GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ______

Project No. E-20-628 GTRI/GIT DATE 10/21/83

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

Sponsor: USDA - Forest Service

Type Agreement: P.O. No. 40-43ZP-0-1400

Award Period: From 8/9/83 To 8/8/84 (Performance) 8/8/84 (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$ 4,500	$ 4,500
Funded:	$ 4,500	$ 4,500

Cost Sharing Amount: $ ______ Cost Sharing No: ______

Title: Evaluation of Resilient Modulus of Selected Forest Haul Road Subgrade Soils

ADMINISTRATIVE DATA

OCA Contact Brian J. Lindberg X4820

1) Sponsor Technical Contact:

Mr. Douglas Scholen
USDA - Forest Service
Room 720-ENG
1720 Peachtree Rd. NW
Atlanta, GA 30367

2) Sponsor Admin/Contractual Matters:

Mr. Charles Hoffman
USDA - Forest Service
Room 802, Procurement
1720 Peachtree Road, NW
Atlanta, GA 30367
881-2003

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 Sponsor; However, none proposed.

COMMENTS:

OCT 1983
RECEIVED
Reports Office

COPIES TO:

Project Director (Robnett)	Procurement/EES Supply Services	GTRI
Research Administrative Network	Research Security Services	Library
Research Property Management	Reports Coordinator (OCA)	Project File
Accounting	Research Communications (2)	Other I. Newton

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 10/4/84

Project No. E-20-628 School/~~Lab~~ CE

Includes Subproject No.(s)

Project Director(s) Dr. Quentin L. Robnett GTRI / ~~GIT~~

Sponsor USDA - Forest Service

Title Evaluation of Resilient Modulus of Selected Forest Haul Road Subgrade Soils

Effective Completion Date: 8/8/84 (Performance) 8/8/84 (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.

COPIES TO:

Project Director
Research Administrative Network
Research Property Management
Accounting
Procurement/EES Supply Services
Research Security Services
Reports Coordinator (OCA)
Legal Services

Library
GTRI
Research Communications (2)
Project File
Other A. Jones

E-20-628

Final Report

Project E20-628

EVALUATION OF RESILIENT MODULUS OF SELECTED FOREST HAUL ROAD SUBGRADE SOILS

prepared by

Dr. Quentin L. Robnett
School of Civil Engineering
Georgia Institute of Technology

submitted to

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

August, 1984

INTRODUCTION

The structural response of the soil under a pavement structure has a profound influence on the behavior and performance of the pavement. Resilience or resilient modulus is an increasingly popular method to evaluate the subgrade supporting capability.

The new U.S. Forest Service Thickness Design method for example uses resilient modulus as a design input. Utilization of resilient modulus for design requires that a fairly complex and time consuming test be conducted on the soil. Furthermore, the response of the soil is not a unique value but rather one that depends on a number of factors including the following:

1. magnitude of applied stress
2. pulse duration of applied stress
3. degree of saturation (density-compaction moisture)
4. soil texture
5. soil plasticity

RESEARCH OBJECTIVE AND SCOPE

The primary objective of the research was to evaluate the resilient response of a broad range of soils which occur as typical forest haul road subgrades in the Southeast Region of the U.S. Forest Service.

Twenty-six different soil samples were subjected to the resilience test. These soils are listed, along with selected engineering properties in Table 1.

LABORATORY TEST METHOD

Georgia Tech was responsible for resilient testing of each soil sample while the U.S. Forest Service was for each soil sample responsible for:

1. collection and shipment of a bulk sample of soil to Georgia Tech.
2. determination of the moisture-density relation (ASTM D-698).
3. determination of the grain size distribution (ASTM D-422).
4. determination of the Atterberg Limits (ASTM D-423 and D-424).

The U.S. Forest Service supplied this information to Dr. Quentin L. Robnett, School of Civil Engineering, Georgia Institute of Technology. It is summarized in Table 1.

Initial Processing

Upon receipt of the bulk samples, they were air-dried and pulverized to pass a No. 4 sieve with all excess material, roots, etc. being discarded.

Resilience Testing

A test procedure similar to the one outlined in Ref. 1 (pp. 36-38) was used to evaluate the resilient behavior of the soil. This procedure is contained in detail in Appendix A. For each of the soils, two specimens were compacted approximately to each of the following conditions: (a) optimum moisture content and 100% of Proctor maximum dry density and (b) above optimum moisture (range was about 2 to 5 percentage points above) and 95% of the Proctor maximum dry density. The actual compaction conditions are summarized in Table 1. A kneading compaction method, shown schematically in Figure 1, was used to compact the 2.8 inch diameter by 5.6 inch high cylindrical specimens.

These specimens were carefully wrapped in plastic and stored at room temperature for at least 7 days prior to resilience to minimize thixotropic effects.

The specimens were then placed in the resilient test apparatus, Figure 2, and subjected to the following test sequence with a repeated loading of 20 applications per minute with a load pulse duration of 0.1 second:

1. apply 1000 loads at a specimen pressure of 7 psi (conditioning phase)

2. apply about 5 loads at specimen pressures incrementally changing as follows: 3 psi → 5 → 7 → 10 → 15 → 20 → 25 → 30 → 25 → 20 → 15 → 10 → 7 → 5 → 3 psi

3. for each repeatedly applied pressure, the specimen deformation was recorded by use of an LVDT, Figure 2, connected to a Hewlett-Packard strip chart recorder

4. the resilient (or elastic) component of this deformation was converted to resilient strain by dividing the specimen height

5. by dividing the resultant resilient strain into the applied specimen pressure, a resilient modulus, E_R, was obtained; that is $E_R = \sigma/\varepsilon_R$

RESULTS

Results from the testing program are summarized in the figures contained on page 7 to 43 of this report.

REFERENCE

1. "Test Procedures for Characterizing Dynamic Stress-Strain Properties of Pavement Materials", Special Report 162, Transportation Research Board, 1975.

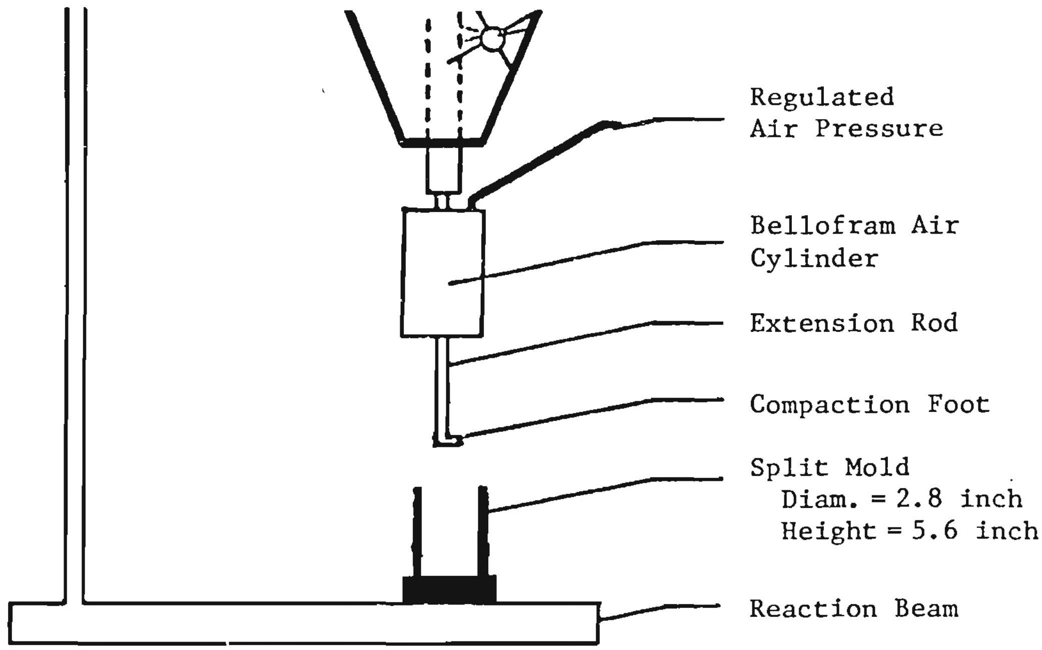
Table 1
Summary of Soils Tested, Selected Properties and Compaction Conditions

Soil	Designation	$\gamma_{d\,max}$,pcf	Optimum Moisture,%	Liquid Limit	Plasticity Index	Compaction Conditions for Test Specimens (A) $\%\gamma_{d\,max}$	(A) $\omega^{(c)}$	(B) $\%\gamma_{d\,max}$	(B) $\omega^{(c)}$
Arkansas	1A	120.3	13.4	34	16	92.4	+2.2%	92.4	+.05%
	2B	116.4	15.0	26	6	94.7	+1.6%	99.0	opt.
	3A	108.2	18.6	49	22	94.3	+1.7%	92.8	+.2%
	4A	103.1	21.5	52	28	94.5	+2.4%	98.0	+.1%
North Carolina	S-1B-NC-ARMS-A	105.5	17.6	NP	NP	94.7	+1.6%	99.8	-.3%
	S-2B-NC-ARMS-H	115.6	14.5	22.5	1	94.8	+0.25%	98.0	+.2%
	S-3B-NC-ARMS-I	108.4	19.0	33	7	95.4	+1.6%	98.8	-.65%
	S-4B-NC-ARMS-AF	104.7	20.4	35	4	96.2	+2.0%	99.7	-.07%
	S-4B-NC-ARMS-AF	104.7	20.4	35	4	92.0	+5.0%	-	-
	S-5B-NC-ARMS-AH	108.4	18.3	38	7	96.2	+1.4%	96.8	-.1%
South Carolina	S-1B-SC-ARMS-AF	105.0	21.0	45	12	95.7	+1.5%	96.2	opt.
	S-2B-SC-ARMS-AH	94.4	27.1	71	34	95.6	+3.8%	99.8	+.3%
	S-3B-SC-ARMS-AG	109.7	17.3	41	19	95.9	+1.9%	99.5	-.3%
	S-4B-SC-ARMS-AJ	99.9	22.7	51	18	95.6	+1.9%	99.5	-.2%
	S-5B-SC-ARMS-H	105.8	19.6	40	5	95.8	+1.6%	98.5	-.1%
	S-6B-SC-ARMS-J	95.0	26.1	63.5	29.5	94.9	+4.1%	100.6	-.2%
Oklahoma	1 (CL8363)	119.6	12.9	23	5	94.8	+2.0%	94.8	+.3%
Mississippi	OV-1-F	83.4	34.8	92	63	94.0	+5.0%	100.7	opt.
	EJ-1-W	92.6	25.2	66	41	98.2	+5.2%	103.3	+.2%
	2 Mph-S	98.5	23.7	62	42	93.8	+4.8%	100.0	opt.
	3 Pap-W	98.1	24.6	65	37	93.2	+5.0%	98.9	+.4%
Texas	Reklaw	111.2	20.7	38	14	94.5	+1.8%	98.2	+.2%
	Lufkin (Fleming)	90.8	27.8	68	45	94.5	+3.0%	101.3	-.4%
	Lufkin (Yazoo)	96.6	24.5	55	31	96.3	+2.9%	100.0	-.3%
	Lufkin (Cook Mt.)	96.8	26.8	60	31	95.5	+3.0%	99.6	-.4%
	Lufkin (Nash Creek)	82.8	33.0	66	36	94.9	+5.3%	98.65	opt.
Work Center		102.0	20.0	45	16	96.7	+3.2%	100.2	+.4%

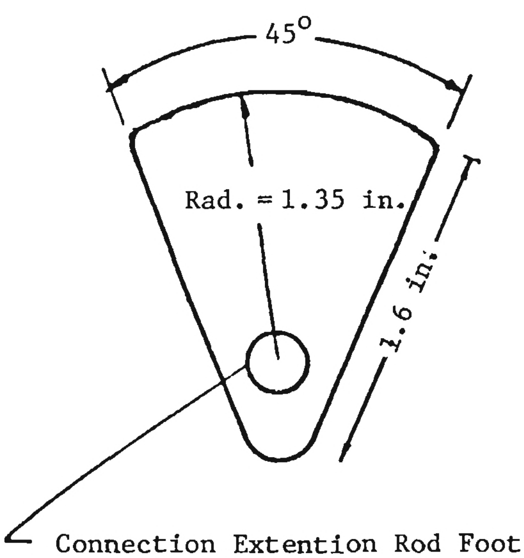
(A) Compaction is about 95% $\gamma_{d\,max}$ and 2 to 5% above optimum moisture content.

(B) Compaction to about 100% $\gamma_{d\,max}$ and optimum moisture content.

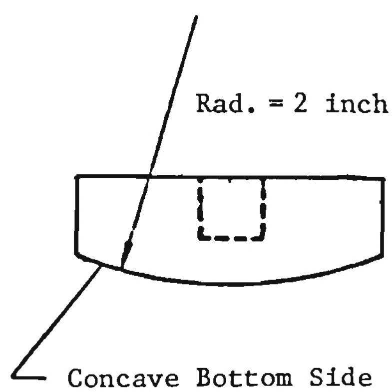
(C) Actual compaction moisture content relative to optimum moisture content.



a. Compaction Equipment Schematic



b. Compaction Foot - Plan View



c. Compaction Foot - Elevation View

FIGURE 1. COMPACTION EQUIPMENT

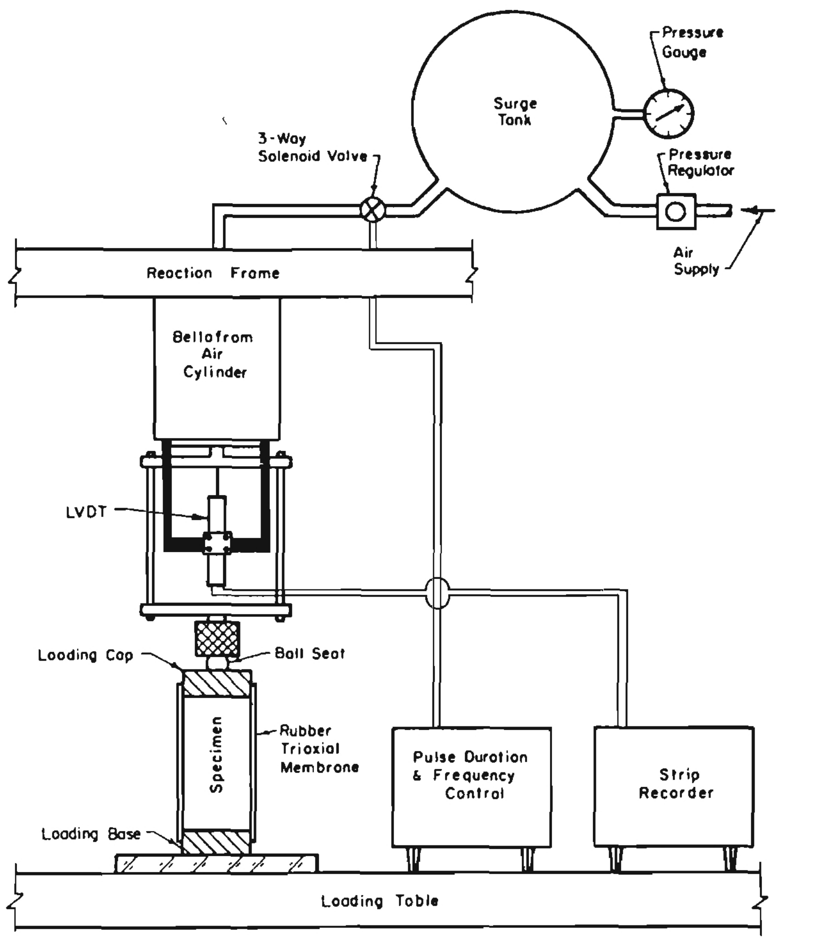
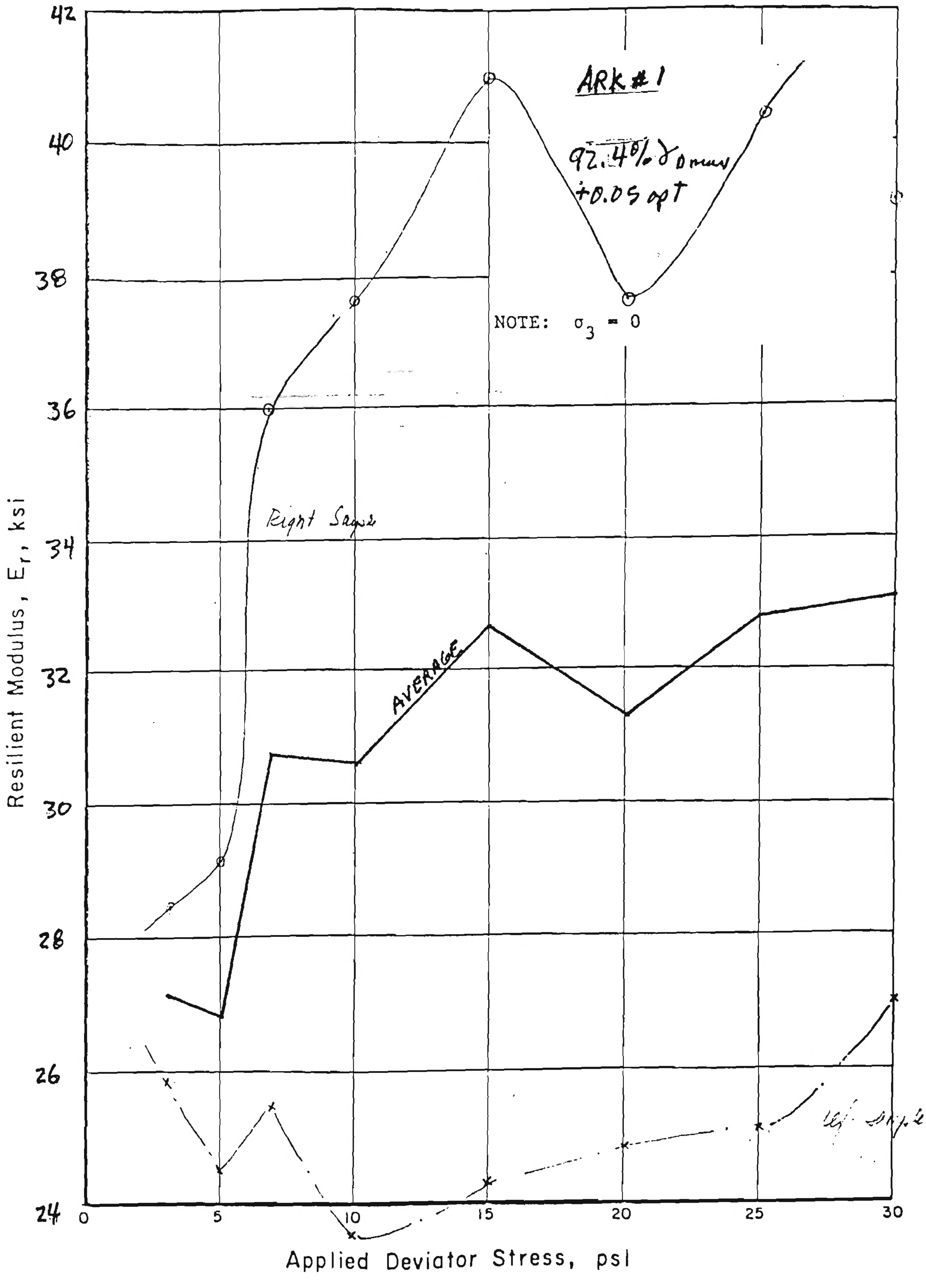
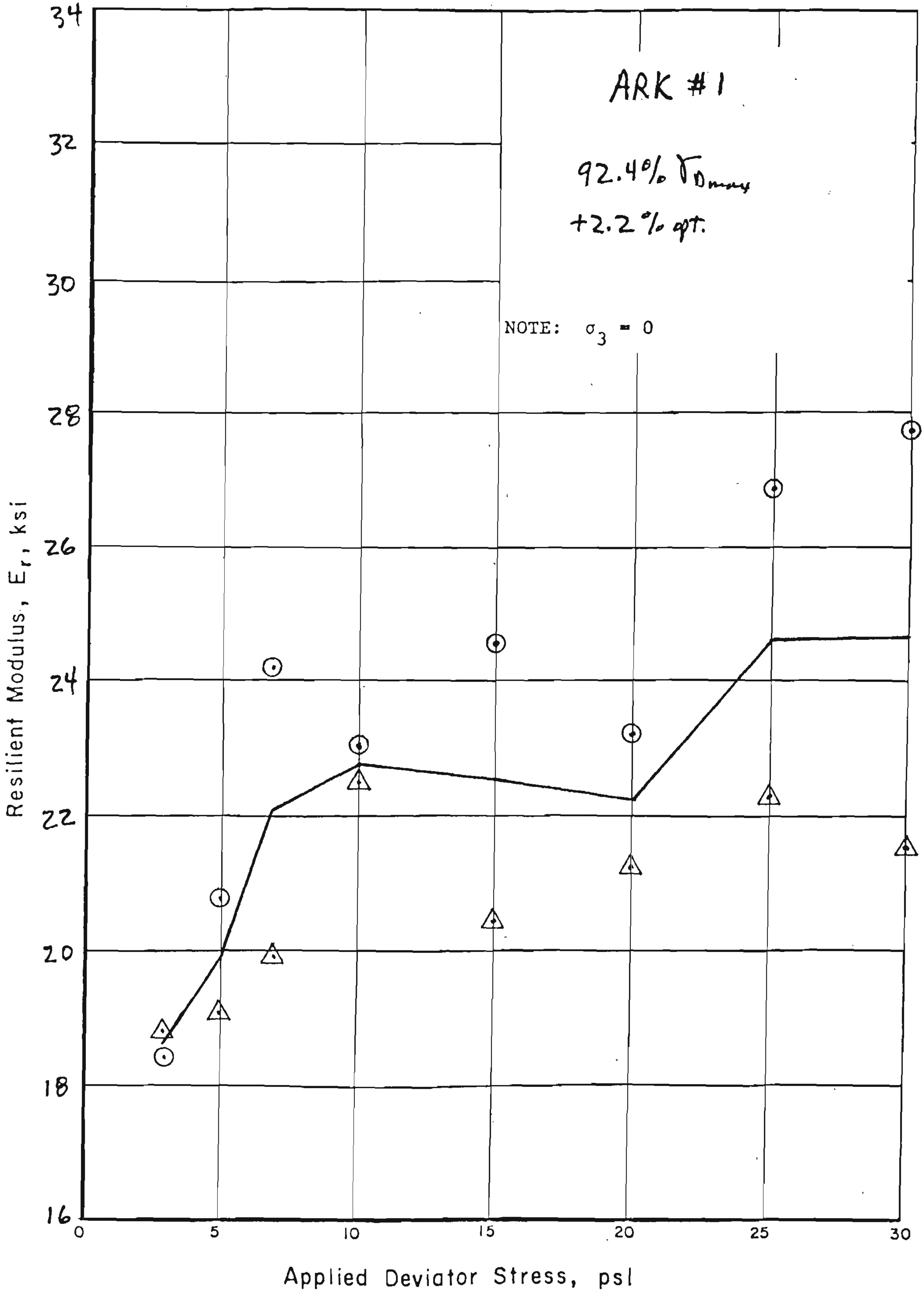
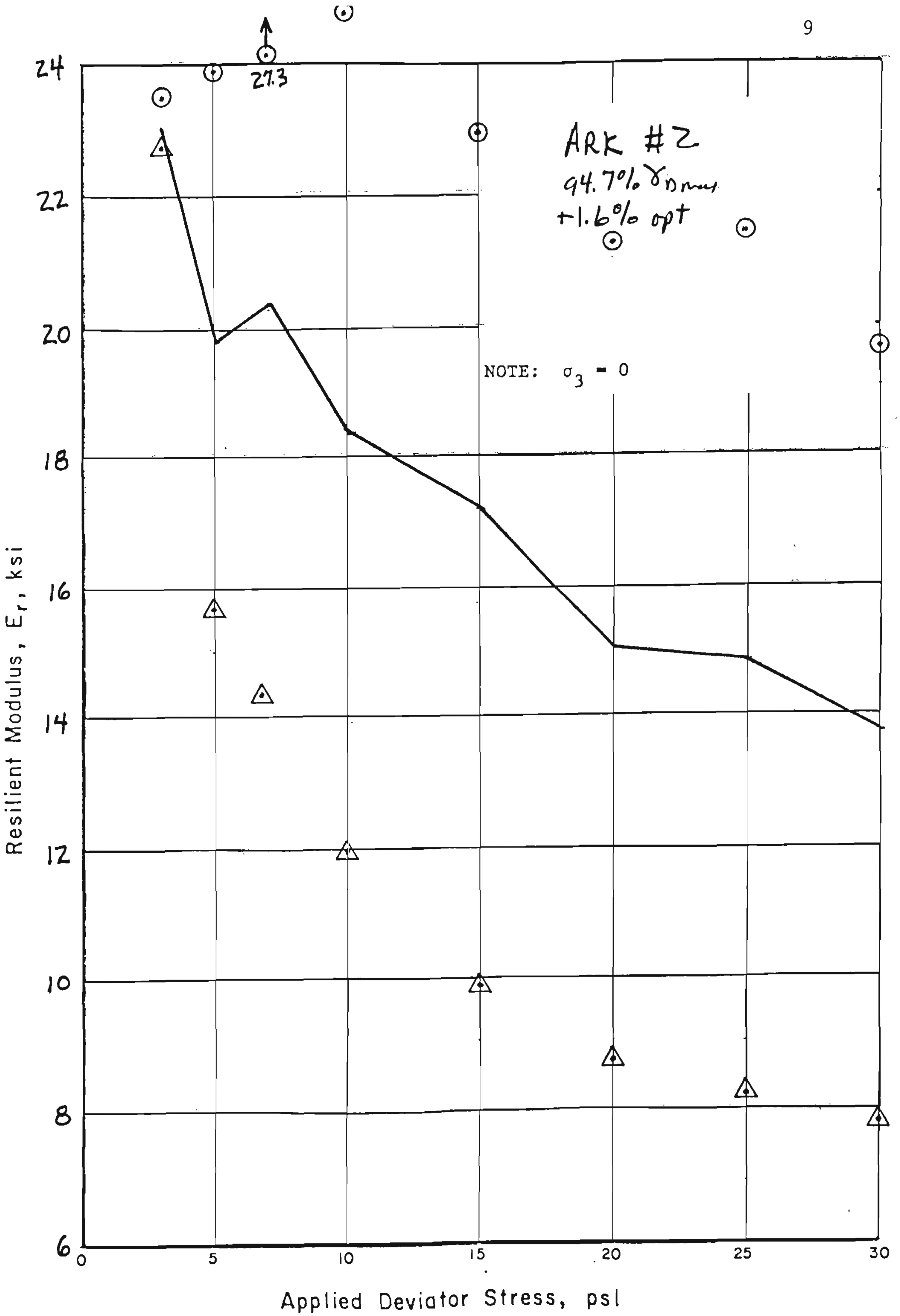


