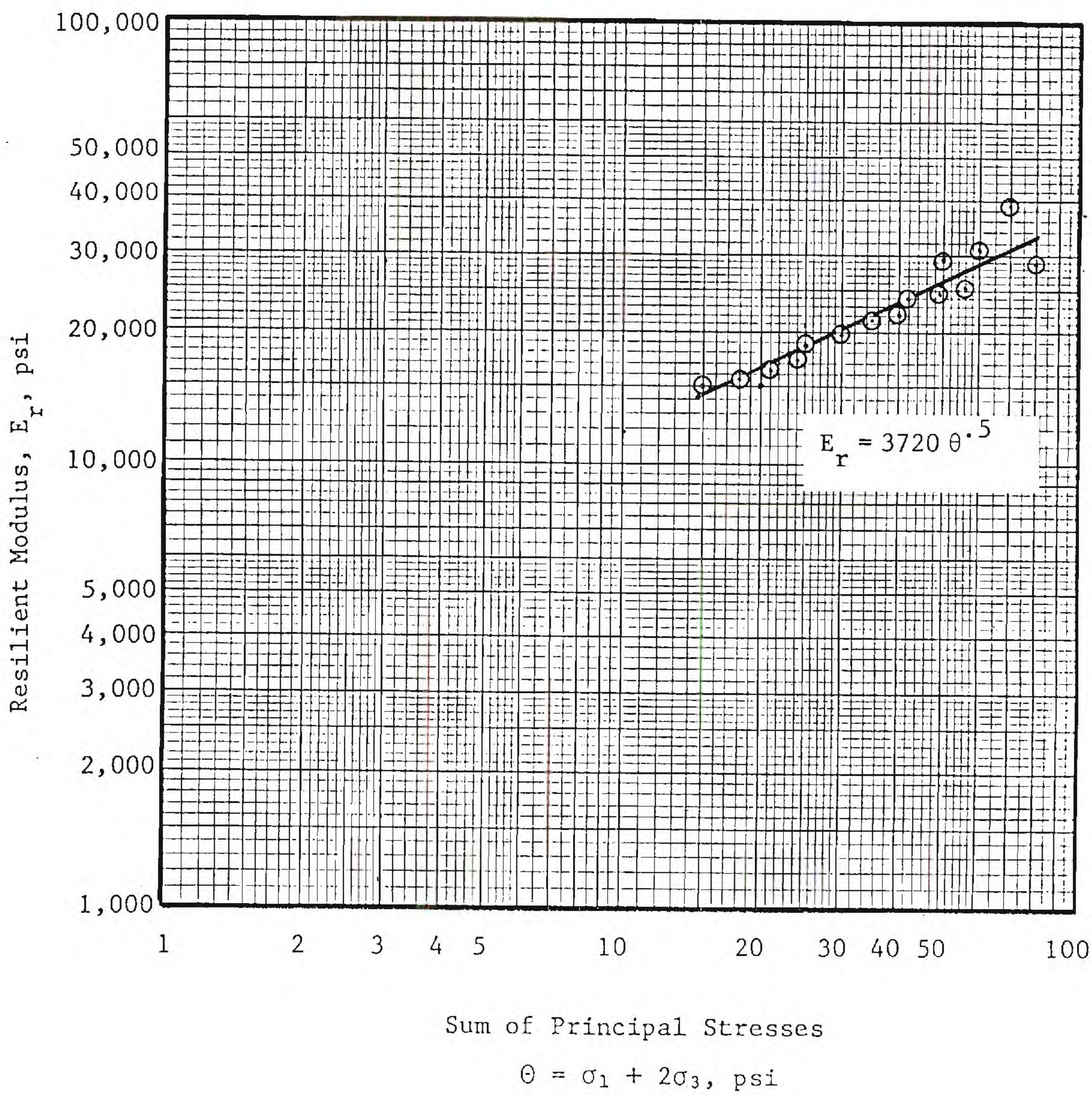

Figure 7. Resilient Modulus vs Applied Stress State for FDR-90 Sample (Tan Silty Fine Sand with Crushed Limerock).