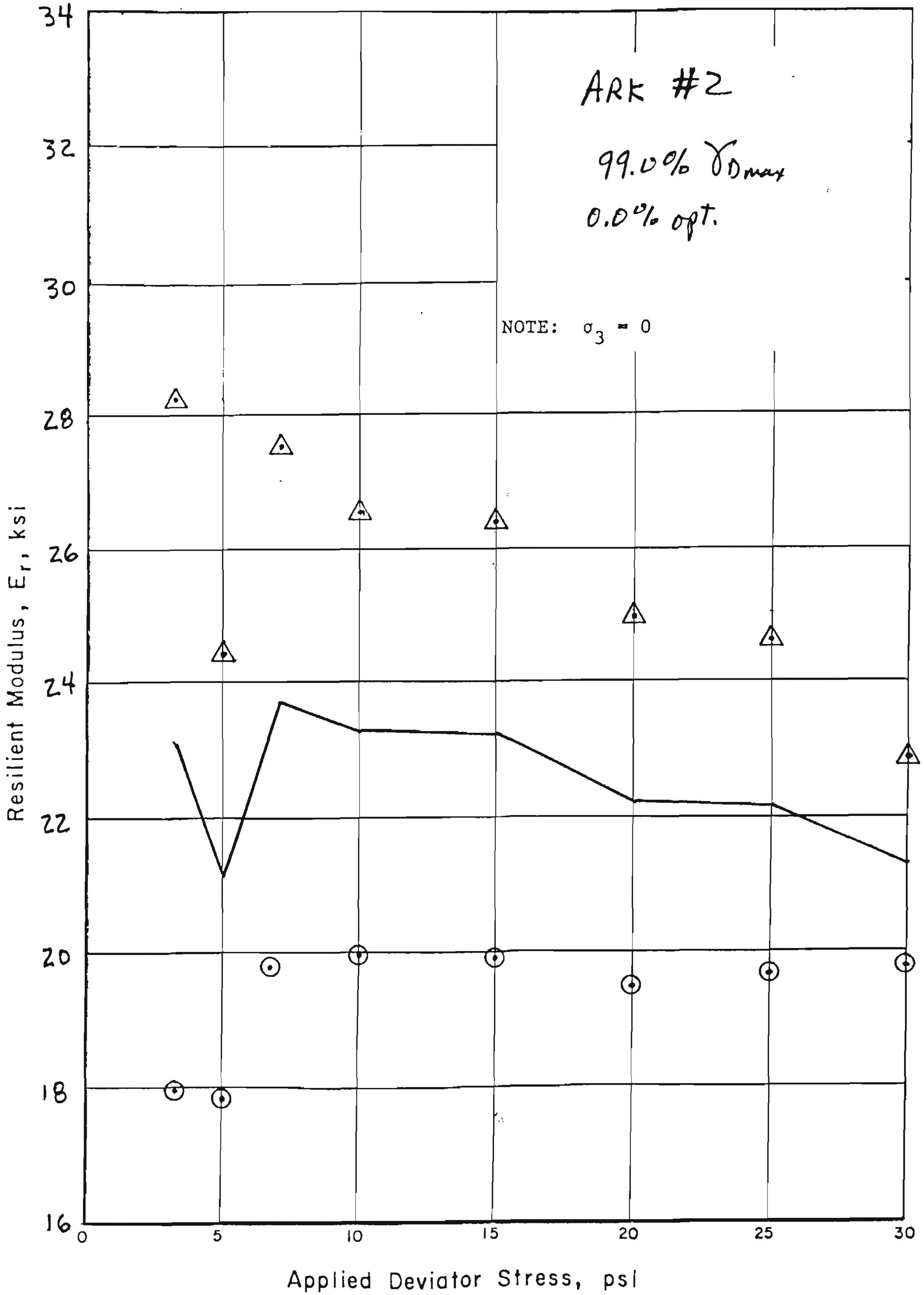
FIGURE 2. SCHEMATIC OF RESILIENCE TEST APPARATUS


ARK #1
92.4% γ Dmax
+0.05 opt
NOTE: σ3 = 0
Right Sample
AVERAGE
Left Sample
Resilient Modulus, Er, ksi
Applied Deviator Stress, psi

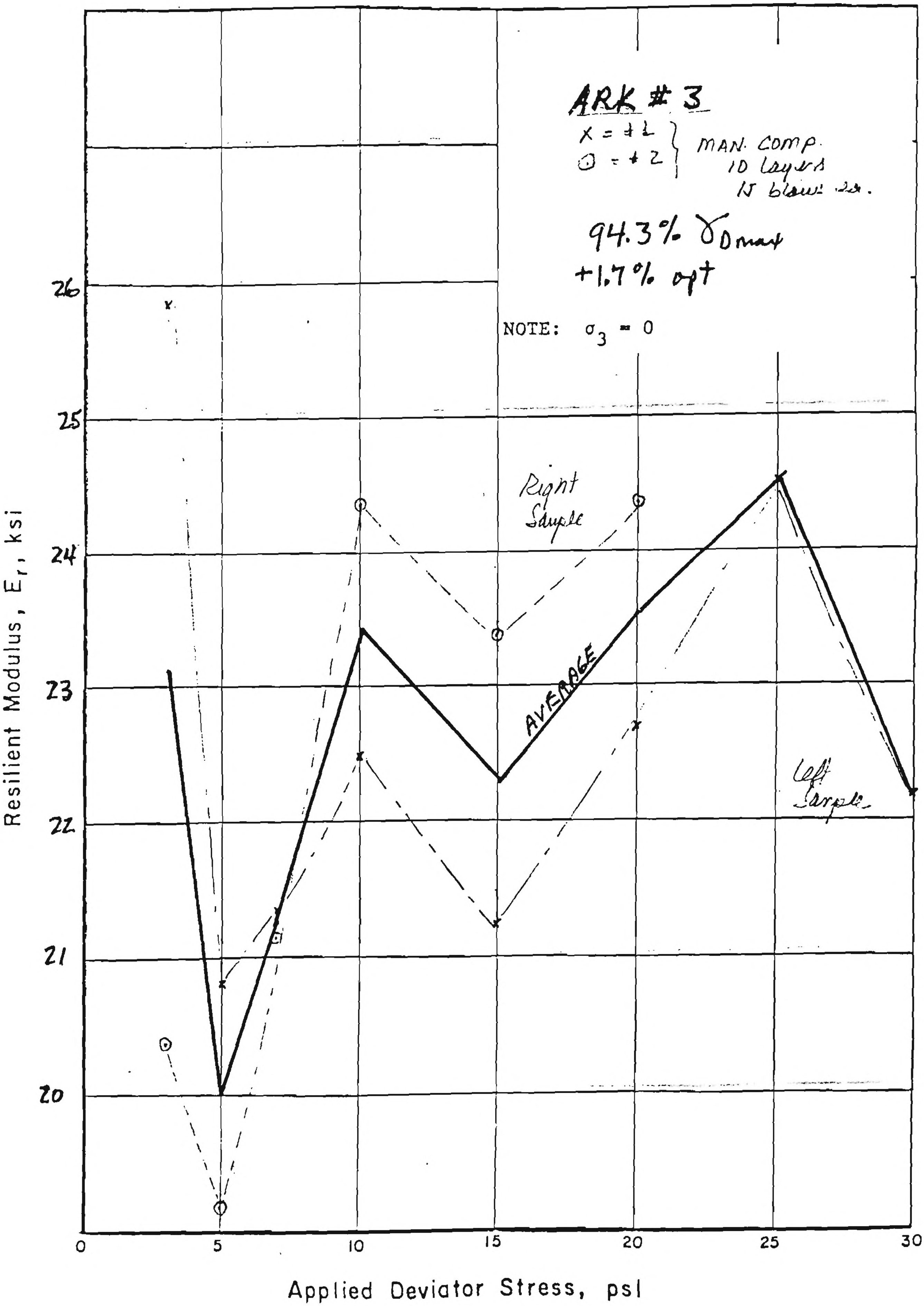

ARK #1
92.4% $\gamma_{D\max}$
+2.2% opt.
NOTE: $\sigma_3 = 0$
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
34
32
30
28
26
24
22
20
18
16
0
5
10
15
20
25
30

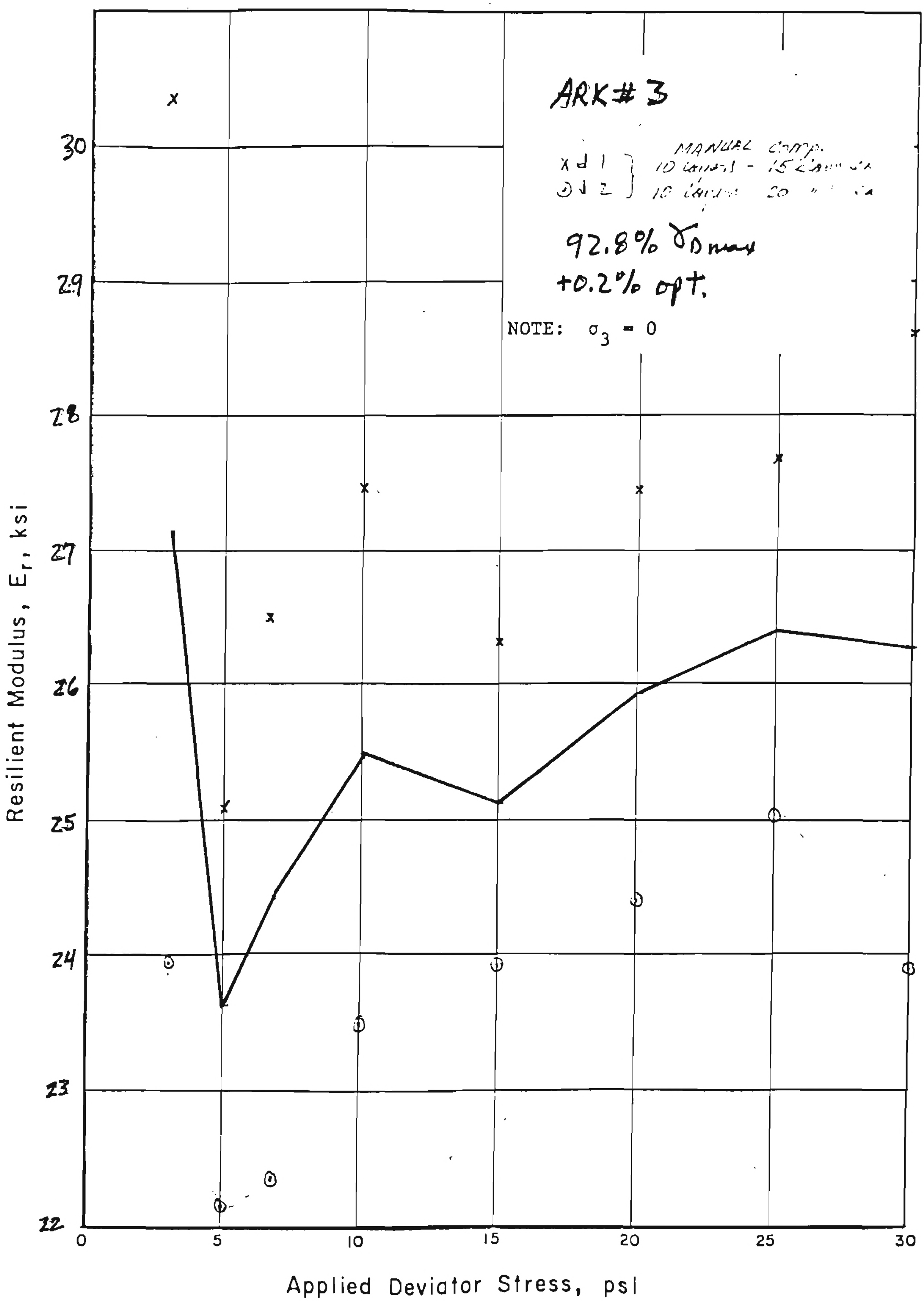


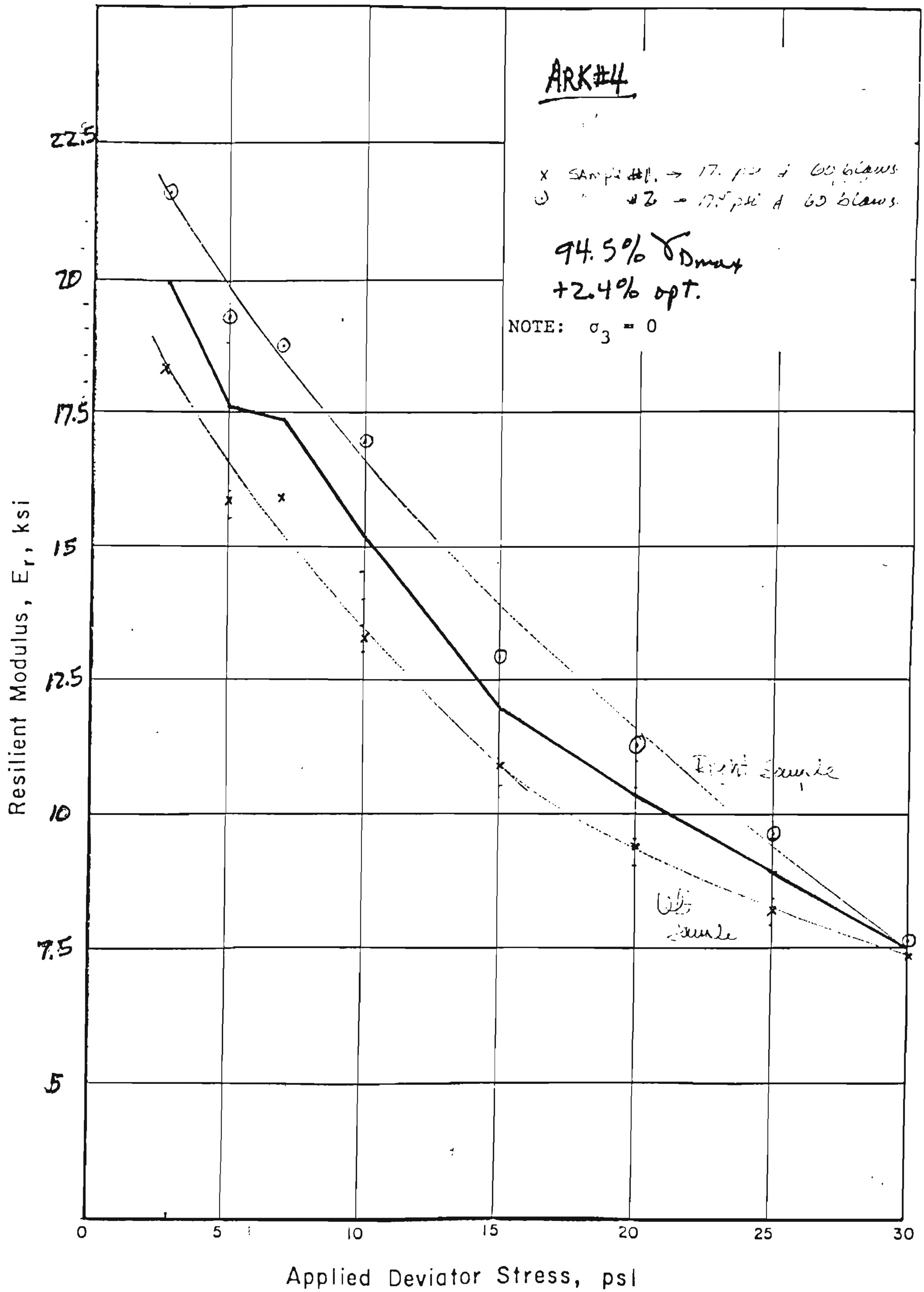
ARK #2
94.7% $\gamma_{D max}$
+1.6% opt
NOTE: $\sigma_3 = 0$
27.3
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
24
22
20
18
16
14
12
10
8
6
0
5
10
15
20
25
30

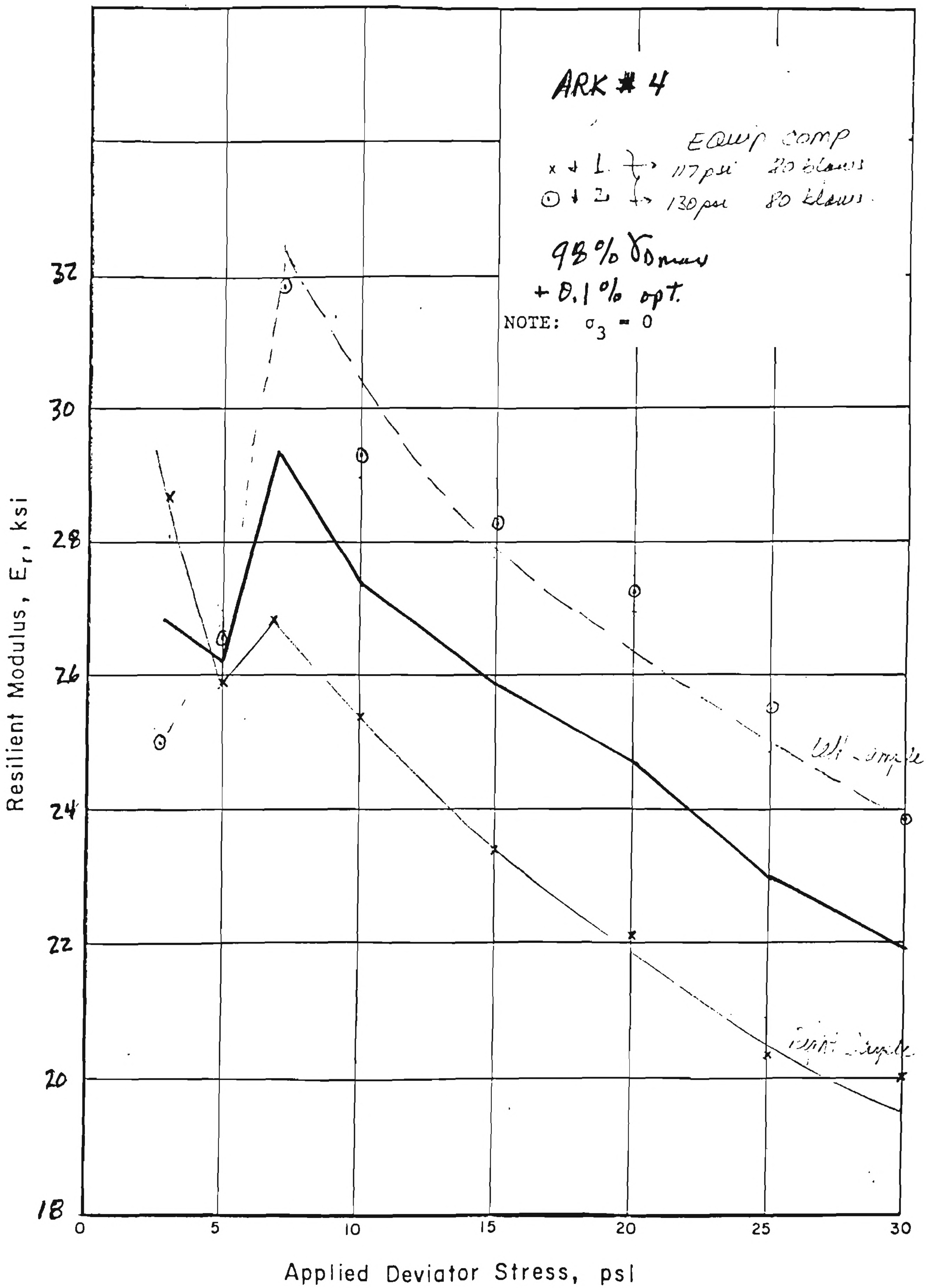


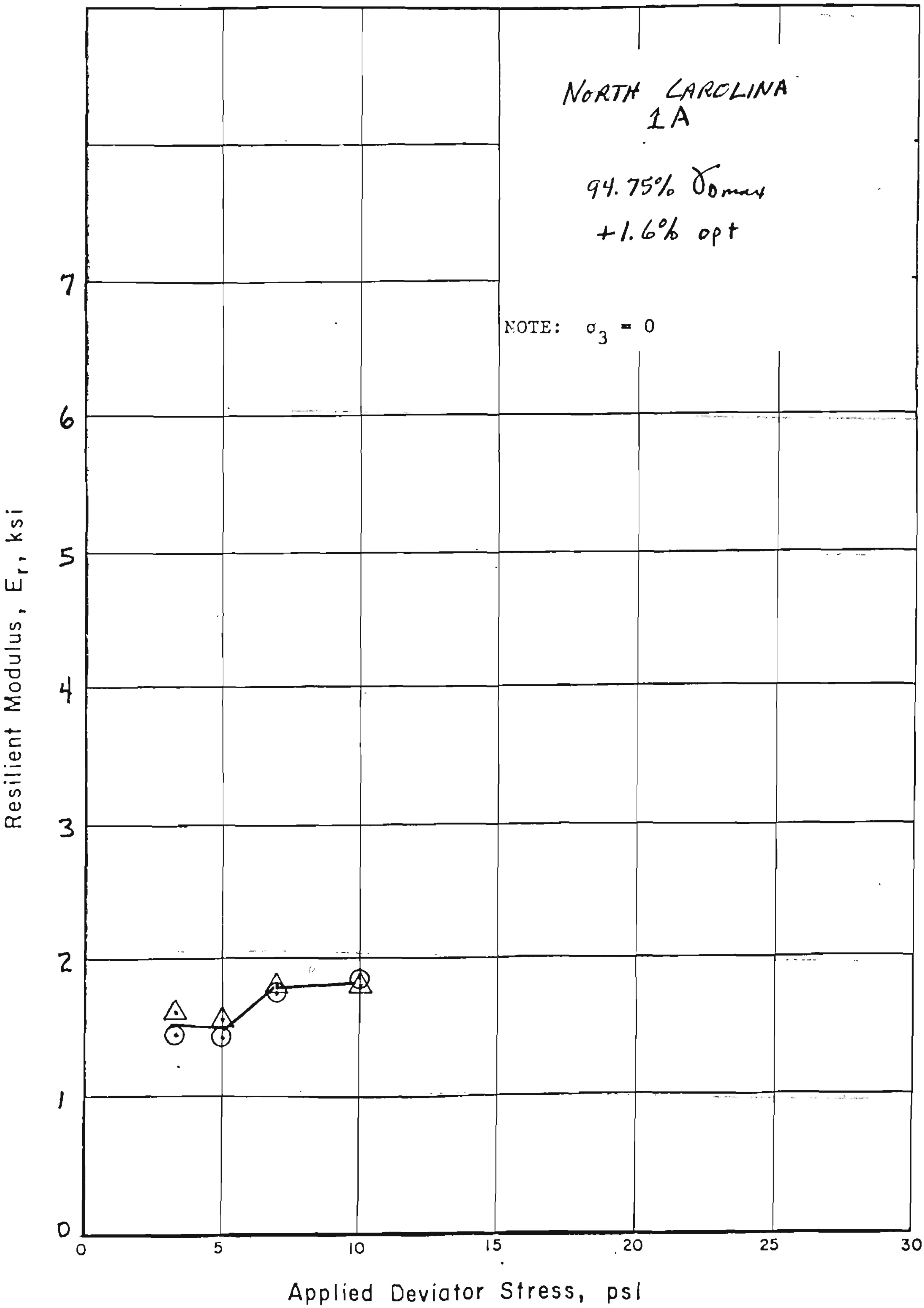
ARK #2
99.0% $\gamma_{D max}$
0.0% opt.
NOTE: σ_3 = 0
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
34
32
30
28
26
24
22
20
18
16
0
5
10
15
20
25
30

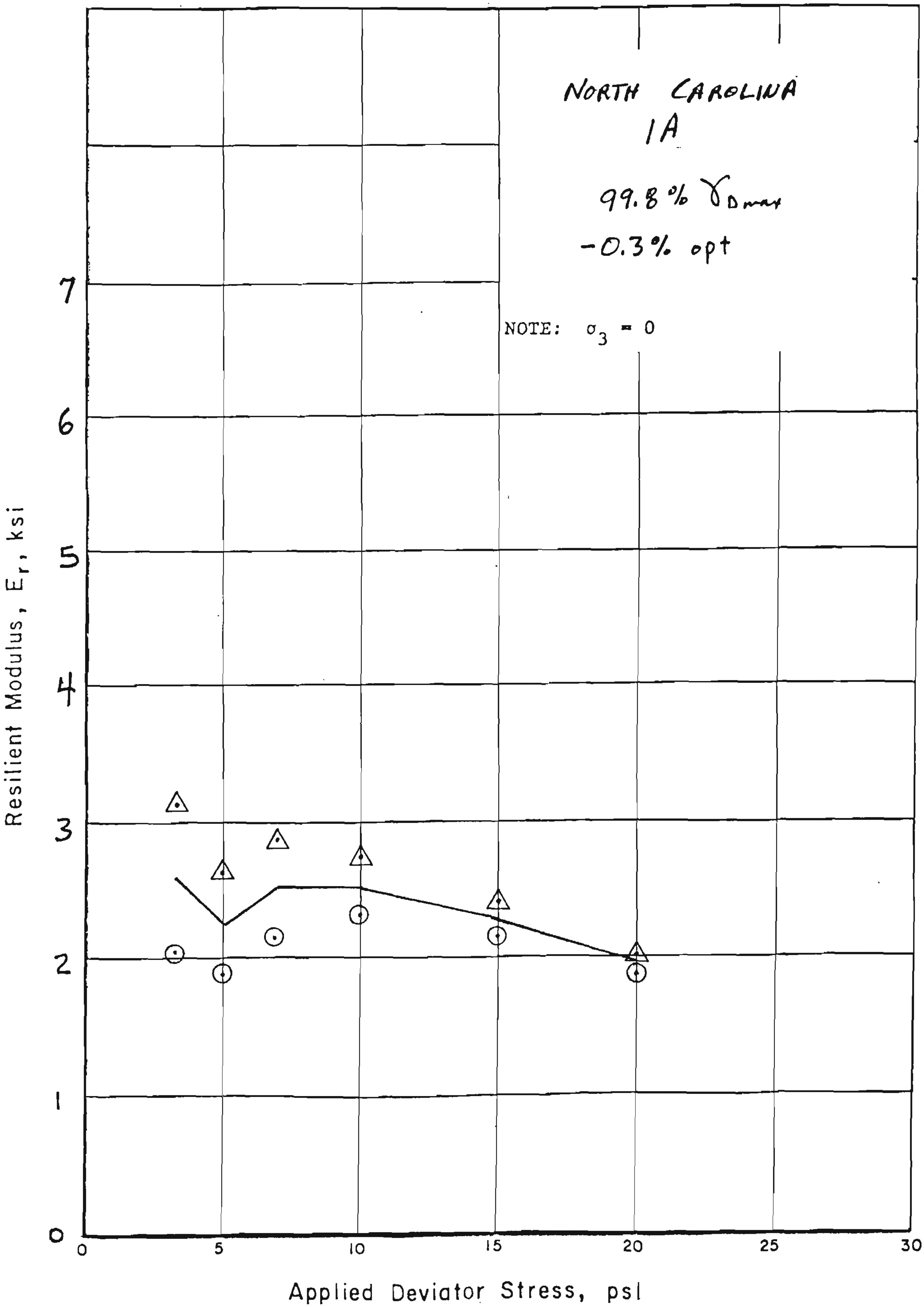

ARK # 3
X = #1
⊙ = #2
MAN. COMP.
10 layers
15 blows ea.
94.3% $\gamma_{D max}$
+1.7% opt
NOTE: σ_3 = 0
Right Sample
Left Sample
AVERAGE
Resilient Modulus, E_r, ksi
26
25
24
23
22
21
20
Applied Deviator Stress, psi
0
5
10
15
20
25
30

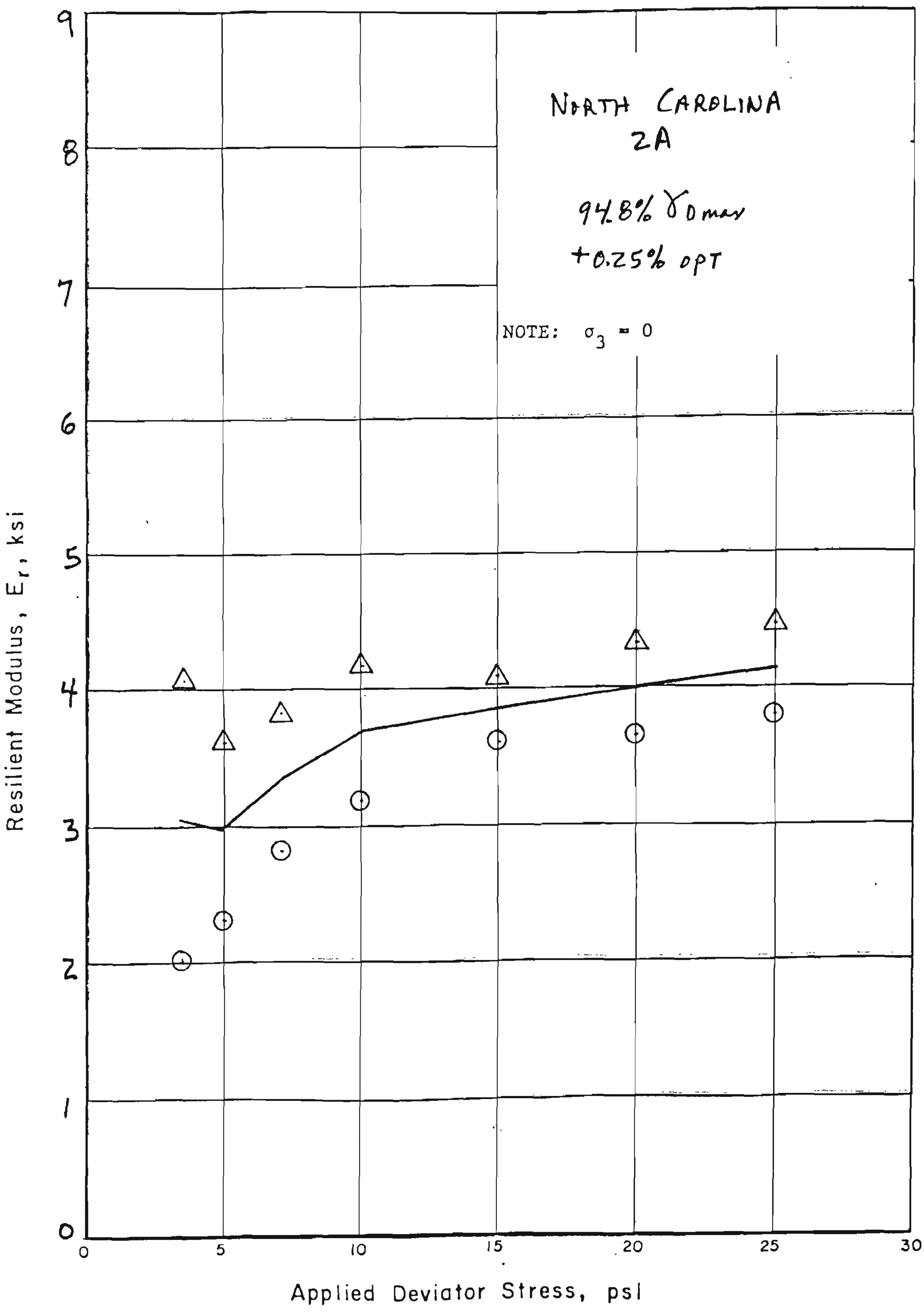

ARK # 3
MANUAL Comp.
NOTE: σ_3 = 0
92.8% $\gamma_{D\,max}$
+0.2% opt.
30
29
28
27
26
25
24
23
22
0
5
10
15
20
25
30
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi


ARK#4
x SAmple #1 → 17. psi @ 60 blows
⊙ " #2 → 17.5 psi @ 60 blows
94.5% γDmax
+2.4% opt.
NOTE: σ3 = 0
Right Sample
Left Sample
Resilient Modulus, Er, ksi
Applied Deviator Stress, psi
22.5
20
17.5
15
12.5
10
7.5
5
0
5
10
15
20
25
30

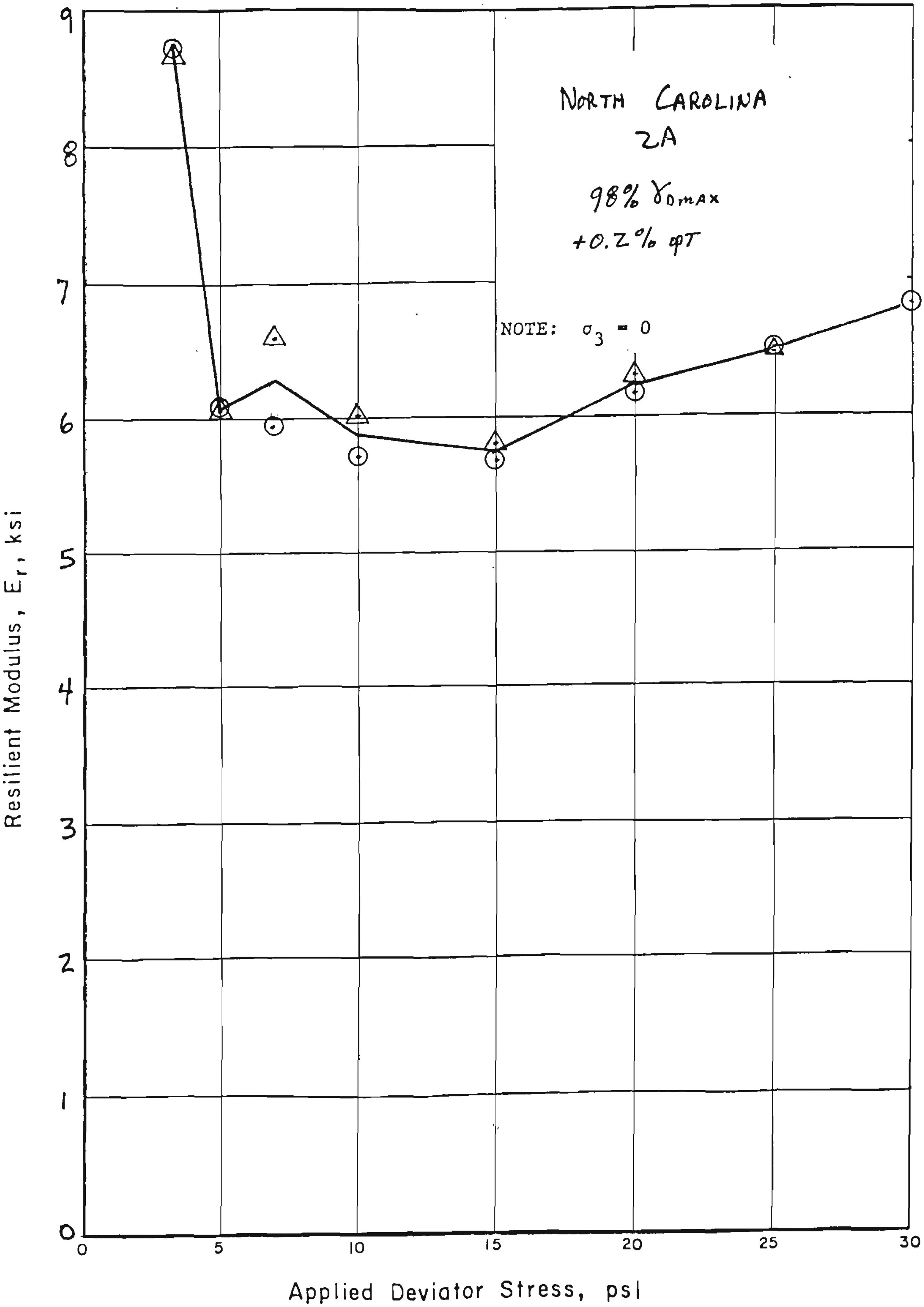

ARK # 4
EQUIP COMP
x + 1 → 117 psi 20 blows
⊙ + 2 → 130 psi 80 blows
98% $\gamma_{D\max}$
+ 0.1% opt.
NOTE: $\sigma_3 = 0$
32
30
28
26
24
22
20
18
0
5
10
15
20
25
30
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi