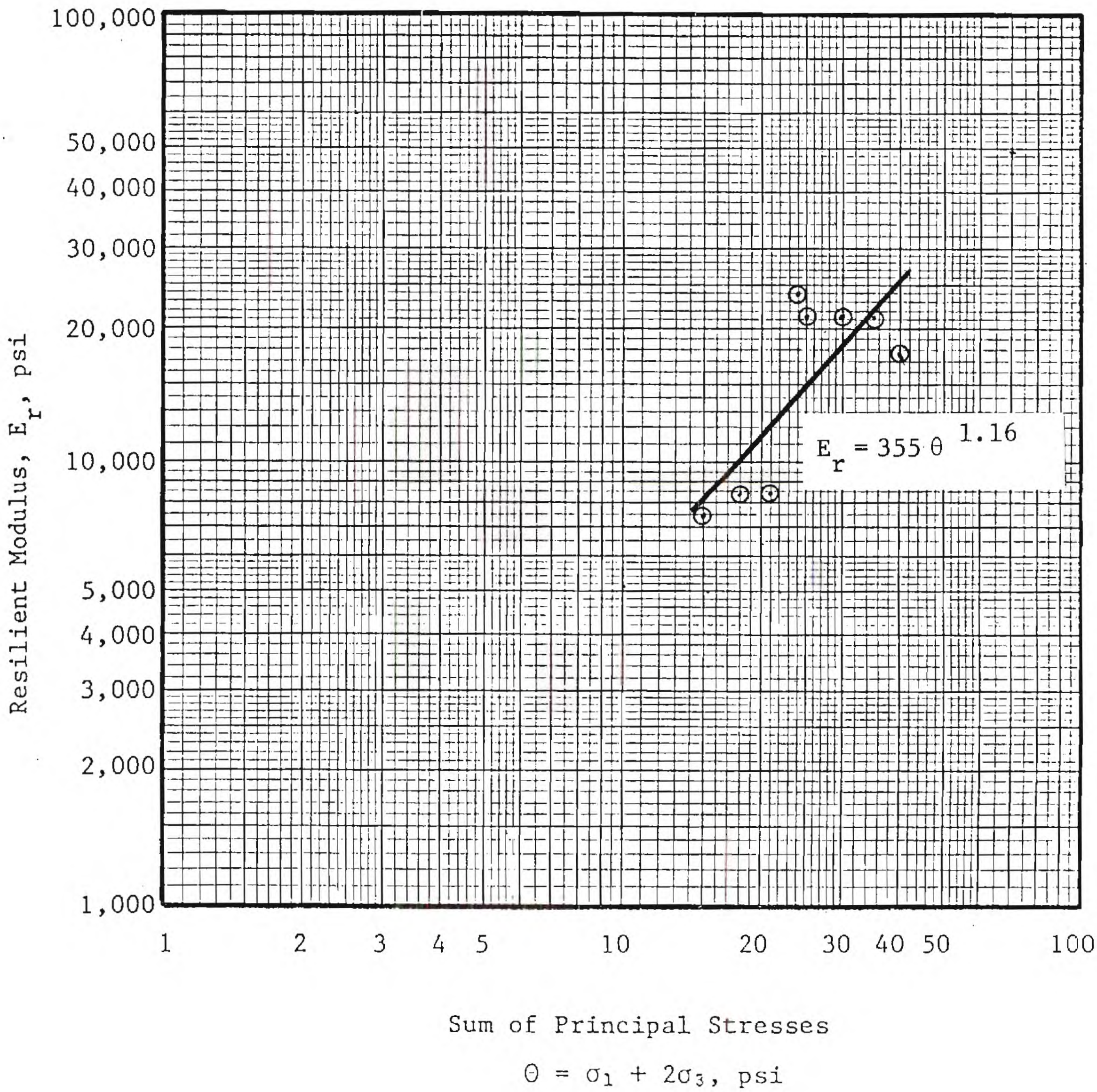

Figure 8. Resilient Modulus vs Applied Stress State for FDR-309 (Gray with Brown Slightly Clayey Silty Fine Sand).

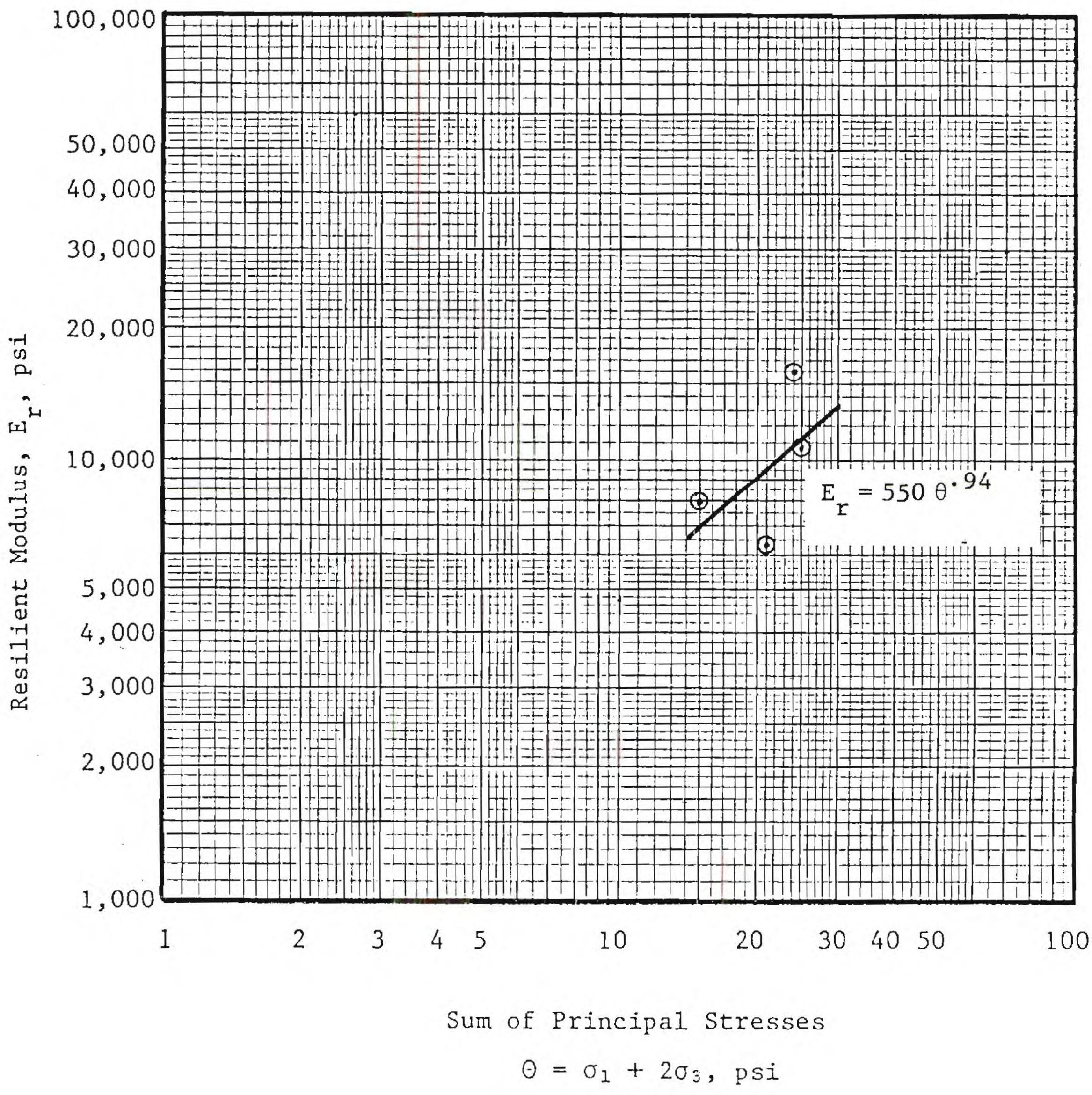

Figure 9. Resilient Modulus vs Applied Stress State for FDR-348 (Brownish-Gray Clayey Fine Sand).