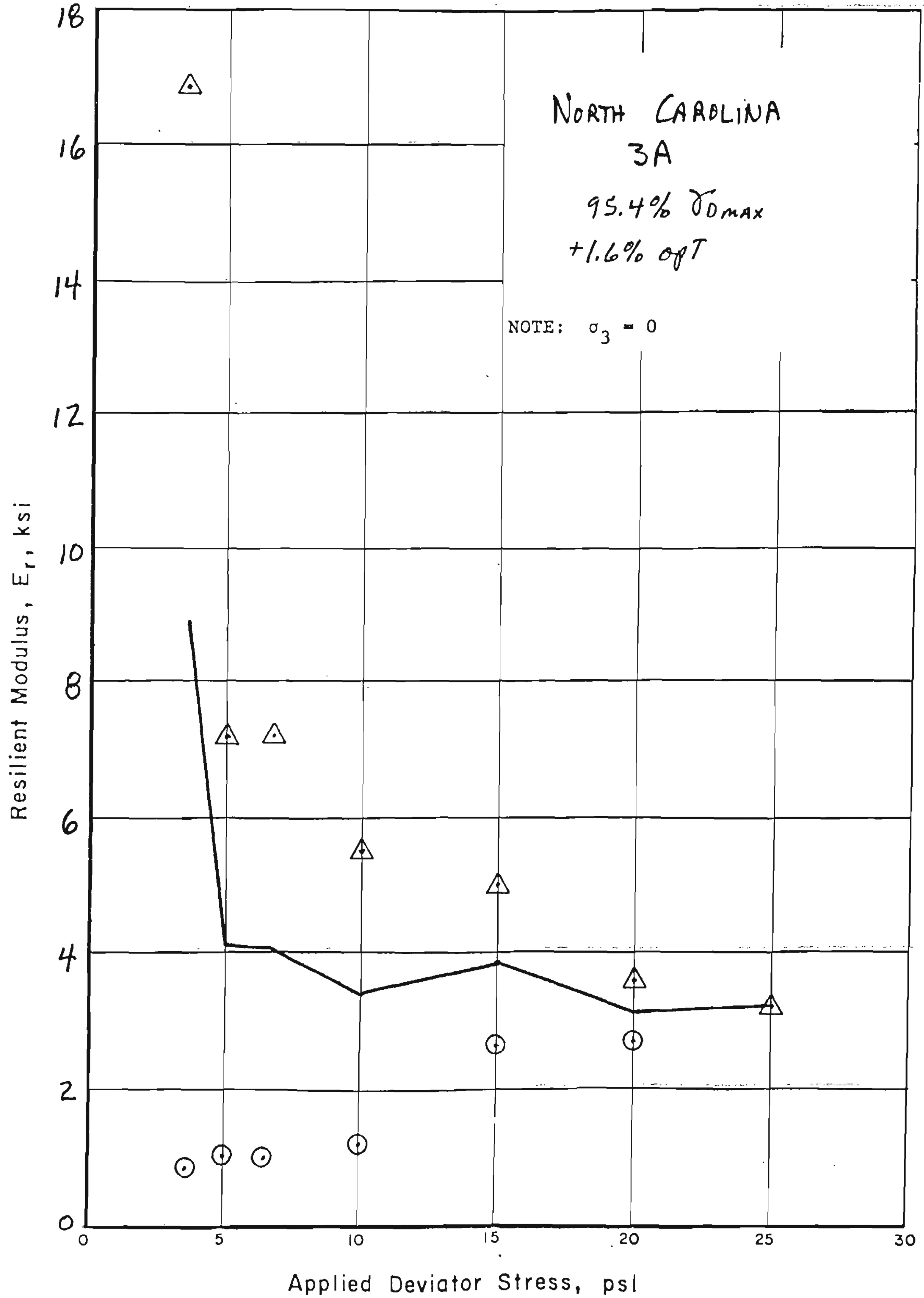

NORTH CAROLINA
1A
94.75% $\gamma_{D\,max}$
+1.6% opt
NOTE: $\sigma_3 = 0$
Resilient Modulus, E_r, ksi
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30
Applied Deviator Stress, psi

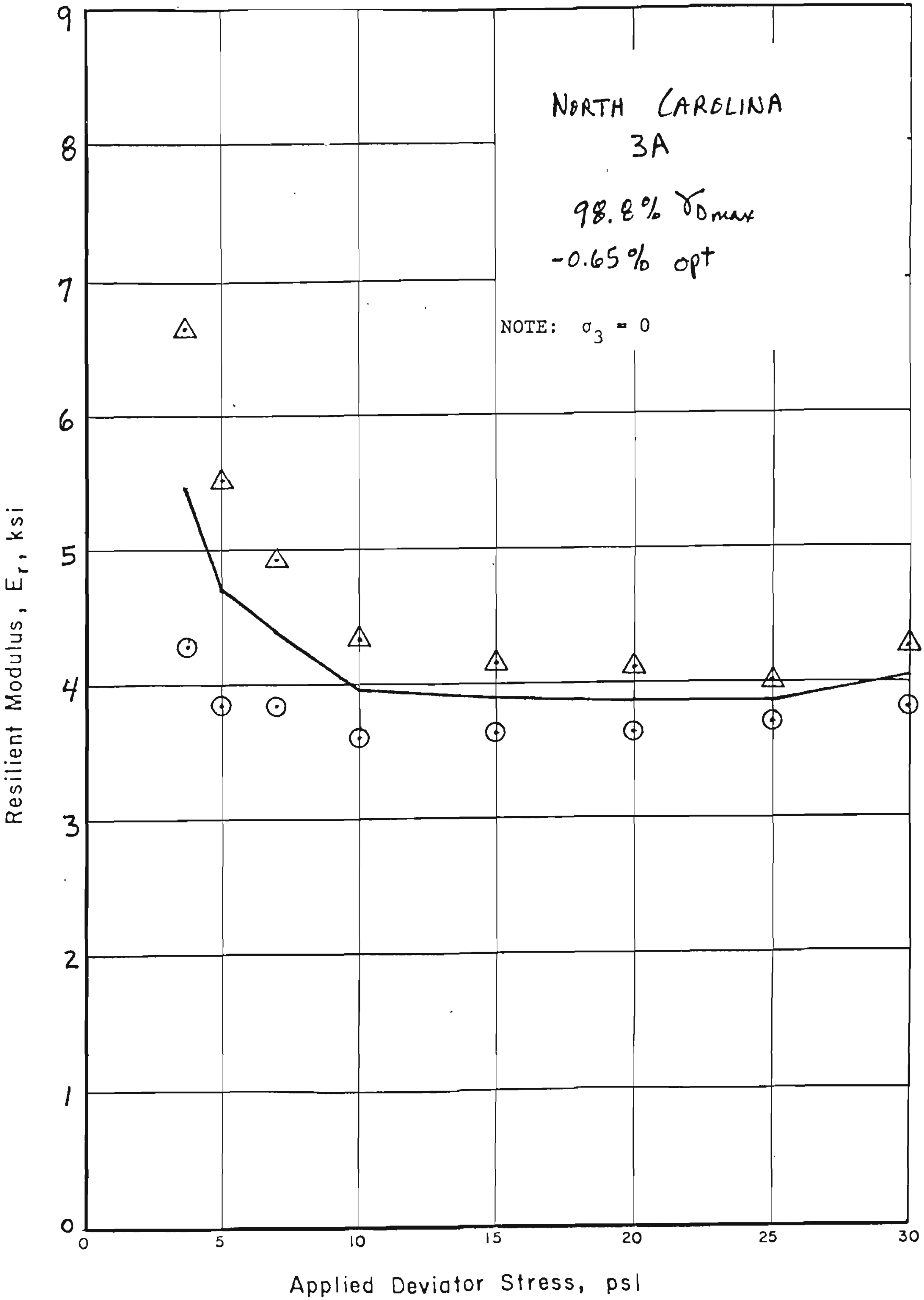

NORTH CAROLINA
1A
99.8% $\gamma_{D\,max}$
-0.3% opt
NOTE: σ_3 = 0
Resilient Modulus, E_r, ksi
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30
Applied Deviator Stress, psi

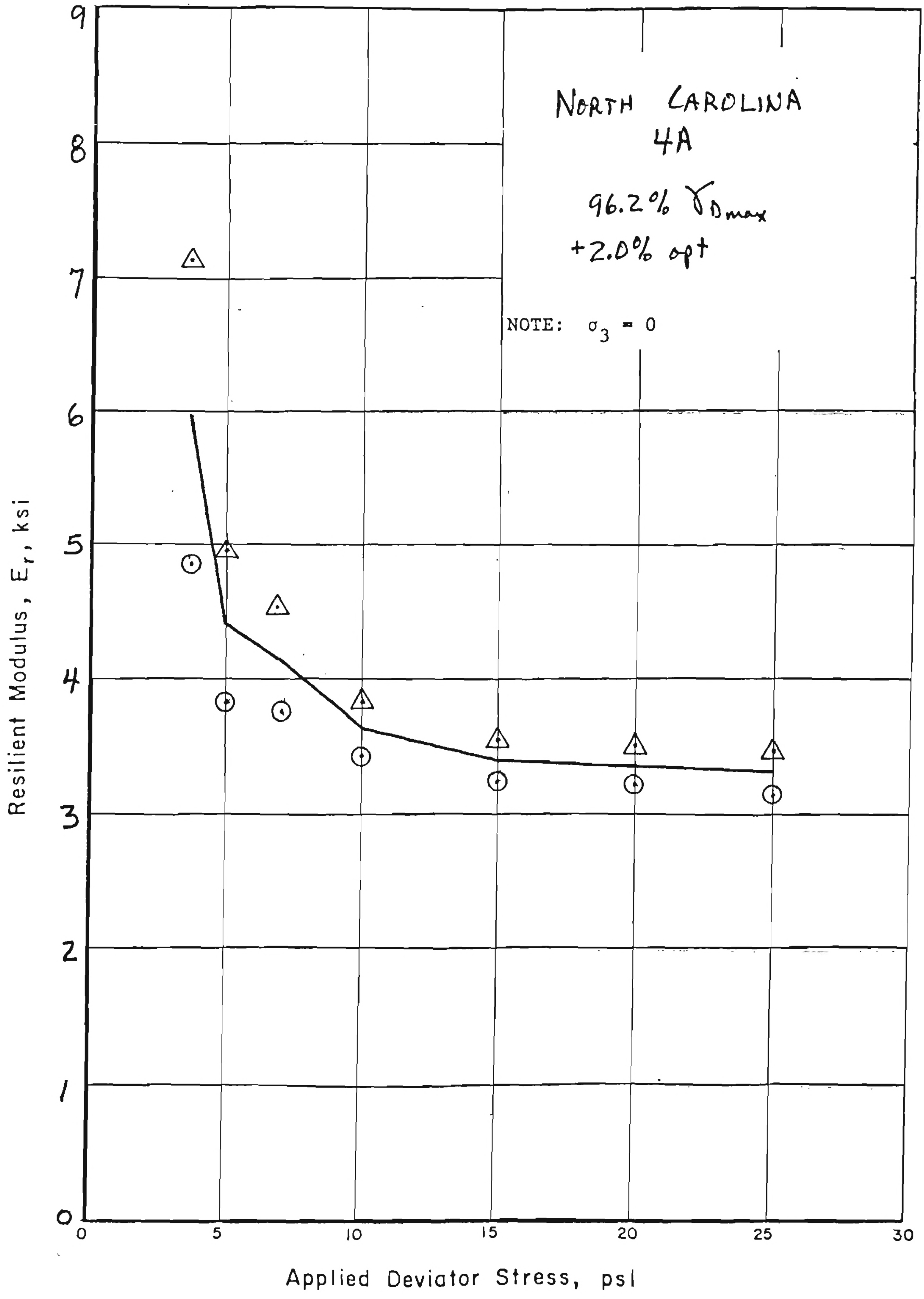


NORTH CAROLINA
2A
94.8% $\gamma_{D\,max}$
+0.25% OPT
NOTE: $\sigma_3 = 0$
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30

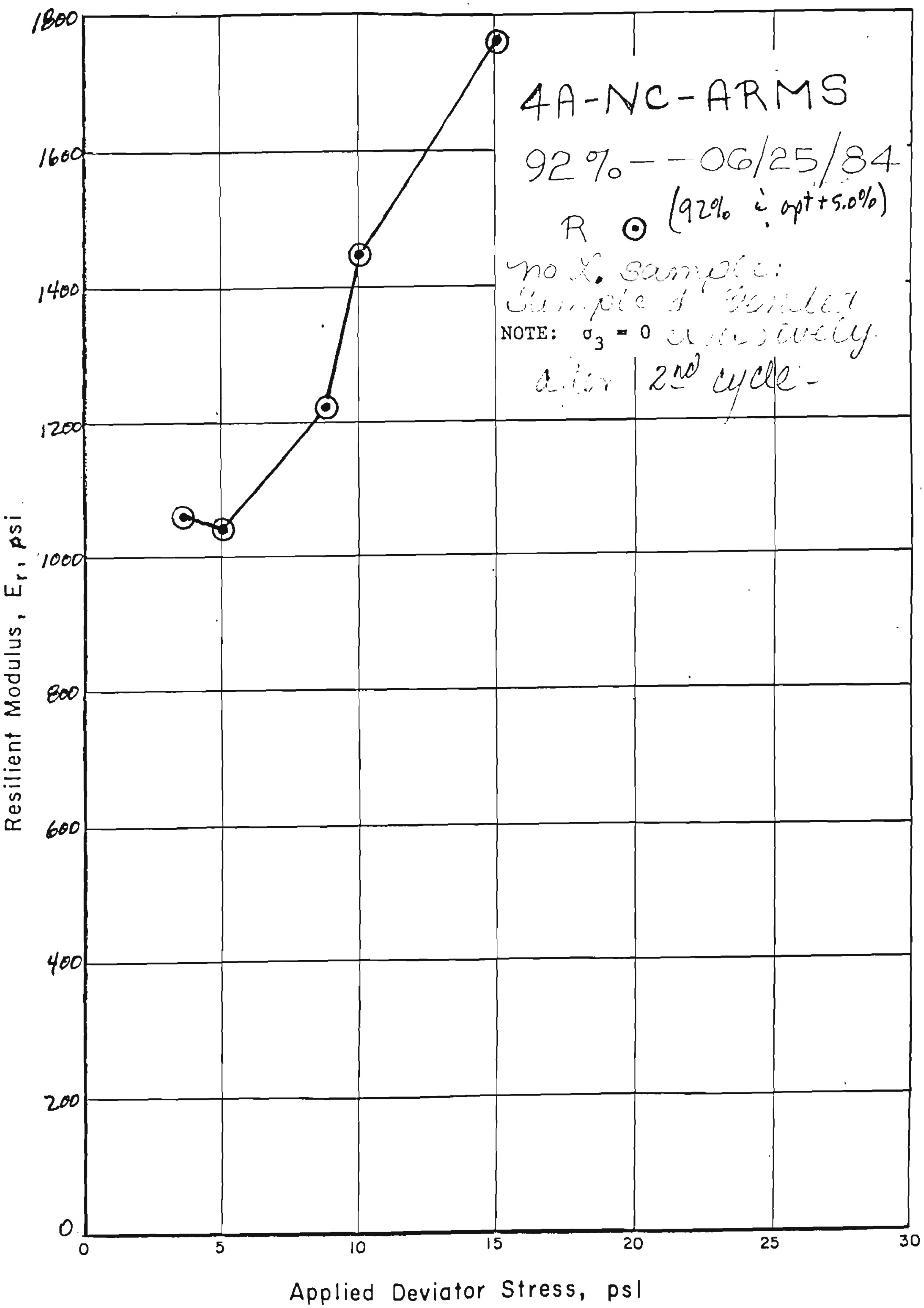

NORTH CAROLINA
2A
98% γDmax
+0.2% φT
NOTE: σ3 = 0
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30
Resilient Modulus, Er, ksi
Applied Deviator Stress, psi


North Carolina
3A
95.4% $\gamma_{D max}$
+1.6% opT
NOTE: $\sigma_3 = 0$
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
0
2
4
6
8
10
12
14
16
18
0
5
10
15
20
25
30

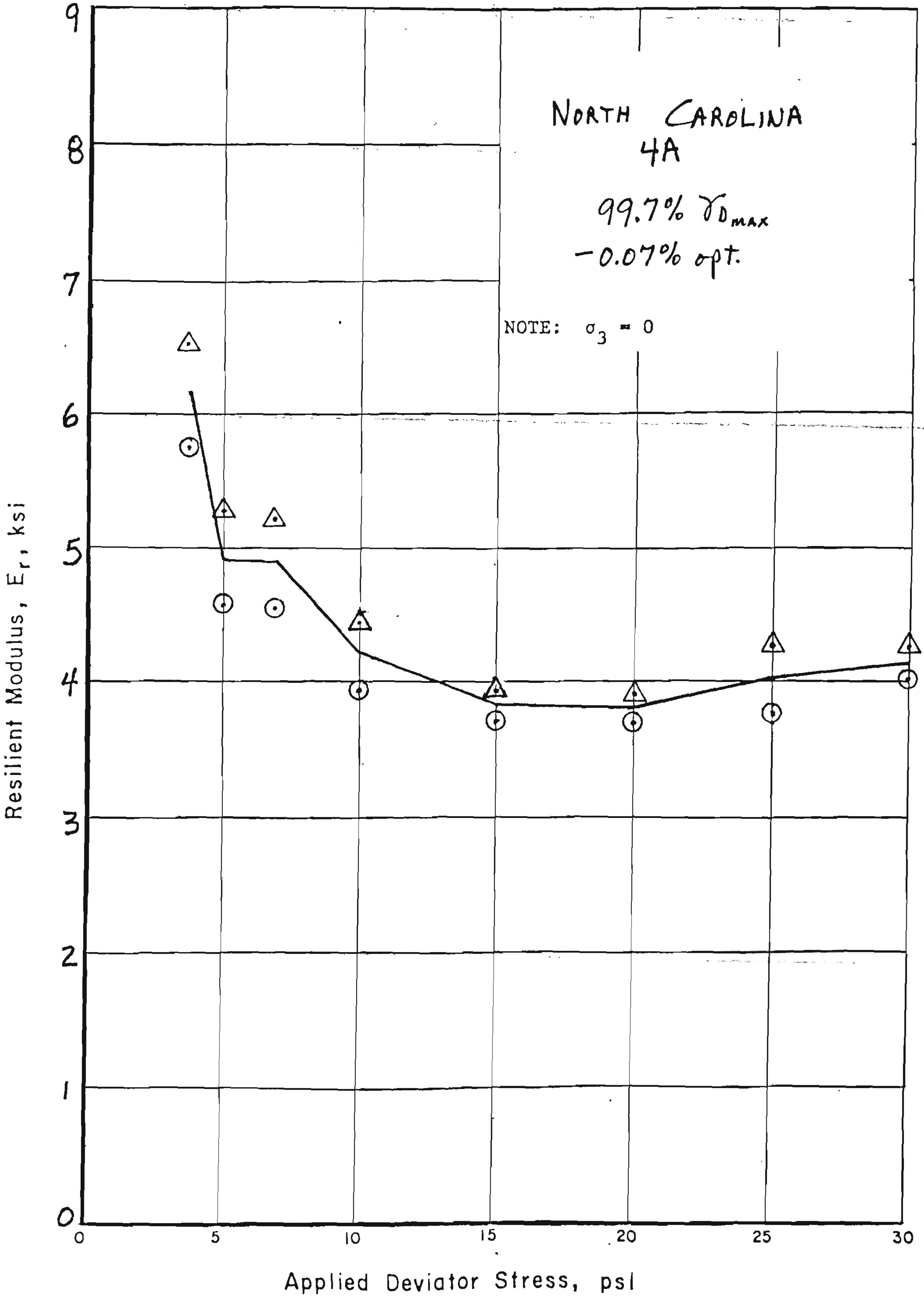

NORTH CAROLINA
3A
98.8% $\gamma_{D max}$
-0.65% opt
NOTE: $\sigma_3 = 0$
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30

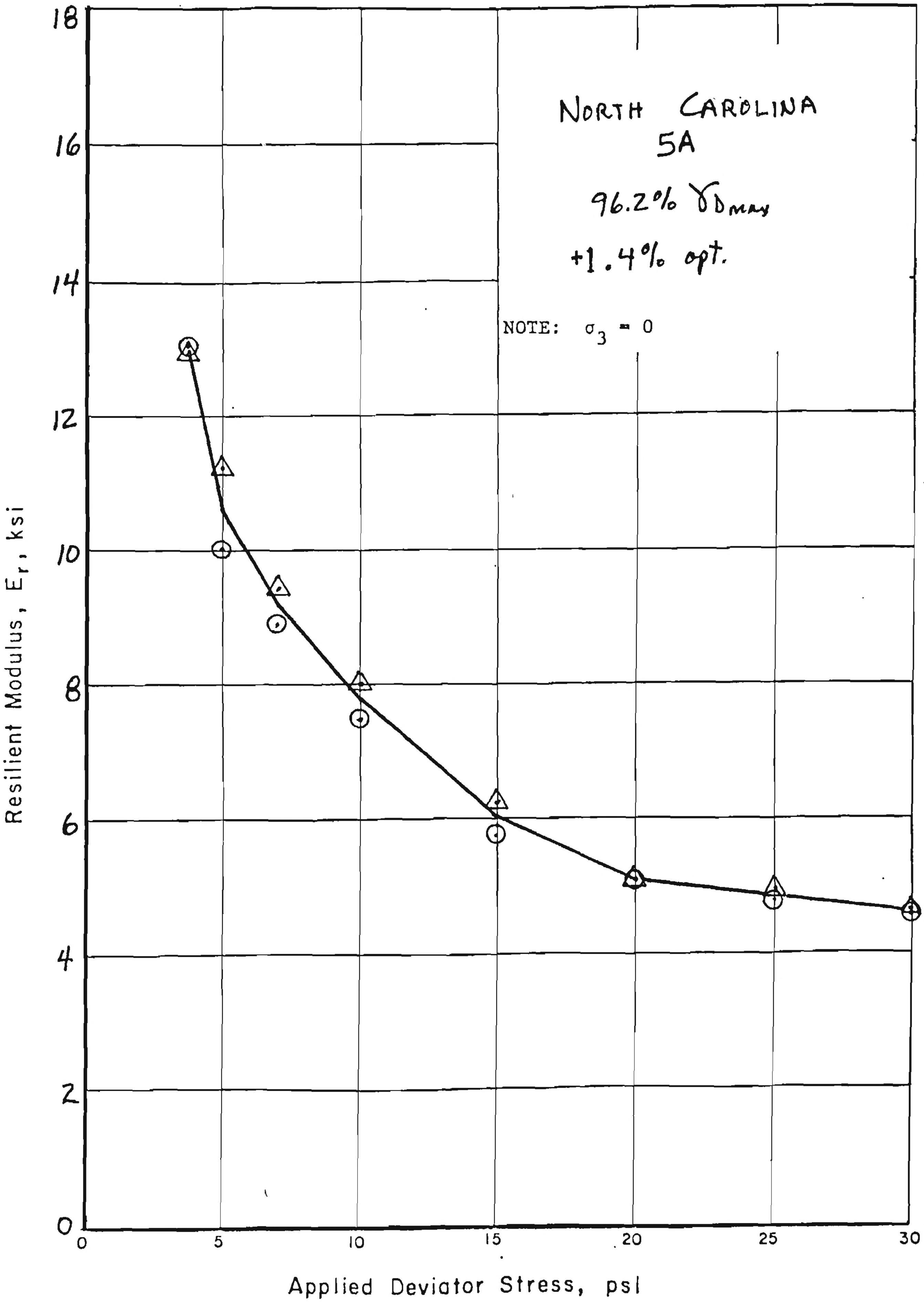


NORTH CAROLINA
4A
96.2% $\gamma_{D max}$
+2.0% opt
NOTE: σ_3 = 0
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30