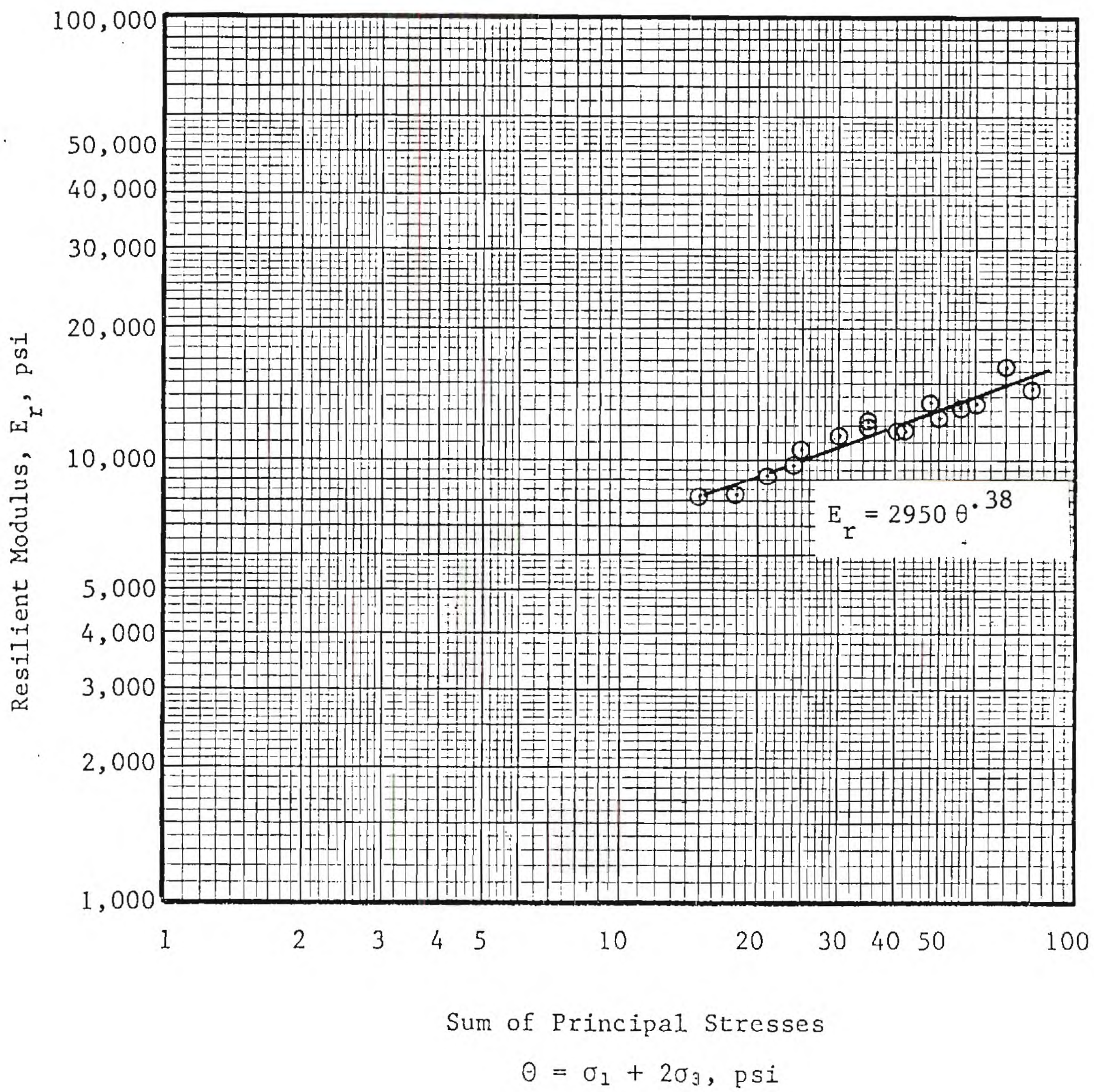

Figure 10. Resilient Modulus vs Applied Stress State for G-1A (Crushed Creek Gravel).

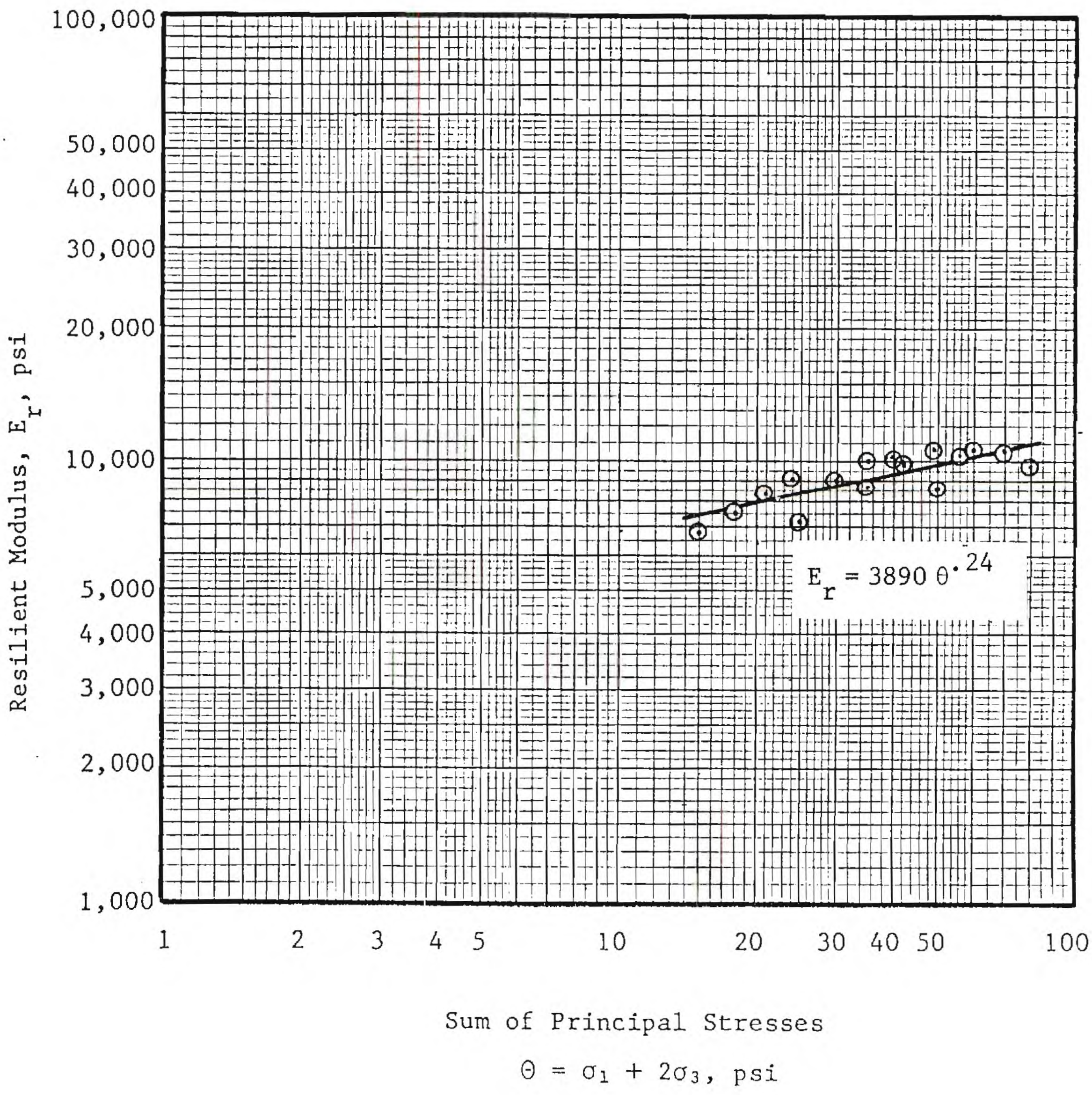

Figure 11. Resilient Modulus vs Applied Stress State for G-2A (Crushed Gneiss).

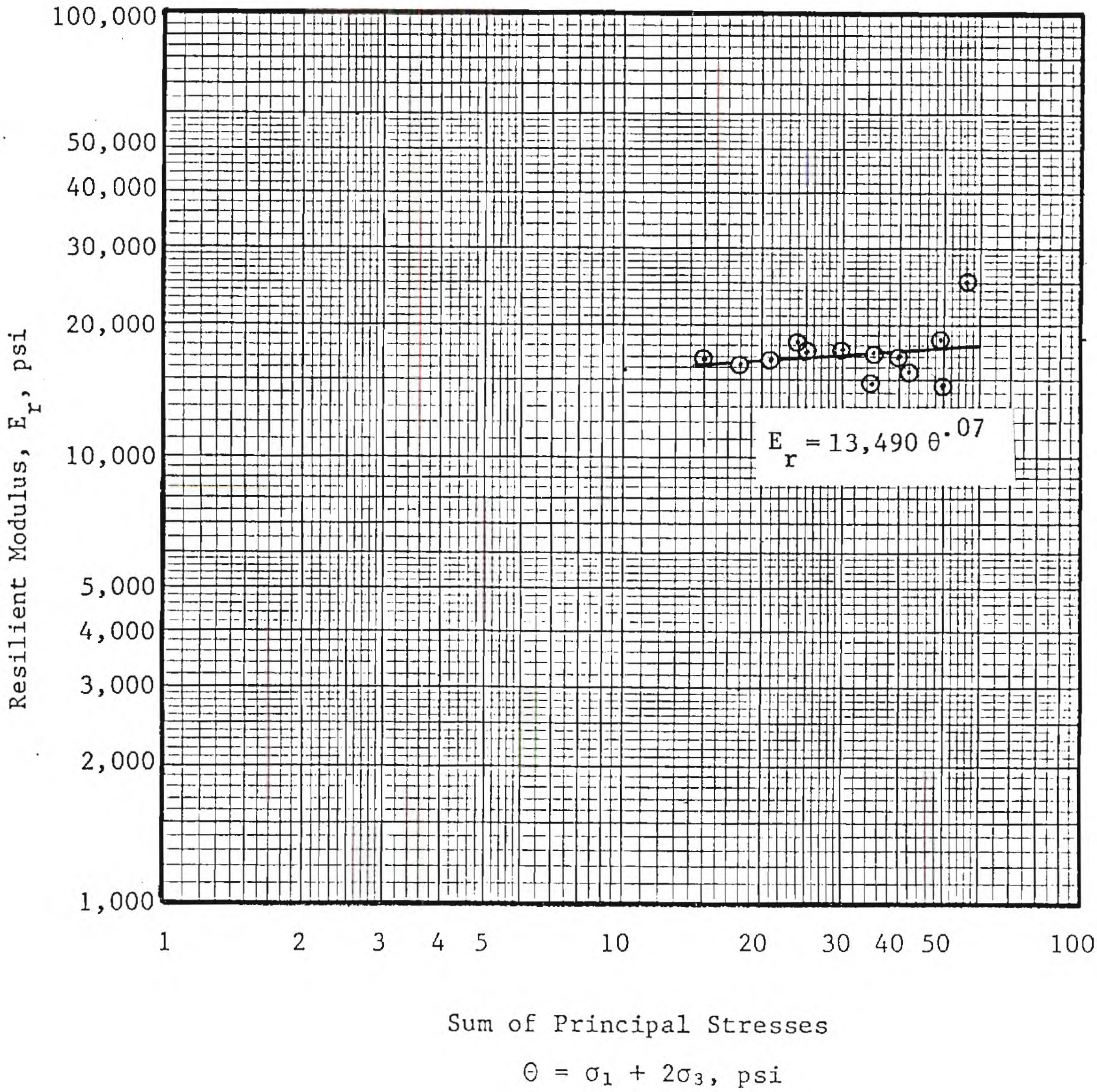

Figure 12. Resilient Modulus vs Applied Stress State for G-3A (Crushed Limestone).