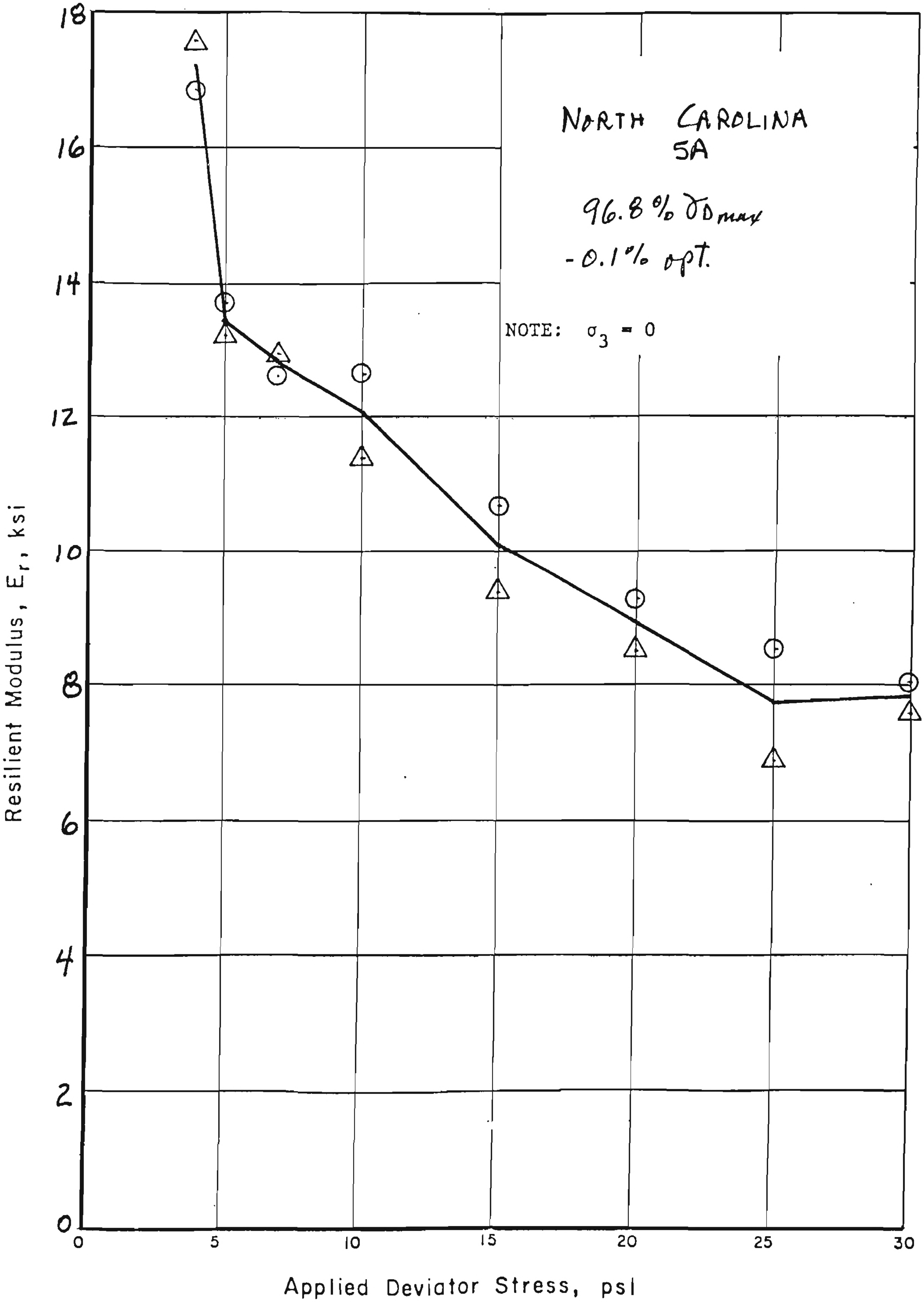


4A-NC-ARMS
92% -- 06/25/84
R (92% ; opt+5.0%)
NOTE: σ3 = 0
2nd cycle
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
Resilient Modulus, Er, psi
Applied Deviator Stress, psi

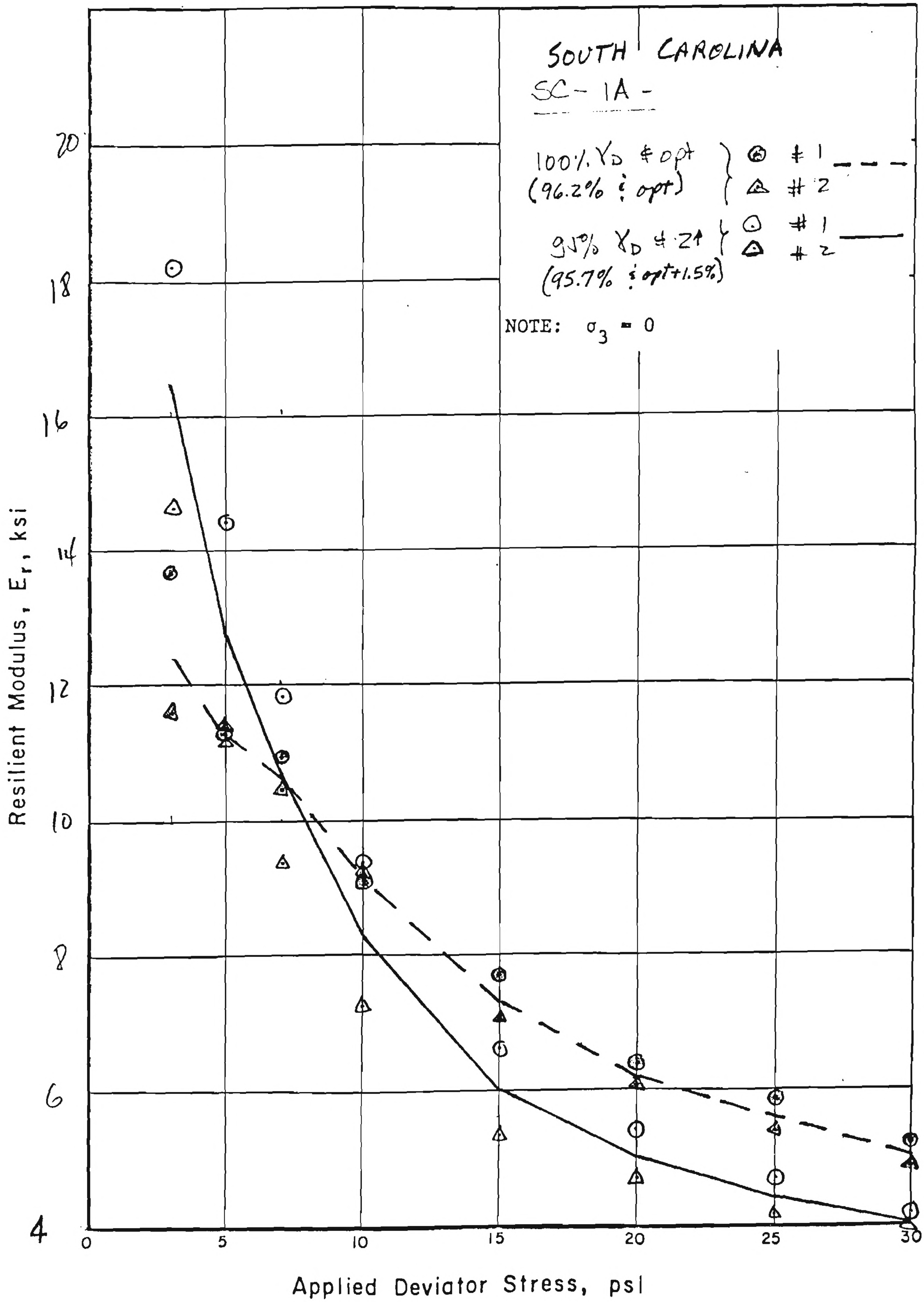

North Carolina
4A
99.7% $\gamma_{D_{max}}$
−0.07% opt.
NOTE: $\sigma_3 = 0$
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30

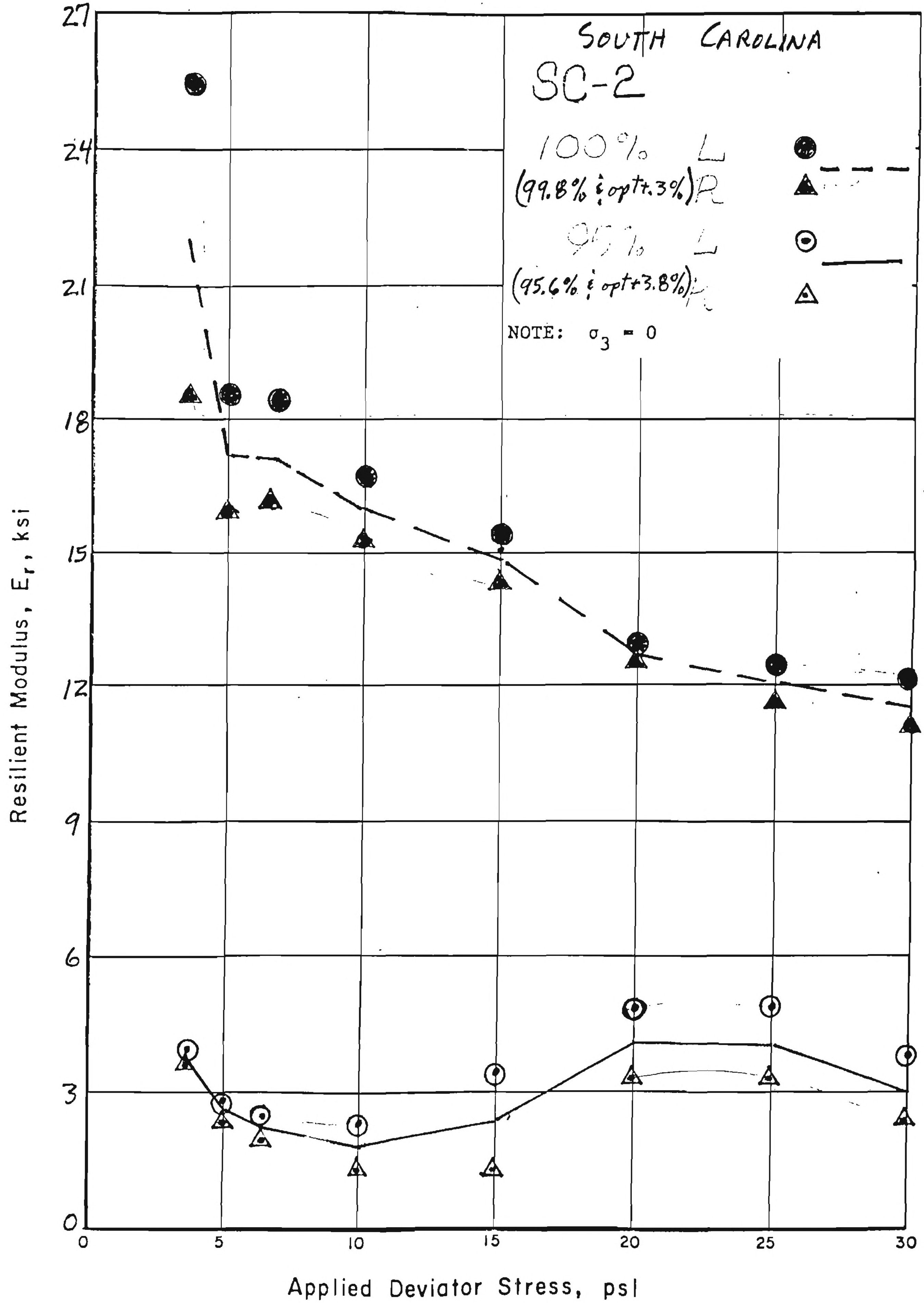


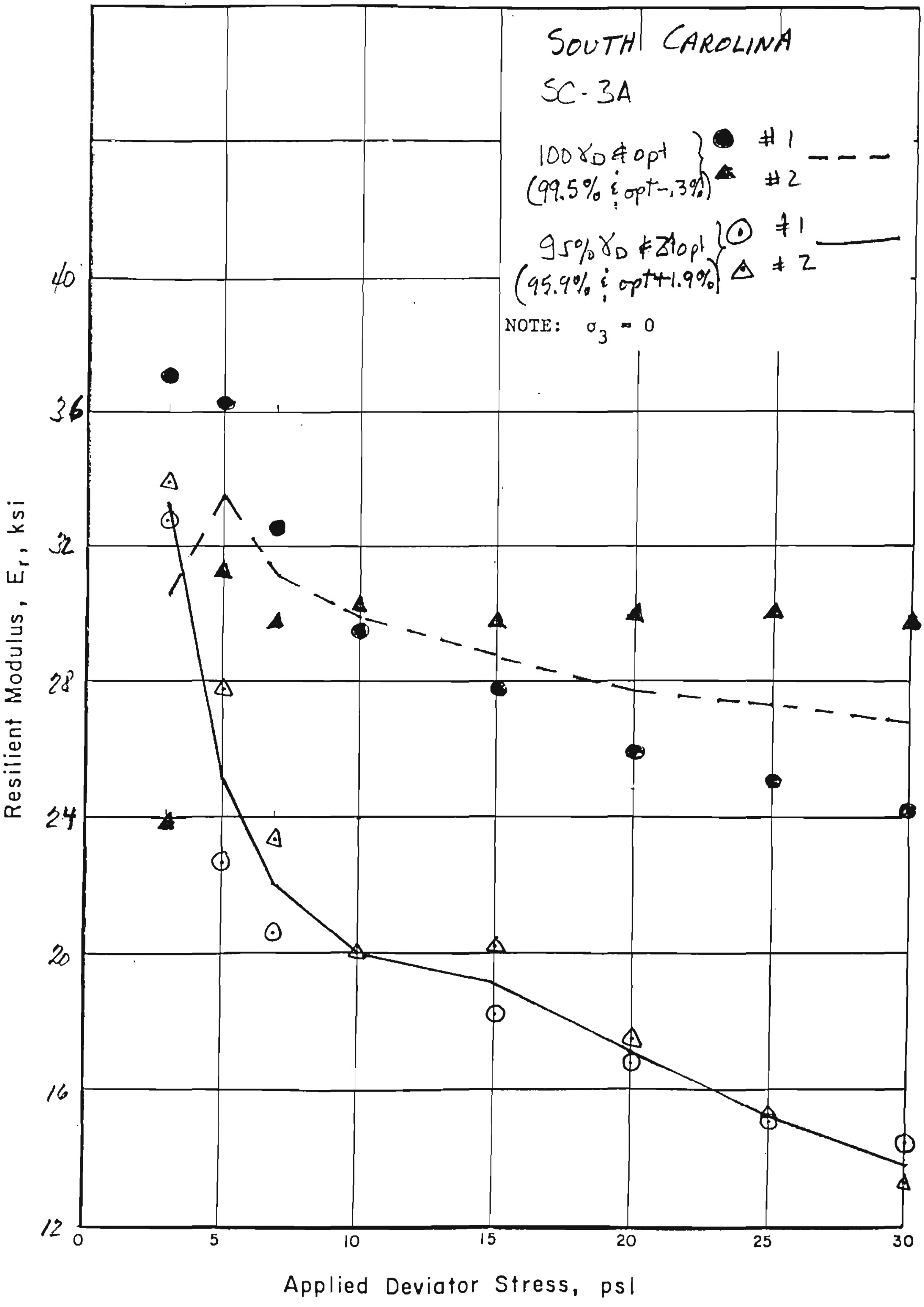
North Carolina
5A
96.2% γD max
+1.4% opt.
NOTE: σ3 = 0
Resilient Modulus, Er, ksi
Applied Deviator Stress, psi
0
2
4
6
8
10
12
14
16
18
5
10
15
20
25
30

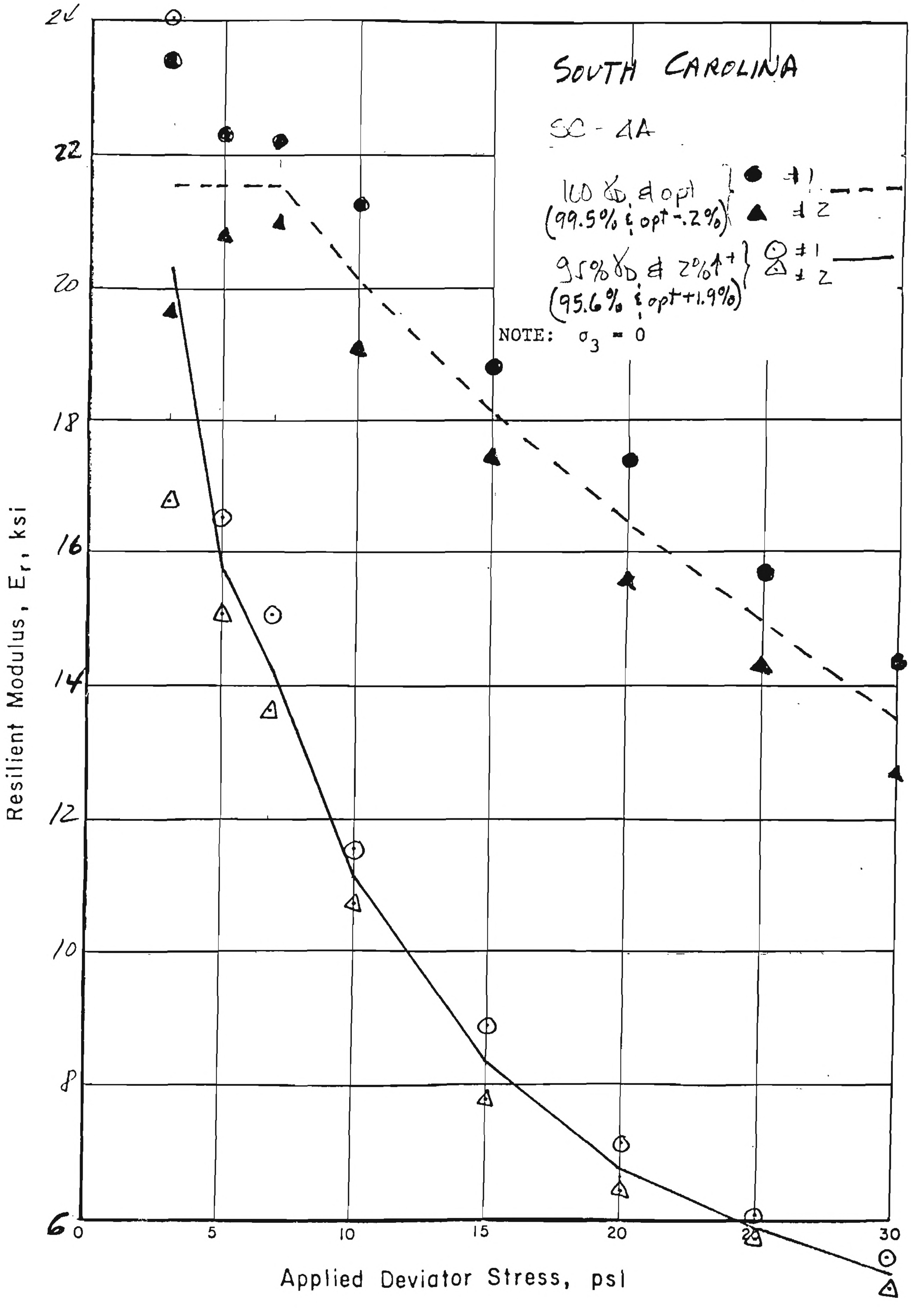


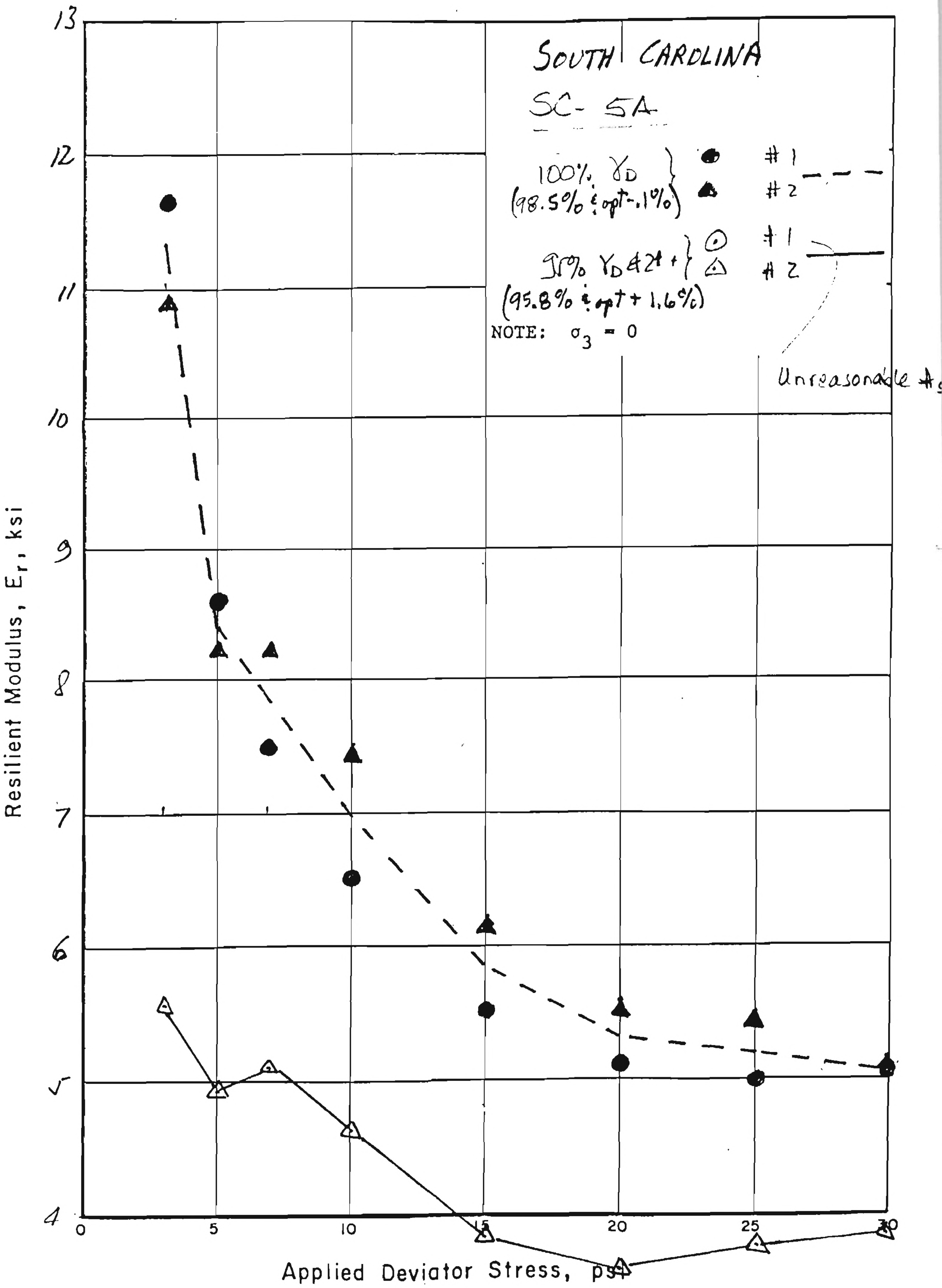
NORTH CAROLINA
5A
96.8 % γD max
-0.1% opt.
NOTE: σ3 = 0
Resilient Modulus, Er, ksi
Applied Deviator Stress, psi
0
2
4
6
8
10
12
14
16
18
0
5
10
15
20
25
30