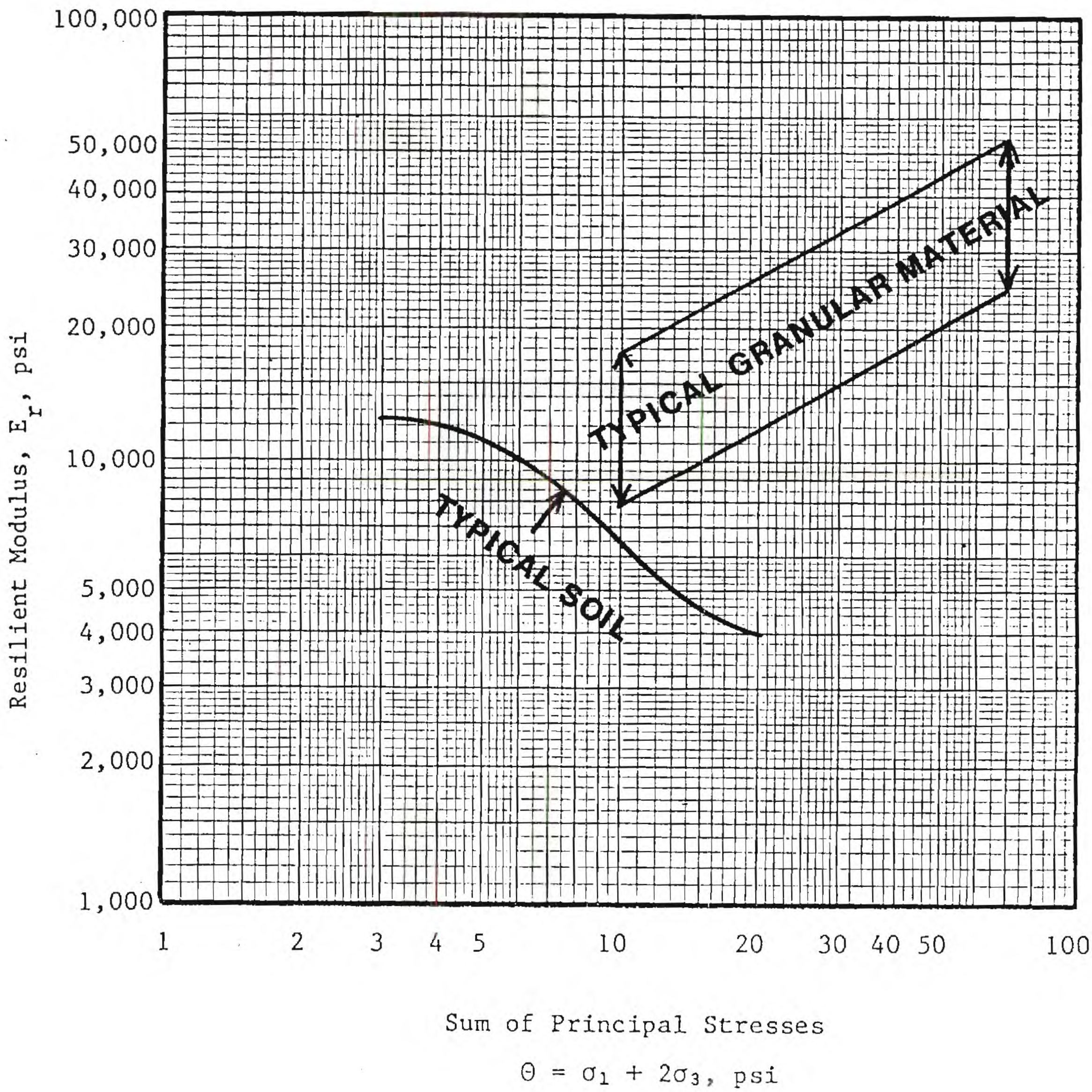

Figure 13. Typical E_r vs. Θ Range for Various Types of Granular Material and a Fine-Grained Soil.

Table 1. Summary of Resilient Test Data for New York Pit Sample.

Laboratory Compaction (AASHTO T-99)	Specimen Compaction
Max. Dry Density = 120.5 pcf	Dry Density = 121.1 pcf
Optimum Moist. = 11.0%	Moist. Content = 10.4%

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Resilient Strain, in/in	Bulk Stress, Θ, $\sigma_1 + 2\sigma_3$, psi	Resilient Mod., E_r, psi
6/3	.00049	15	12,270
9/3	.00067	18	13,500
12/3	.00084	21	14,210
15/3	.00111	24	13,500
10/5	.00067	25	15,000
15/5	.0010	30	15,000
20/5	.00128	35	15,650
25/5	.00183	40	13,630
14/7	.00085	35	16,470
21/7	.00104	42	20,210
28/7	.00151	49	18,530

Table 2. Summary of Resilient Test Data for Cotton Pit Sample (Specimen #1).