SOUTH CAROLINA
SC - 1A -
100% γD & opt (96.2% & opt) # 1 # 2
95% γD & Z↑ (95.7% & opt+1.5%) # 1 # 2
NOTE: σ3 = 0
Resilient Modulus, Er, ksi
Applied Deviator Stress, psi
4
6
8
10
12
14
16
18
20
0
5
10
15
20
25
30

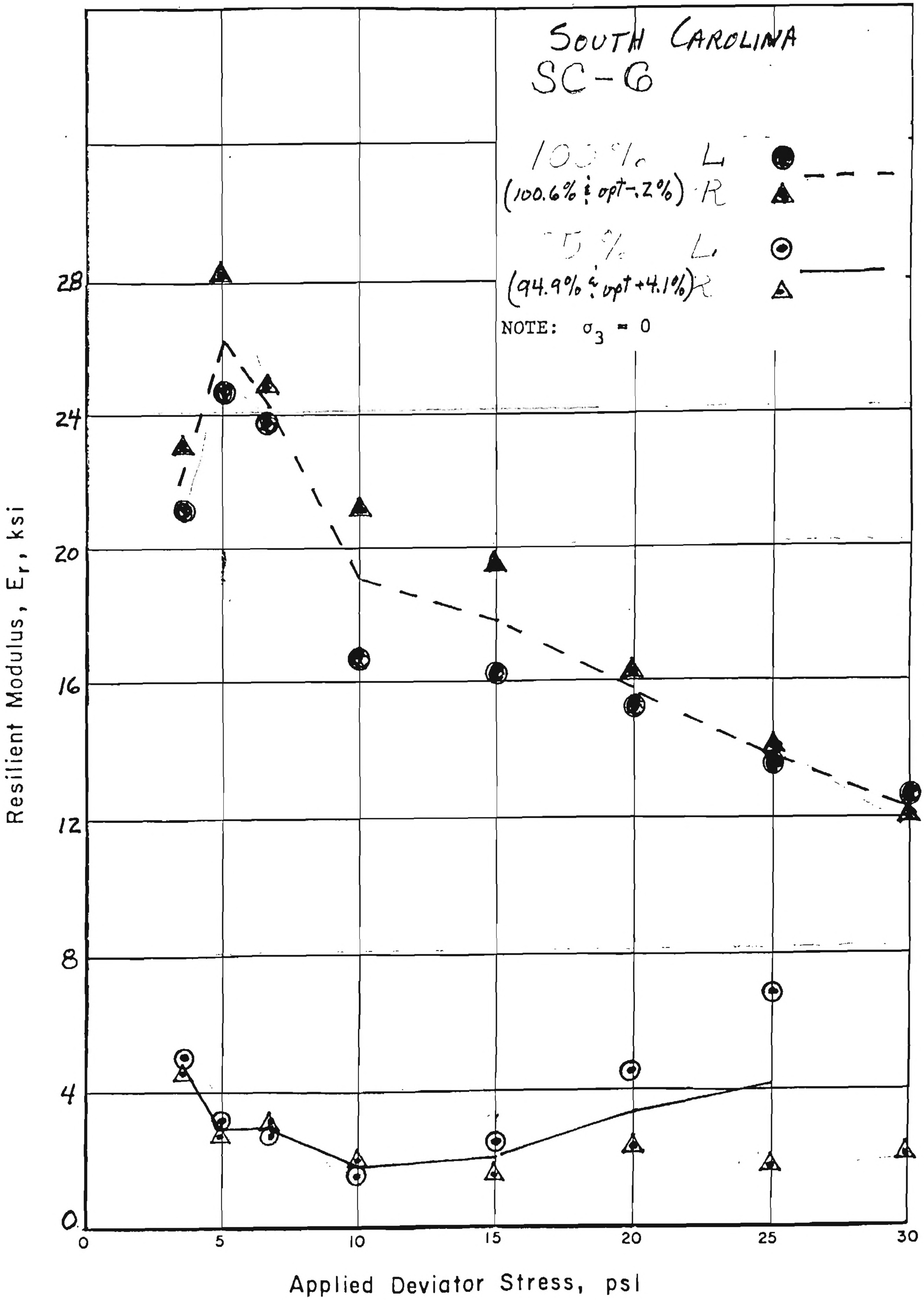

SOUTH CAROLINA
SC-2
100% L
(99.8% & opt+.3%) R
95% L
(95.6% & opt+3.8%) R
NOTE: σ_3 = 0
Resilient Modulus, E_r, ksi
0
3
6
9
12
15
18
21
24
27
Applied Deviator Stress, psi
0
5
10
15
20
25
30

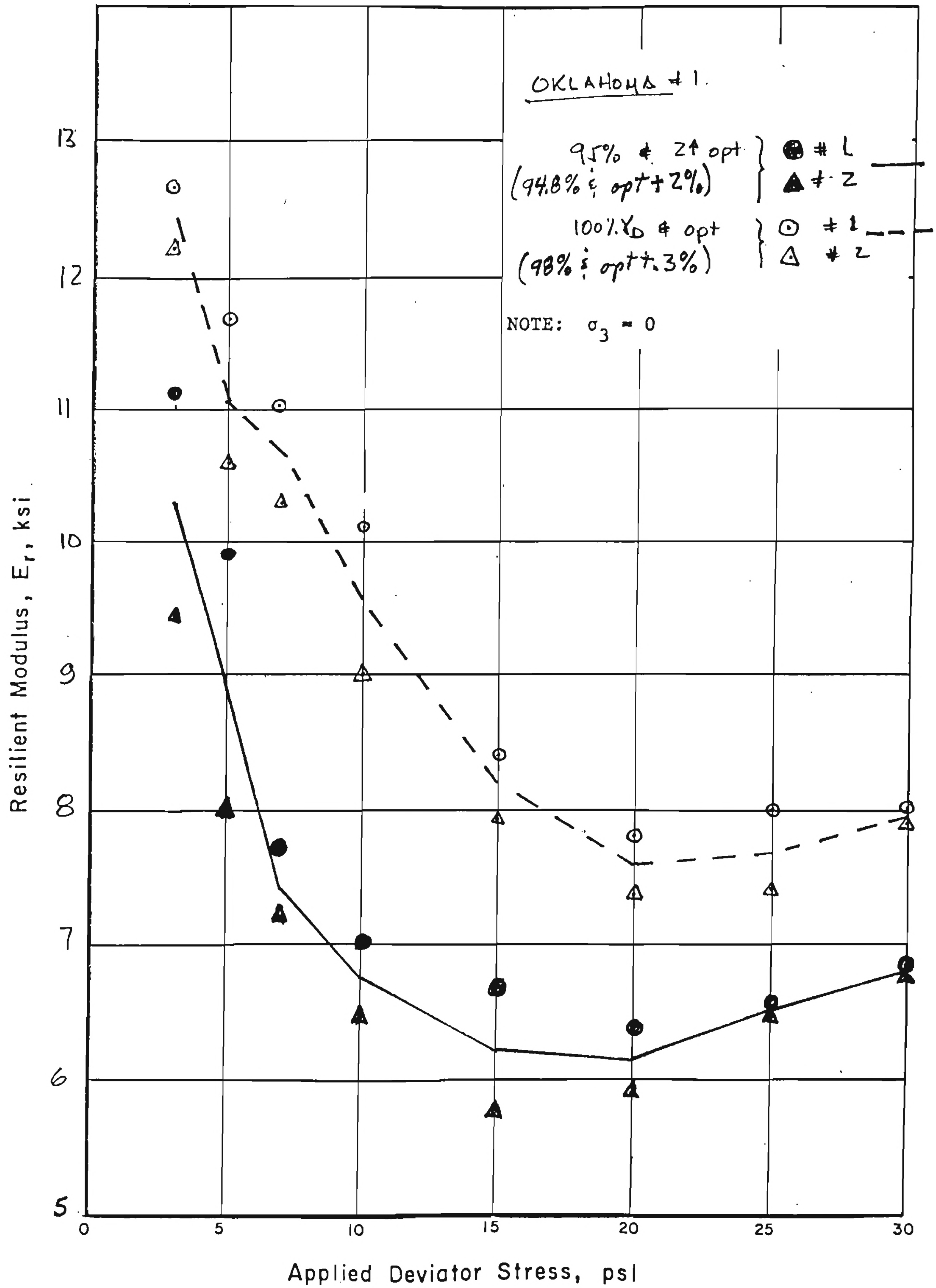

SOUTH CAROLINA
SC-3A
100 γ_D & opt (99.5% & opt-.3%) #1 #2
95% γ_D & 2% opt (95.9% & opt+1.9%) #1 #2
NOTE: $\sigma_3 = 0$
Resilient Modulus, E_r, ksi
12
16
20
24
28
32
36
40
0
5
10
15
20
25
30
Applied Deviator Stress, psi


SOUTH CAROLINA
SC - 4A
100% γD & opt (99.5% & opt -.2%) #1 #2
95% γD & 2% ↑+ (95.6% & opt +1.9%) #1 #2
NOTE: σ3 = 0
Resilient Modulus, Er, ksi
Applied Deviator Stress, psi
24
22
20
18
16
14
12
10
8
6
0
5
10
15
20
25
30

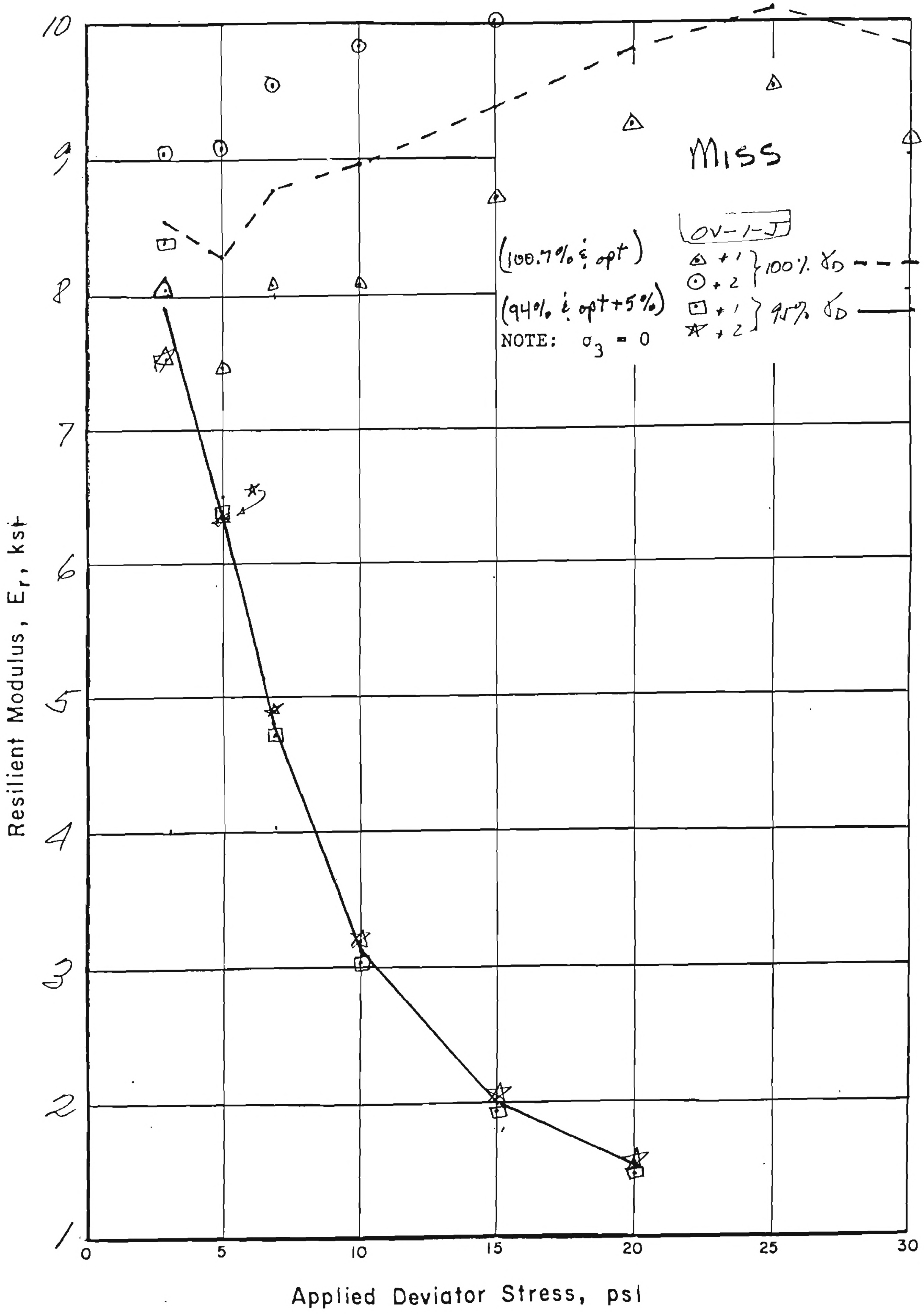


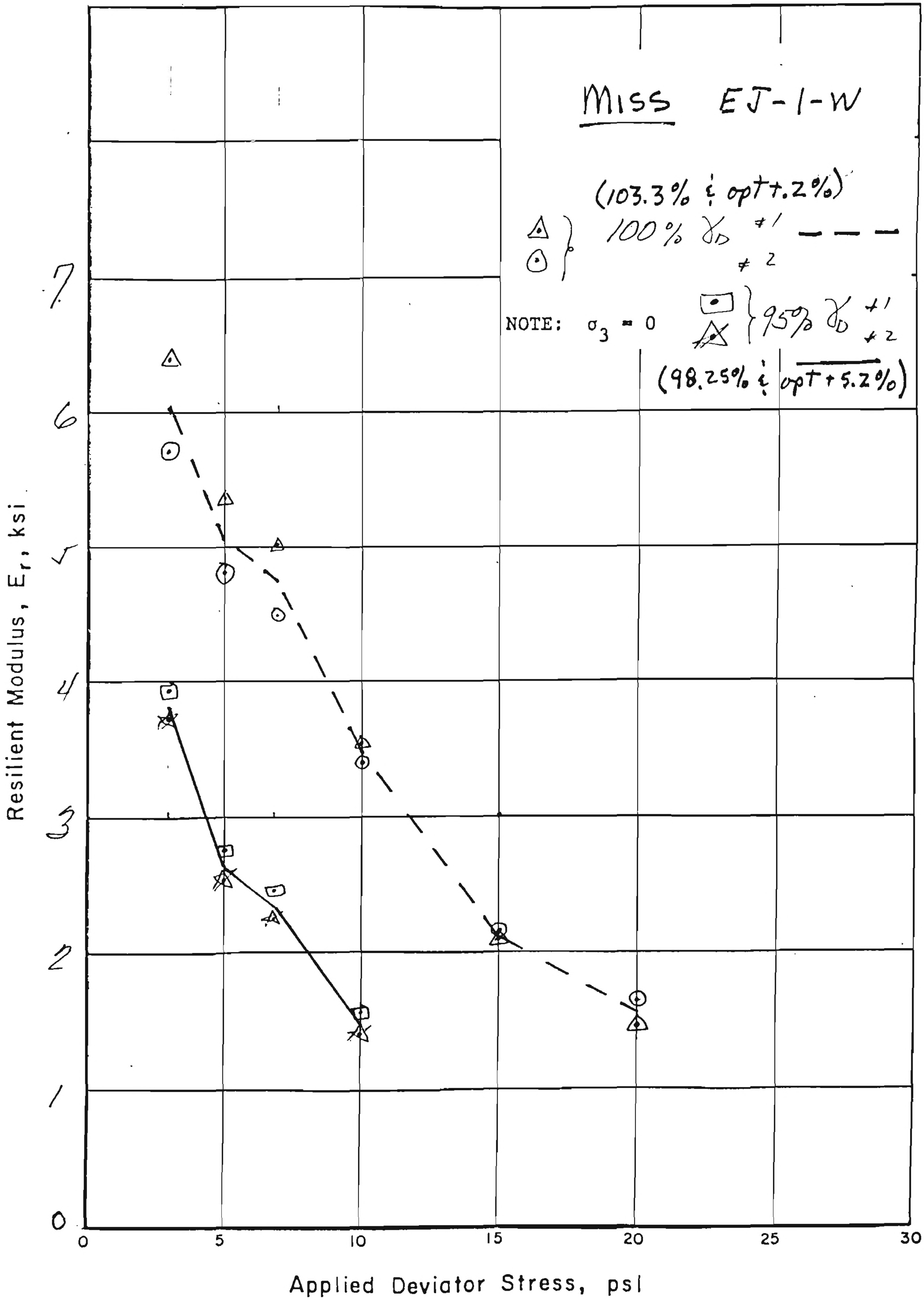
SOUTH CAROLINA
SC- 5A
100% γ_D (98.5% & opt-.1%) ● #1 ▲ #2
95% γ_D & 2% + (95.8% & opt + 1.6%) ⊙ #1 △ #2
NOTE: σ_3 = 0
Unreasonable
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
13
12
11
10
9
8
7
6
5
4
0
5
10
15
20
25
30