Laboratory Compaction (AASHTO T-99)

Max. Dry Density = 130.8 pcf
Optimum Moist. = 7.9%

Specimen Compaction

Dry Density = 132.05 pcf
Moist. Content = 7.1%

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Resilient Strain, in/in	Bulk Stress, Θ, $\sigma_1 + 2\sigma_3$, psi	Resilient Mod., E_r, psi
6/3	0.00018	15	33,750
9/3	0.00033	18	27,000
12/3	0.00051	21	33,480
15/3	0.00069	24	21,780
10/5	0.00031	25	32,140
15/5	0.00058	30	25,960
20/5	0.00078	35	25,710
25/5	0.0010	40	25,000
14/7	0.0049	35	28,800
21/7	0.0008	42	27,000
28/7	0.0011	49	25,200
35/7	0.00156	56	22,500
20/10	0.00085	50	23,550
30/10	0.00129	60	23,280
40/10	0.00161	70	24,830

Table 3. Summary of Resilient Test Data for Cotton Pit Sample (Specimen # 2).

Laboratory Compaction (AASHTO T-99)

Max. Dry Density = 130.8 pcf
Optimum Moist. = 7.9%

Specimen Compaction

Dry Density = 131.4 pcf
Moist. Content = 7.4%

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Resilient Strain, in/in	Bulk Stress, Θ, $\sigma_1 + 2\sigma_3$, psi	Resilient Mod., E_r, psi
6/3	.00049	15	12,270
9/3	.00067	18	13,500
12/3	.00087	21	13,850
15/3	.0011	24	13,780
10/5	.00058	25	17,310
15/5	.00084	30	17,760
20/5	.0011	35	18,000
25/5	.0014	40	17,860
14/7	.00077	35	18,170
21/7	.00096	42	21,810
28/7	.00144	49	19,390
35/7	.00193	56	18,170

Table 4. Summary of Resilient Test Data for Iron Ore Sample.

Laboratory Compaction (AASHTO T-99)

Max. Dry Density = 129.5 pcf
Optimum Moist. = 11.0%

Specimen Compaction

Dry Density = 129.04 pcf
Moist. Content = 11.4%

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Resilient Strain, in/in	Bulk Stress, Θ, $\sigma_1 + 2\sigma_3$, psi	Resilient Mod., E_r, psi
6/3	.00031	15	19,280
9/3	.00093	18	16,870
12/3	.00071	21	16,780
15/3	.00084	24	17,760
10/5	.00056	25	18,000
15/5	.0008	30	19,750
20/5	.00104	35	18,150
25/5	.00124	40	20,090
14/7	.00076	35	18,530
21/7	.00107	42	19,690
28/7	.00133	49	21,000
35/7	.0016	56	21,870
20/10	.00098	50	20,450
30/10	.00138	60	21,770
40/10	.00189	70	21,180
50/10	.00317	80	15,790

Table 6. Summary of Resilient Test Data for FDR-59 Sample.

Laboratory Compaction (AASHTO T-99)

Max. Dry Density = 115.9 pcf
Optimum Moist. = 12.4%

Specimen Compaction

Dry Density = 116.1 pcf
Moist. Content 11.0%

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Resilient Strain, in/in	Bulk Stress, Θ, $\sigma_1 + 2\sigma_3$, psi	Resilient Mod., E_r, psi
6/3	.00045	15	13,370
9/3	.00067	18	13,370
12/3	.00085	21	14,080
15/3	.00099	24	15,200
10/5	.00056	25	17,830
15/5	.00085	30	17,600
20/5	.00109	35	18,200
25/5	.00139	40	17,980
14/7	.00072	35	19,510
21/7	.00105	42	19,920
28/7	.00139	49	20,130
35/7	.00202	56	17,340
20/10	.00107	50	18,770
30/10	.00146	60	20,580
40/10	.00202	70	19,810
50/10	.00269	80	18,580

Table 5. Summary of Resilient Test Data for Crushed Sandstone Sample.

Laboratory Compaction (AASHTO T-99)

Max. Dry Density = 110.4 pcf
Optimum Moist. = 15.2%

Specimen Compaction

Dry Density = 110.4 pcf
Moist. Content = 14.2%

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Resilient Strain, in/in	Bulk Stress, Θ, $\sigma_1 + 2\sigma_3$, psi	Resilient Mod., E_r, psi
6/3	.001155	15	5,190
9/3	.001504	18	5,990
12/3	.00172	21	6,980
15/3	.00343	24	4,360
	↓	Failed	↓

Table 7. Summary of Resilient Test Data for FDR-90 Sample.