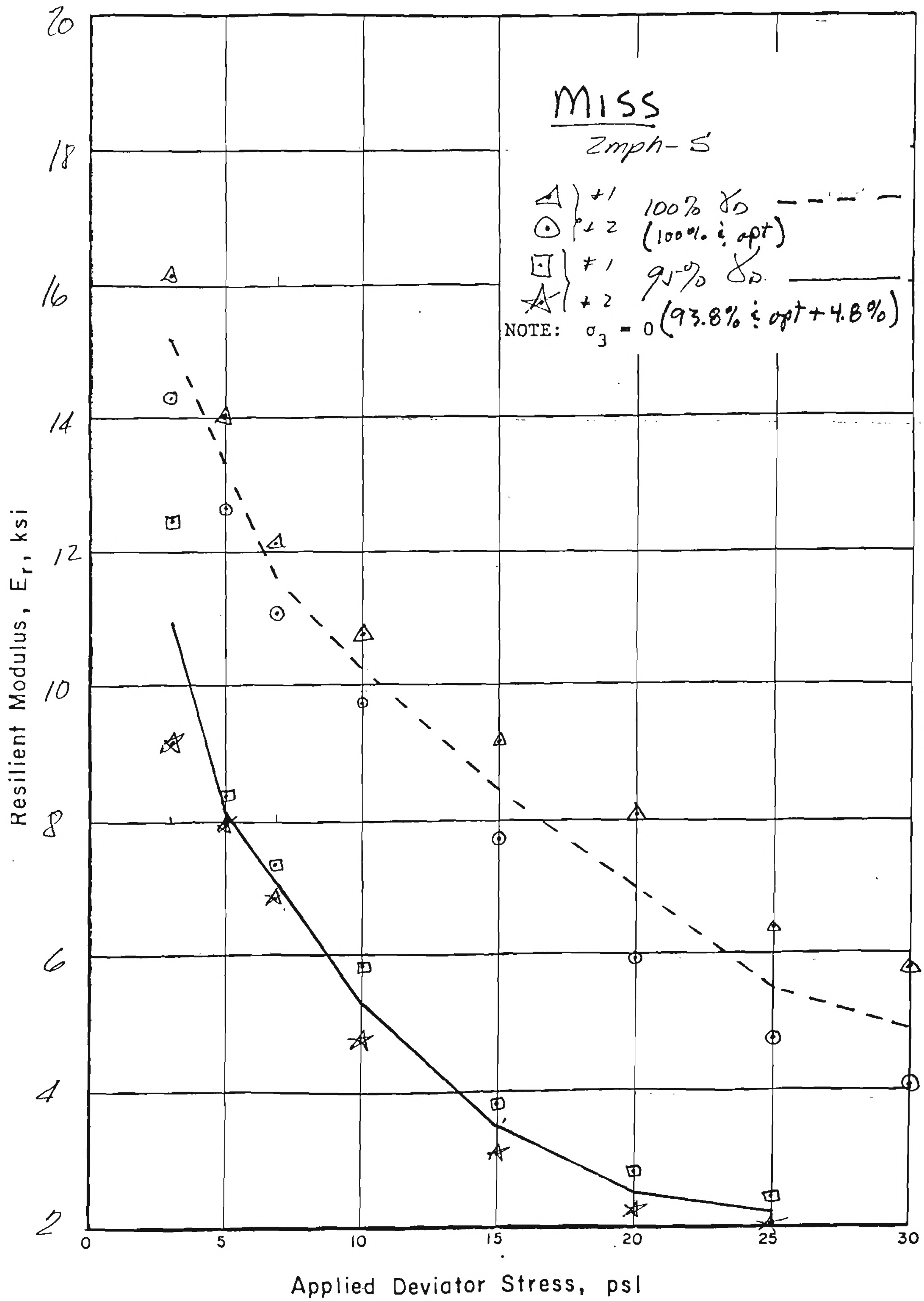

SOUTH CAROLINA
SC-6
L
(100.6% : opt-.2%) R
L
(94.9% : opt+4.1%) R
NOTE: σ3 = 0
28
24
20
16
12
8
4
0
0
5
10
15
20
25
30
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi



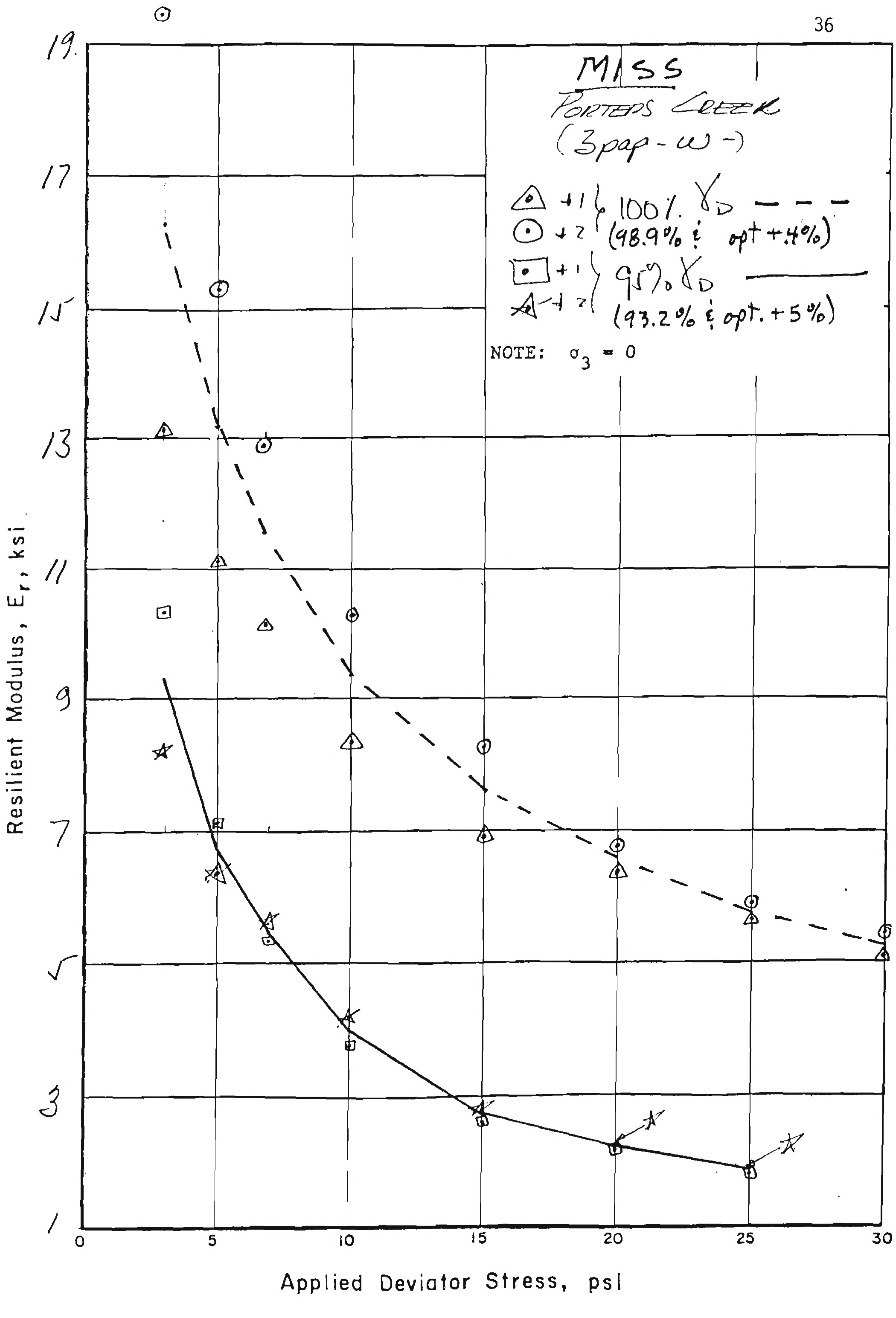
OKLAHOMA #1
95% & 2% opt (94.8% & opt + 2%) #1 #2
100% γ_D & opt (98% & opt + 3%) #1 #2
NOTE: σ_3 = 0
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
5
6
7
8
9
10
11
12
13
0
5
10
15
20
25
30

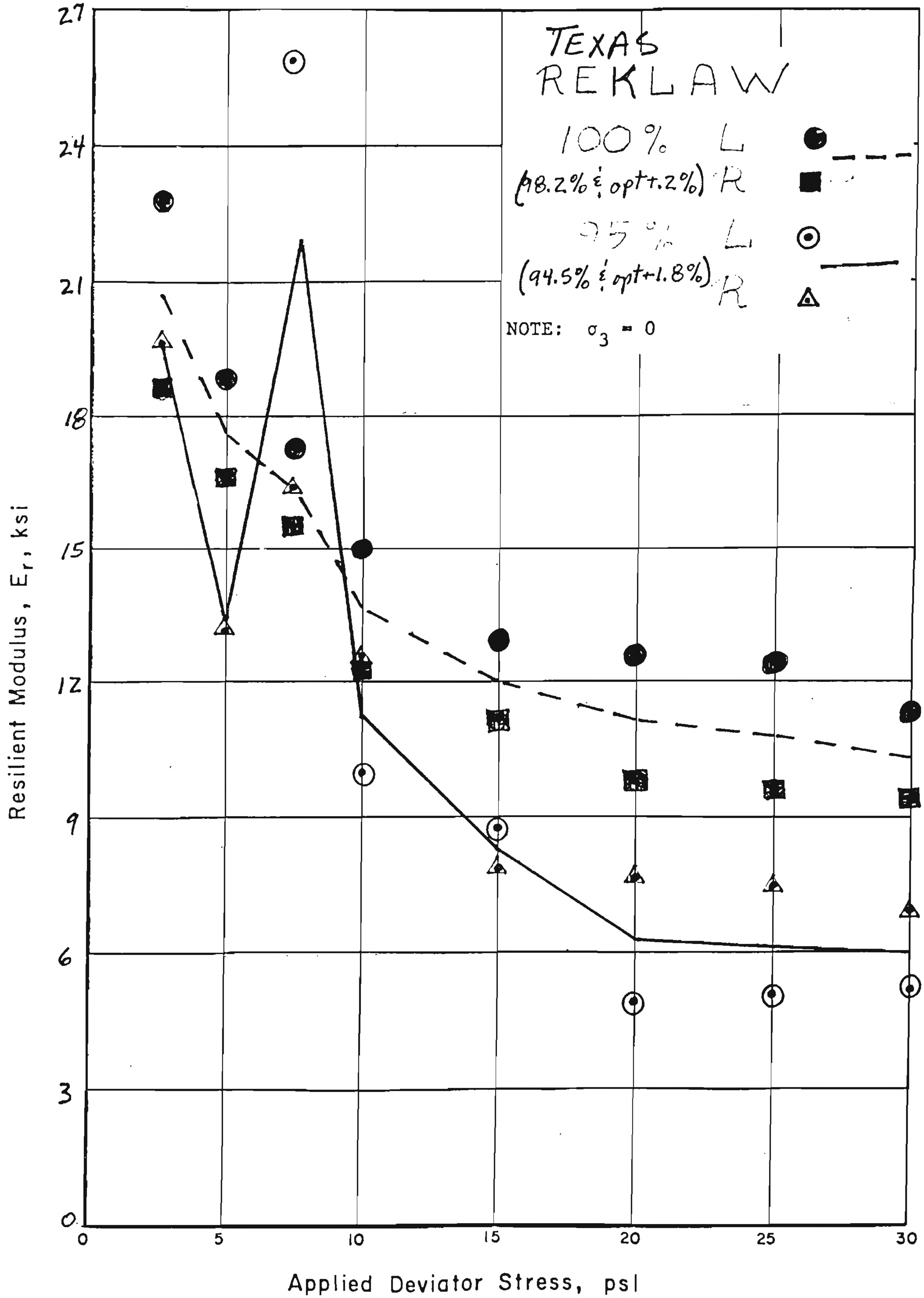

Miss
OV-1-J
(100.7% ¿ opt)
(94% ¿ opt+5%)
NOTE: σ_3 = 0
+1 } 100% γ_D
+2
+1 } 95% γ_D
+2
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi


Miss EJ-1-W
(103.3% ; opt+.2%)
100% γ_D #1
#2
NOTE: $\sigma_3 = 0$
95% γ_D #1
#2
(98.25% ; opt+5.2%)
Resilient Modulus, E_r, ksi
0
1
2
3
4
5
6
7
0
5
10
15
20
25
30
Applied Deviator Stress, psi

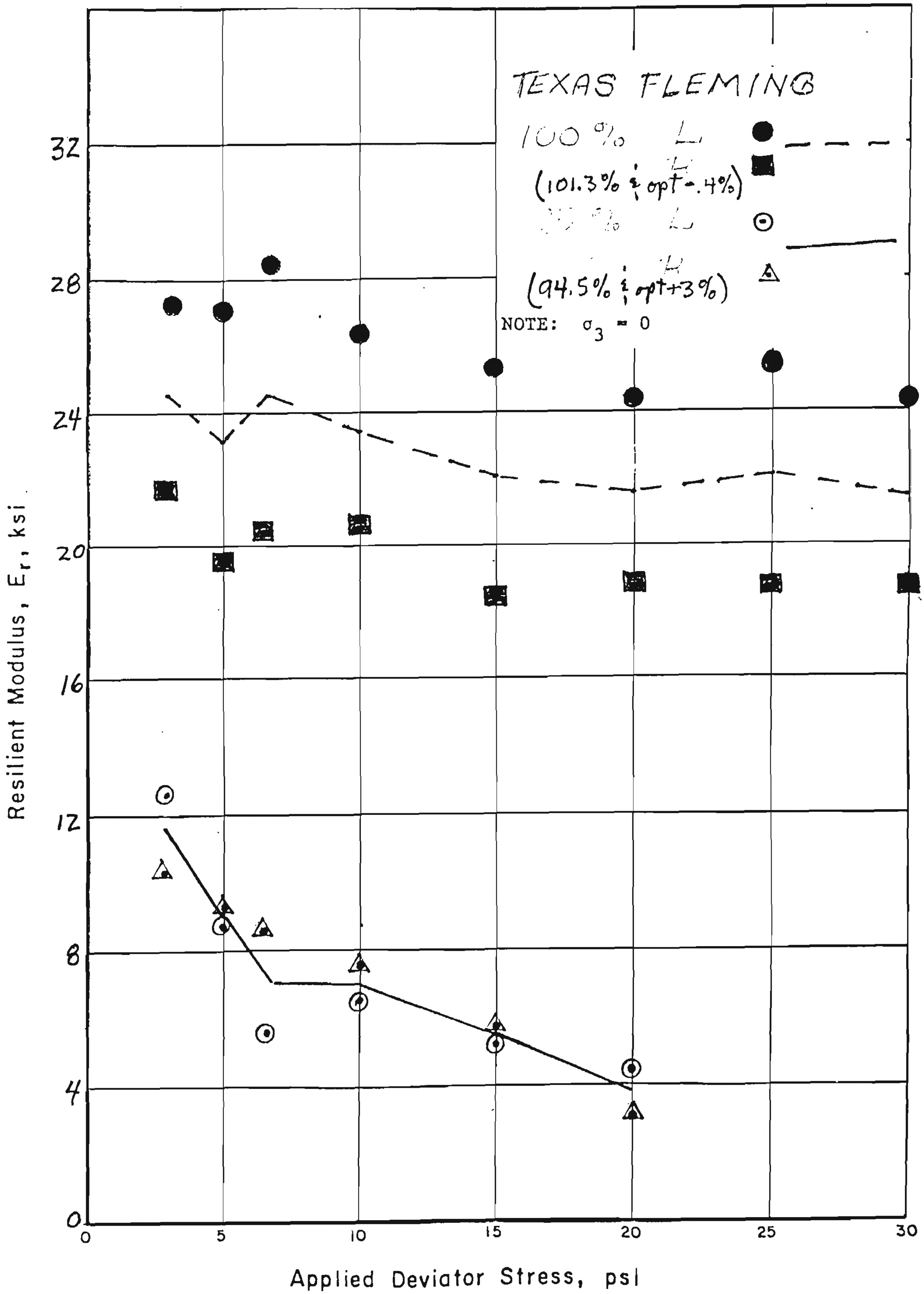


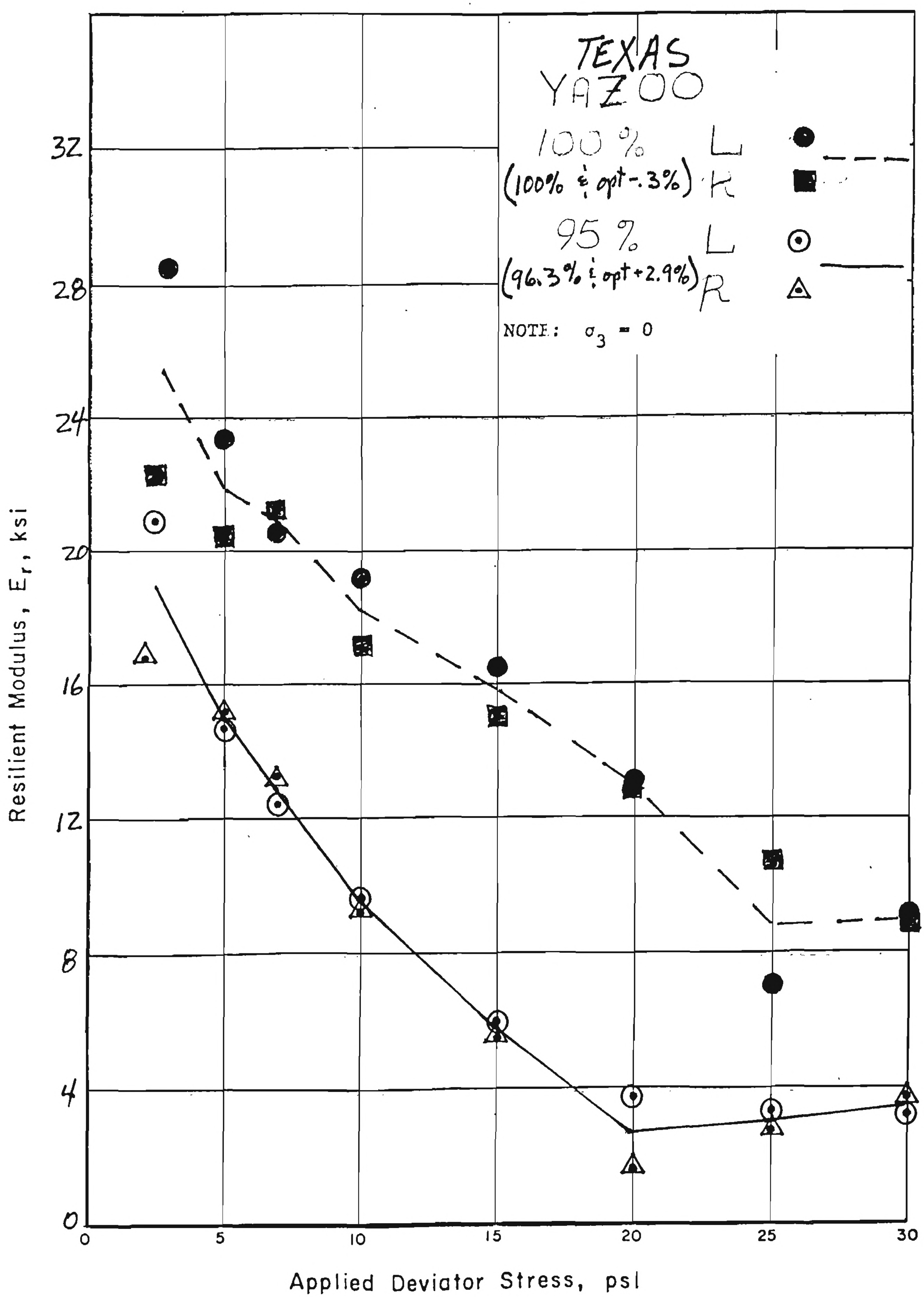
MISS
2mph-S
+1 100% γD
+2 (100% ; opt)
+1 95% γD
+2 (93.8% ; opt+4.8%)
NOTE: σ3 = 0
Resilient Modulus, Er, ksi
Applied Deviator Stress, psi
20
18
16
14
12
10
8
6
4
2
0
5
10
15
20
25
30

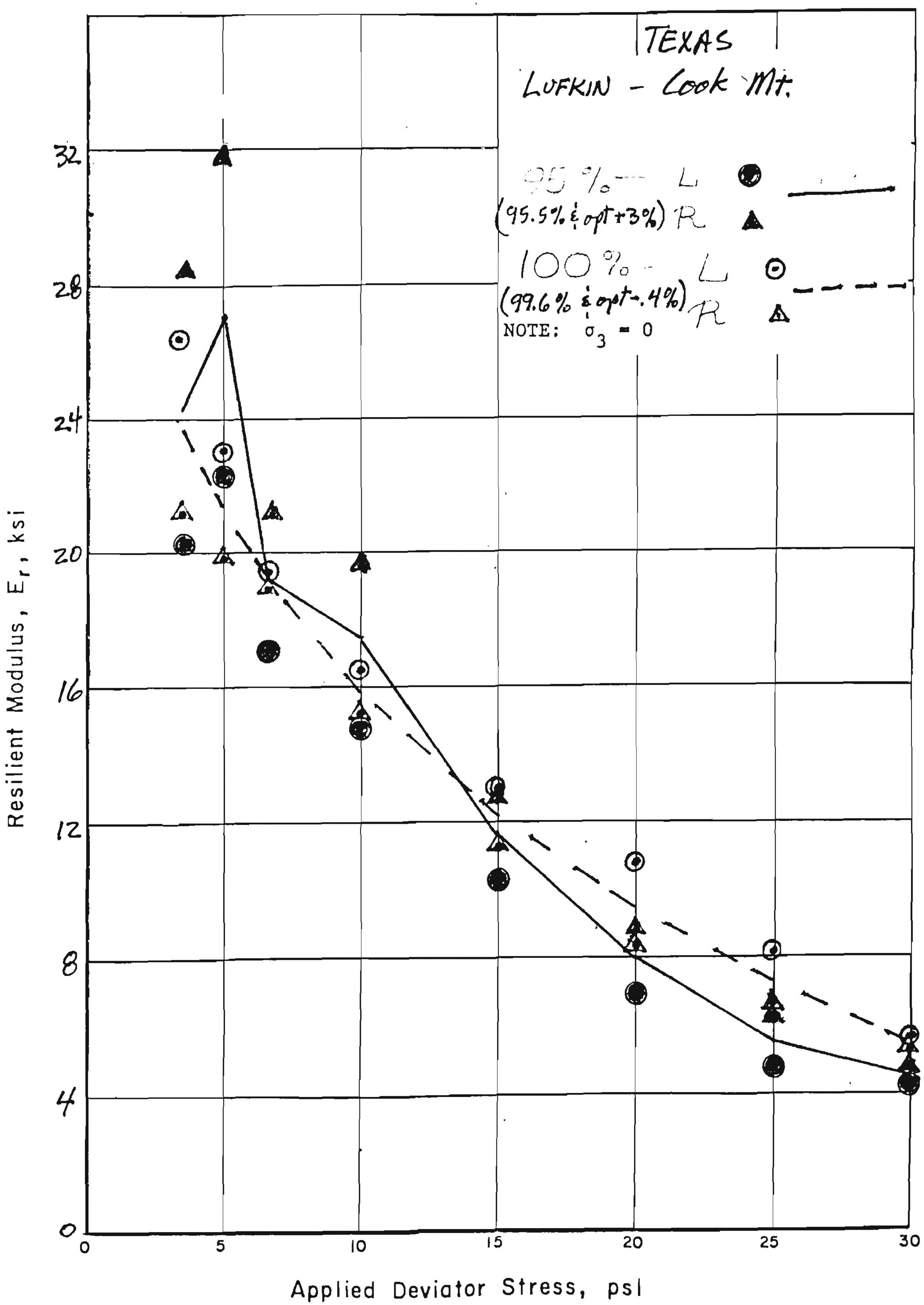

MISS
PORTERS CREEK
(3pap-w-)
+1 } 100% γ_D
+2 (98.9% & opt+4%)
+1 } 95% γ_D
+2 (93.2% & opt.+5%)
NOTE: $\sigma_3 = 0$
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
1
3
5
7
9
11
13
15
17
19
0
5
10
15
20
25
30