Laboratory Compaction (AASHTO T-99)

Max. Dry Density = 116.6 pcf
Optimum Moist. = 10.7%

Specimen Compaction

Dry Density = 116.9 pcf
Moist. Content = 10.4%

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Resilient Strain, in/in	Bulk Stress, Θ, $\sigma_1 + 2\sigma_3$, psi	Resilient Mod., E_r, psi
6/3	.0004	15	15,000
9/3	.00057	18	15,580
12/3	.00073	21	16,360
15/3	.0009	24	17,310
10/5	.00053	25	18,750
15/5	.00076	30	19,850
20/5	.00093	35	21,430
25/5	.00113	40	22,060
14/7	.00064	35	21,720
21/7	.00087	42	24,230
28/7	.00113	49	24,710
35/7	.00137	56	25,400
20/10	.00067	50	29,670
30/10	.00096	60	31,150
40/10	.00115	70	34,610
50/10	.00173	80	28,850

Table 8. Summary of Resilient Test Data for FDR-309 Sample.

Laboratory Compaction (AASHTO T-99)	Specimen Compaction
Max. Dry Density = 115.9 pcf	Dry Density = 117.2 pcf
Optimum Moist. = 9.4%	Moist. Content = 9.4%

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Resilient Strain, in/in	Bulk Stress, Θ, $\sigma_1 + 2\sigma_3$, psi	Resilient Mod., E_r, psi
6/3	.00080	15	7,470
9/3	.00107	18	8,400
12/3	.00142	21	8,430
15/3	.000625	24	24,000
10/5	.00047	25	21,330
15/5	.000703	30	21,330
20/5	.00938	35	21,330
25/5	.00141	40	17,780
	↓	Failed	↓

Table 9. Summary of Resilient Test Data for FDR-348 Sample.

Laboratory Compaction (AASHTO T-99)	Specimen Compaction
Max. Dry Density = 113.0 pcf	Dry Density = 113.9 pcf
Optimum Moist. 12.0%	Moist. Content = 11.1%

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Resilient Strain, in/in	Bulk Stress, Θ, $\sigma_1 + 2\sigma_3$, psi	Resilient Mod., E_r, psi
6/3	.00076	15	7,940
9/3	-	18	-
12/3	.00187	21	6,430
15/3	.00093	24	16,070
10/5	.00093	25	10,710
	↓	Failed	↓

Table 10. Summary of Resilient Test Data for G-1A Sample.

Laboratory Compaction (AASHTO T-99)

Max. Dry Density = 133.3 pcf
Optimum Moist. = 7.8%

Specimen Compaction

Dry Density = 133.6 pcf
Moist. Content = 8.5%

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Resilient Strain, in/in	Bulk Stress, Θ, $\sigma_1 + 2\sigma_3$, psi	Resilient Mod., E_r, psi
6/3	.00073	15	8,180
9/3	.00109	18	8,260
12/3	.00131	21	9,150
15/3	.00153	24	9,780
10/5	.00093	25	10,710
15/5	.00131	30	11,440
20/5	.00164	35	12,160
25/5	.00211	40	11,840
14/7	.00117	35	12,000
21/7	.00178	42	11,810
28/7	.00211	49	13,260
35/7	.00267	56	13,120
20/10	.00161	50	12,410
30/10	.00222	60	13,500
40/10	.00246	70	16,290
50/10	.00340	80	14,710

Table 11. Summary of Resilient Test Data for G-2A Sample.

Laboratory Compaction (AASHTO T-99)

Max. Dry Density = 138.1 pcf
Optimum Moist. = 7.6%

Specimen Compaction

Dry Density = 140.2 pcf
Moist. Content = 7.0%

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Resilient Strain, in/in	Bulk Stress, Θ, $\sigma_1 + 2\sigma_3$, psi	Resilient Mod., E_r, psi
6/3	.00088	15	6,750
9/3	.0012	18	7,500
12/3	.00142	21	8,440
15/3	.00164	24	9,120
10/5	.00139	25	7,200
15/5	.00167	30	9,000
20/5	.0020	35	10,000
25/5	.00244	40	10,230
14/7	.00161	35	8,690
21/7	.00215	42	9,780
28/7	.00258	49	10,860
35/7	.00344	56	10,180
20/10	.00235	50	8,530
30/10	.00281	60	10,660
40/10	.00375	70	10,660
50/10	.00513	80	9,740

Table 12. Summary of Resilient Test Data for G-3A Sample.

Laboratory Compaction (AASHTO T-99)

Max. Dry Density = 147.4 pcf
Optimum Moist. = 5.2%

Specimen Compaction

Dry Density = 150.2 pcf
Moist. Content = 4.2%

Stress Ratio $(\sigma_1 - \sigma_3)/\sigma_3$	Resilient Strain, in/in	Bulk Stress, Θ, $\sigma_1 + 2\sigma_3$, psi	Resilient Mod., E_r, psi
6/3	.00036	15	16,870
9/3	.00056	18	16,200
12/3	.00071	21	16,870
15/3	.00082	24	18,240
10/5	.00058	25	17,310
15/5	.00084	30	17,760
20/5	.00116	35	17,310
25/5	.00156	40	16,070
14/7	.00094	35	14,820
21/7	.00132	42	15,880
28/7	.00151	49	18,530
35/7	.0014	56	25,000
20/10	.0014	50	14,290