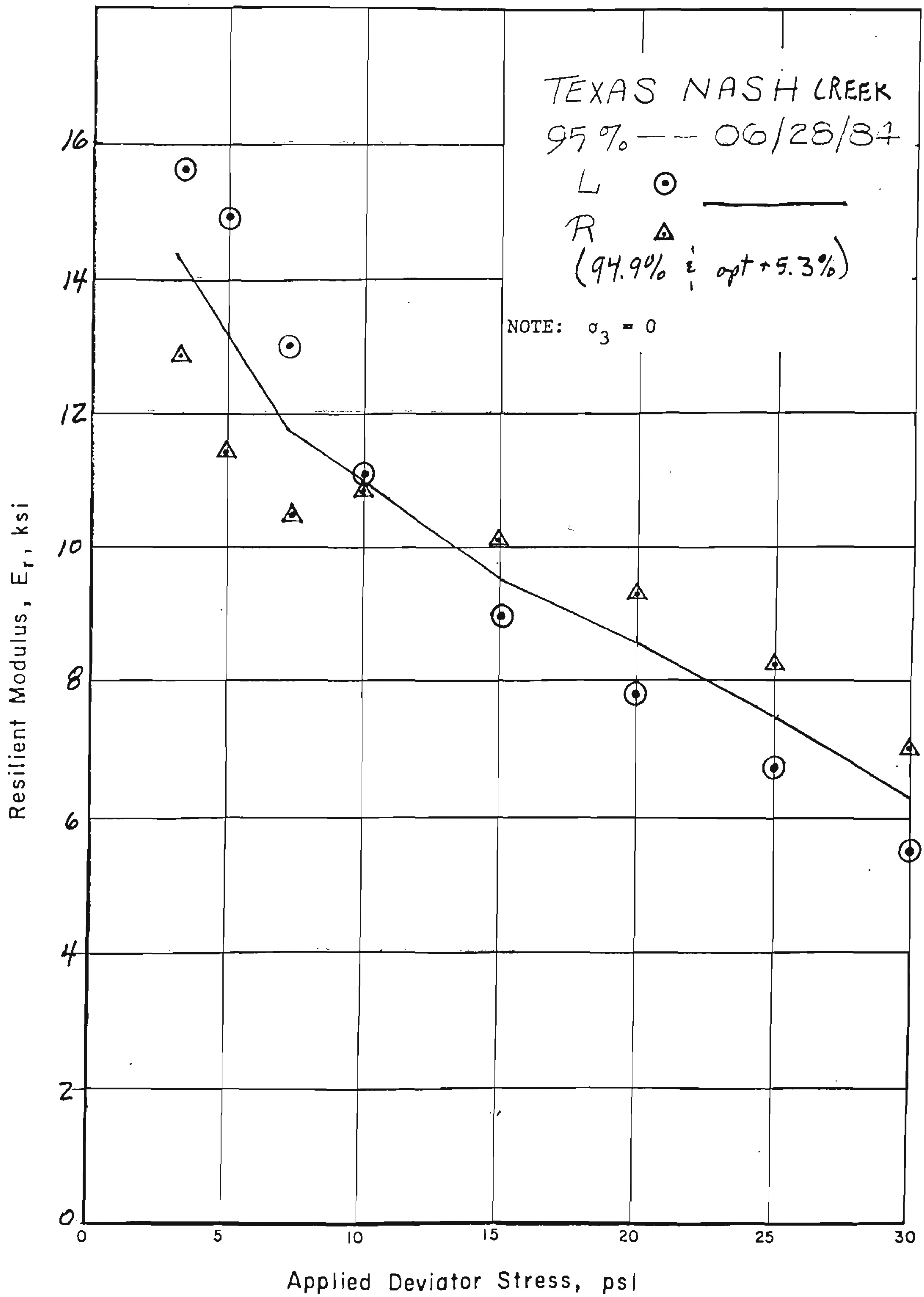


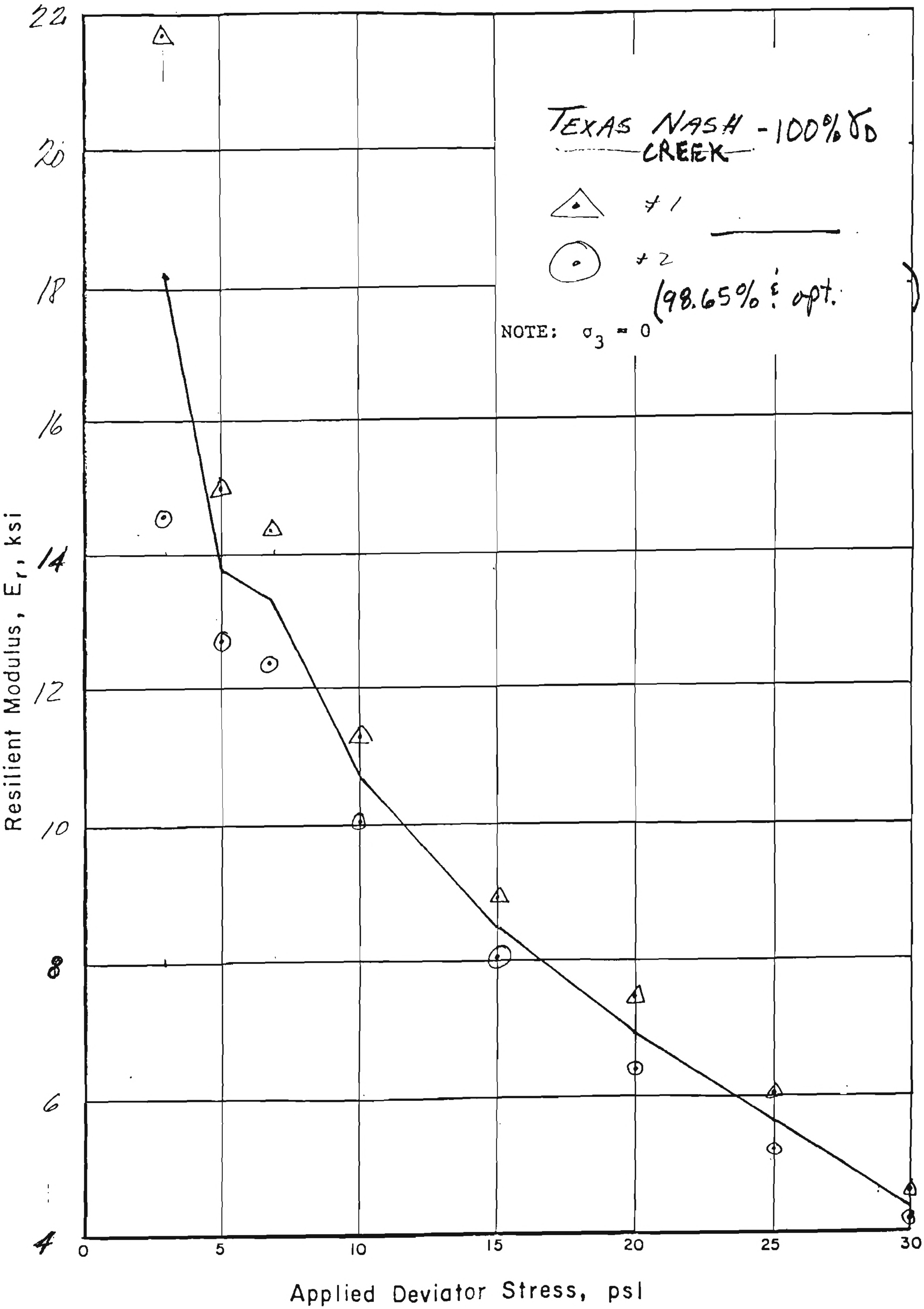
TEXAS
REKLAW
100% L
(98.2% & opt+.2%) R
95% L
(94.5% & opt+1.8%) R
NOTE: $\sigma_3 = 0$
27
24
21
18
15
12
9
6
3
0
0
5
10
15
20
25
30
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi


TEXAS FLEMING
100 % L
(101.3% ; opt -.4%)
(94.5% ; opt+3%)
NOTE: σ3 = 0
0
4
8
12
16
20
24
28
32
0
5
10
15
20
25
30
Resilient Modulus, Er, ksi
Applied Deviator Stress, psi

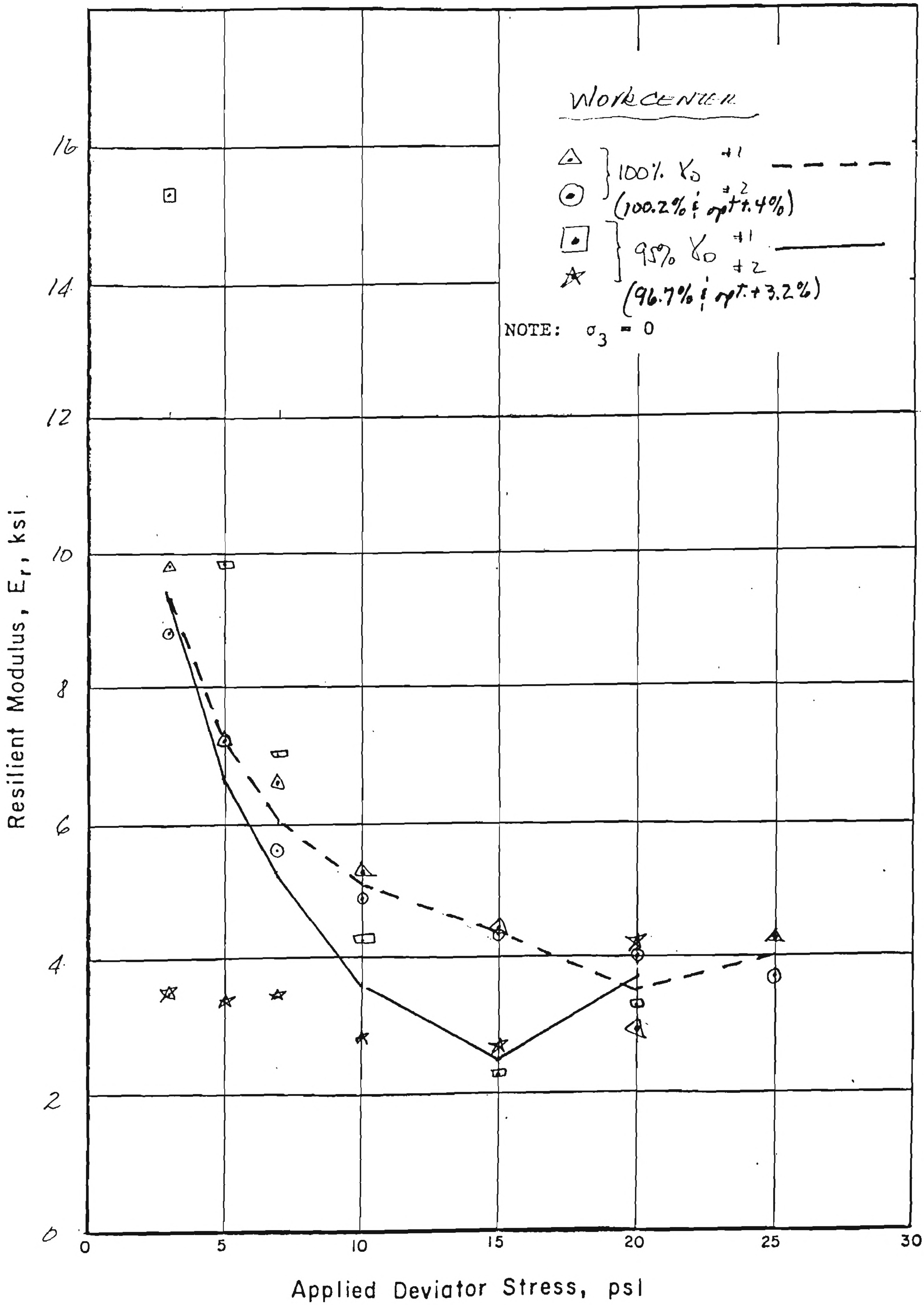

TEXAS
YAZOO
100 % L
(100% & opt-.3%) R
95 % L
(96.3% & opt+2.9%) R
NOTE: σ3 = 0
Resilient Modulus, Er, ksi
Applied Deviator Stress, psi
0
4
8
12
16
20
24
28
32
5
10
15
20
25
30


TEXAS
LUFKIN - Cook Mt.
95% — L
(95.5% & opt+3%) R
100% - L
(99.6% & opt-.4%) R
NOTE: σ3 = 0
Resilient Modulus, Er, ksi
0
4
8
12
16
20
24
28
32
0
5
10
15
20
25
30
Applied Deviator Stress, psi


TEXAS NASH CREEK
95% -- 06/28/84
L
R
(94.9% & opt + 5.3%)
NOTE: $\sigma_3 = 0$
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
0
2
4
6
8
10
12
14
16
0
5
10
15
20
25
30



TEXAS NASH CREEK - 100% γ_D
#1
#2
(98.65% ≤ opt.)
NOTE: σ_3 = 0
22
20
18
16
14
12
10
8
6
4
0
5
10
15
20
25
30
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi



WORKCENTER
100% γ_0 #1 #2
(100.2% ; opt + 4%)
95% γ_0 #1 #2
(96.7% ; opt + 3.2%)
NOTE: $\sigma_3 = 0$
Resilient Modulus, E_r, ksi
Applied Deviator Stress, psi
0 2 4 6 8 10 12 14 16
0 5 10 15 20 25 30

APPENDIX A

SIMPLIFIED TEST METHOD FOR DETERMINING THE RESILIENT MODULUS OF COHESIVE SOILS

The simplified test method described in this chapter is similar to the method for cohesive soils described in the section on resilience testing of unstabilized soils. This simplified method is part of a production-type resilience testing procedure that has been developed for and used extensively with fine-grained cohesive soils. A more complete description of the simplified testing procedure is given elsewhere (4).

In general, the procedure consists of preparing sets of at least three 2-in.-diameter (50.8-mm-diameter) by 4-in.-high (101.6-mm-high) cylindrical specimens by using a miniature kneading compactor. The specimen sets are prepared at moisture and density conditions representative of expected field conditions and then are tested by using the simplified method.

The method takes advantage of the simplicity, ease of testing, and minimal equipment requirements normally associated with an unconfined compression-type repeated load test (i.e., $\sigma_3 = 0$). Because no confining pressure is required, a triaxial cell is not needed.

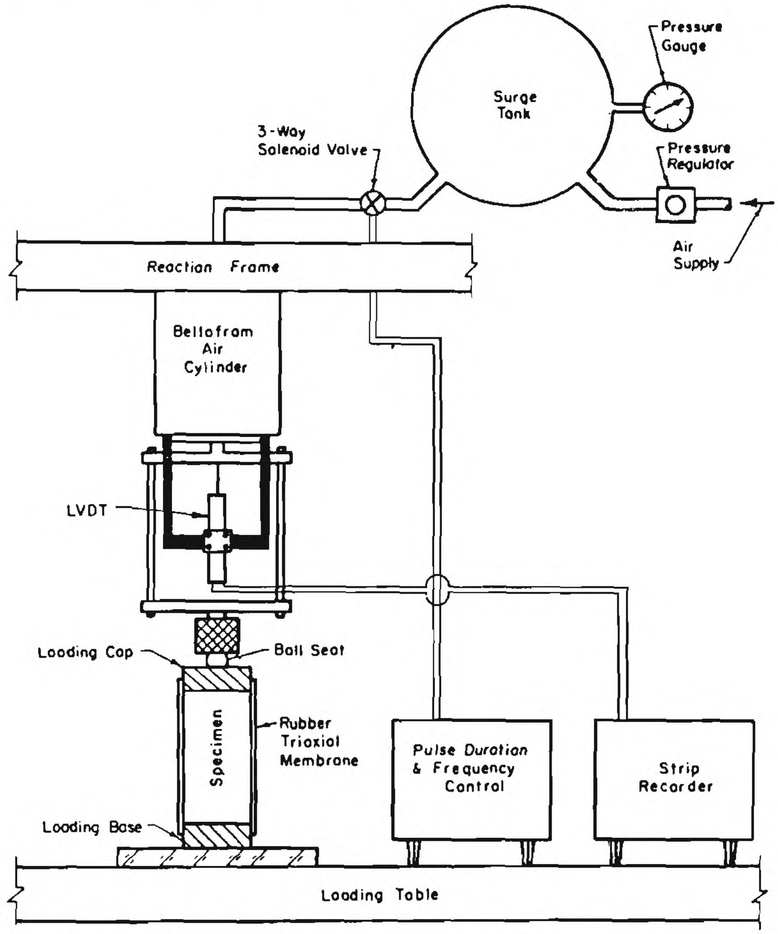
Justification for not using a confining pressure during the testing of cohesive soils lies in the fact that (a) the magnitude of confining pressure normally encountered in a subgrade is typically in the range of 1 to 5 lbf/in.^{2} (6.9 to 34.5 kPa) and (b) the effect of small magnitudes of confining pressure on the resilient response of fine-grained cohesive soils is very slight and typically is less than "between specimen" testing variability.

An additional advantage inherent in the simplified method is the use of an LVDT mounted in line with the longitudinal axis of the test specimen, which eliminates the need for mounting deformation measuring equipment on the specimen. It is important that the LVDT be mounted in this position because of the effect that eccentricity has if the LVDT is mounted to the side. A schematic diagram of the mounting position of the LVDT and the resilience testing equipment is shown in Figure 22.

As indicated in the section on fundamental considerations, something such as LVDT clamps or optical tracking equipment should be used for deformation measurement if the resilient modulus is greater than about 15,000 lbf/in.^{2} (103 500 kPa). However, for fine-grained cohesive soils, the axially mounted LVDT is satisfactory provided a sufficiently rigid machine is used.

It is suggested that at least 3 specimens be tested for a given set of variables and that the results be averaged. The reason for this is that "between specimen" variability for typical laboratory resilient testing is substantial (typical coefficients of variation of 10 to 15 percent or higher are not uncommon for cohesive soils and this type of test); thus the results from 1 specimen may be substantially different from the average of the results from a number of specimens.

Figure 22. Repeated load testing apparatus for simplified resilient modulus test.



SIMPLIFIED TEST METHOD

Ten steps make up the simplified test method.

1. Carefully place the specimen on the loading base.
2. Carefully place the loading cap on top of the specimen.
3. Stretch a rubber membrane tightly over the interior surface of a membrane stretcher. Carefully slip the stretched membrane over the specimen. Roll the membrane off the stretcher onto the base and cap. Remove the stretcher. Place O-ring seals or rubber bands around the base and cap. (The purpose of the membrane is to prevent loss of moisture during the test.)
4. Place the membrane-encapsulated specimen into position in the loading machine as shown in Figure 22. A steel ball bearing is placed between the top loading cap and the axial loading device. It is important to obtain proper alignment of the specimen and axial loading device to minimize eccentricities.

Resilient properties of cohesive soils are greatly dependent on the magnitude of the deviator stress (total repeated axial stress in this case). It is therefore necessary to conduct the test over a range of deviator stress values, for example: 3, 5, 7.5, 10, 15

$lbf/in.^2$ (20.7, 34.5, 51.75, 69, 103.5 kPa) and possibly higher values.

A conditioning phase is used to properly seat the loading cap and base and eliminate or minimize initial loading effects.

5. Condition the specimen with 1,000 applications (load duration of 0.060 s and cycle duration of 3 s) of an axial stress equal to about 7 $lbf/in.^2$ (48.3 kPa) followed by 20 applications each of an axial stress of 3, 5, 7.5, 10, and 15 $lbf/in.^2$ (20.7, 34.5, 51.75, 69, and 103.5 kPa). (Observe permanent axial deformation during the latter stages of the conditioning phase. If appreciable permanent deformation starts to accumulate, then eliminate the higher values of axial conditioning stress from the conditioning phase.)
6. Decrease the deviator stress to about 3 $lbf/in.^2$ (20.7 kPa).
7. Apply approximately 10 to 20 deviator stress applications and record the resilient axial deformation.
8. Increase the axial stress level incrementally about 3 $lbf/in.^2$ (20.7 kPa).
9. Repeat step 7.
10. Repeat step 8 and step 7 until the desired upper value of axial stress is reached. An upper value of at least 20 to 25 $lbf/in.^2$ (138 to 172.5 kPa) is recommended.