MISSOURI COOPERATIVE HIGHWAY RESEARCH PROGRAM
FINAL REPORT

75-1

STRENGTH AND DRAINAGE PROPERTIES OF A ROCKY RESIDUAL SOIL

MISSOURI STATE HIGHWAY DEPARTMENT

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STUDY NO. 75-1

Prepared by

MISSOURI STATE HIGHWAY DEPARTMENT

Division of Materials and Research

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ABSTRACT

The quantity of granular material in a Clarksville residual clay was varied to determine the effect on strength parameters as determined by triaxial test procedures. Consolidation and permeability characteristics were also studied. Some general conclusions are drawn on the relationship of granular content to permeability and pore pressure development in embankment construction.

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LIST OF ABBREVIATIONS AND SYMBOLS

c	-	apparent cohesion (y intercept of Mohr's total stress strength envelope)
c'	-	cohesion (y intercept of Mohr's effective stress strength envelope)
$\triangle h$	-	change in height
$\overline{R}$	-	consolidated undrained triaxial test with pore pressure measurements
u	-	total pore pressure
u_o	-	pore pressure resulting from $\sigma 3$ confining pressure
$u-u_o$	-	induced pore pressure during shear
ϵ	-	strain
ϕ	-	angle of internal friction based on total stress
ϕ'	-	angle of internal friction based on effective stress
ϕ_1	-	effective angle of internal friction based on deviator stress of 15 psi
ϕ_2	-	effective angle of internal friction based on deviator stress of 30 psi
ϕ_3	-	effective angle of internal friction based on deviator stress of 60 psi
$\sigma 1-\sigma 3$	-	deviator stress (total axial stress minus confining pressure)

INTRODUCTION

Many of the highest roadway fills in Missouri are constructed of residual clays from the Clarksville series which contain varying amounts of admixed chert ranging in size from sand to boulders. Slope designs for such high fills have been based on experience gained from fills of lesser heights. Equipment restrictions have limited previous consolidation and direct shear testing to samples with the granular fraction larger than sand size removed.

In a previous research report entitled Moisture, Density and Slope Requirements in High Fills, it was concluded that such soils, when encountered without significant granular content, should be limited by stability considerations to about 40 feet in height with 2 to 1 slopes. This conclusion was based upon interpretation of direct shear tests of essentially granular free soil. However, it was acknowledged that, since granular-free occurrences were rare, such slope and height restrictions were inconsistent with demonstrated performance of the normal occurrences of the soil. The present study was designed to overcome these limitations and to develop data on strength, consolidation and permeability characteristics of the soil with granular contents more typical of normal occurrences. It was concluded that triaxial testing was the most practical means of achieving these objectives for this soil.

CONCLUSIONS

1. With less than about 40 percent retained on the No. 10 sieve, the study soil was indicated by triaxial tests to have an effective angle of internal friction averaging 32 degrees. The average effective angle increased to a maximum of 34 degrees with 50 percent granular content, the maximum tested.

Total strength parameters show a large increase in apparent cohesion at granular contents exceeding 40 percent.

2. Triaxial and consolidation test data indicate the study soil to be highly impermeable at granular contents of less than about 40 percent. At granular contents over 40 percent, the permeability increases as much as fifty fold.

3. Triaxial testing, while slow and expensive, is judged to provide more realistic strength parameters than were previously determined by direct shear testing for this soil. Similar testing would appear appropriate for any other gravelly soil to be used in embankments of such height that stability problems could be likely or of serious consequences should they occur.

4. Within the ranges tested, no significant differences in effective strength parameters were found as a result of varying triaxial specimen sizes or the top size of the included granular material.

IMPLEMENTATION

Consideration should be given to requiring determination during the soil survey of the granular content of residual clays. This would be most useful in design of fills built of such soils. A determination that the granular content exceeds about 40 percent would suggest free drainage, rapid settlement and minimal stability problems. Those soils with granular contents less than about 40 percent should receive special consideration of settlement and stability problems where embankment heights exceed about 40 feet, the limitation suggested by a previous study of this soil with minimal granular content.

Triaxial shear parameters, in the light of past experience, appear to provide a realistic basis for predicting behavior of gravelly clay residual soils. As most of the residual soil series in Missouri usually have high granular content, triaxial testing should be used in future studies of slope requirements for high fills of such soils.

Both experience and the data derived in this study confirm that steeper fill slopes are practical with such gravelly residual soils than are possible with most other soils in the state.

SCOPE

A residual gravelly clay commonly encountered in heavy grading for highway embankments in southern Missouri was modified with varying amounts of granular material from a minimum of 10% to a maximum of 50% retained on the No. 10 sieve. These varying mixtures were tested for determination of shear strength, consolidation and permeability characteristics.

Triaxial test specimens were graded to match natural gravelly clays, statically compacted wet of optimum and back pressured to saturation. Shear tests were performed by consolidated, undrained ($\overline{R}$) procedures to permit evaluation of both effective and total stresses.

Specimen sizes of 1.4 inch, 2 inch and 2.75 inch diameters, with varying sizes of gravel added, were tested for evaluation of the effect of top size and gradation of the granular fraction.

Permeability data derived from both triaxial and consolidation tests was evaluated to determine the granular content at which internal drainage would permit rapid consolidation and dissipation of pore pressures.

THE STUDY SOIL

The study soil is a residual clay from the Clarksville series derived from the decomposition of cherty dolomitic limestones. It is found throughout the Ozark Region of southern Missouri. The soil sample used in the study is from Route 21 in Reynolds County and was used in a previous study entitled Moisture, Density and Slope Requirements of High Fills. It is relatively free of granular content with 10 percent retained on the No. 10 sieve and 78 percent passing the No. 200 sieve. As sampled, it is non-typical for the series although representative of chert free pockets frequently encountered. A liquid limit of 69 and a plastic limit of 41 were determined. Soils of this series are found with a liquid limit range of 25 to 85 and a plastic index range of 9 to 54.

Compaction records from past projects show Clarksville series clays to exhibit a wide range in granular contents and maximum densities. Typical compaction curves and gradations are shown in Figures 1 and 2. In Figure 1, Group A represents 6 samples having less than 40 percent passing the No. 200 sieve and Group B 16 samples having between 40 and 60 percents passing the No. 200 sieve. As these curves would suggest, considerable difficulty is experienced in construction control since the applicable maximum density varies widely with the amount, size and specific gravity of the granular fraction. Frequently the chert content is such that the soil is judged "too rocky to test" by inspectors.

The known range of specific gravity of the admixed chert varies from 1.85 to 2.65. That added in preparation of test specimens had a specific gravity of 2.26 and was composed of typical angular fragments obtained by washing of natural Clarksville gravelly clay mixtures.

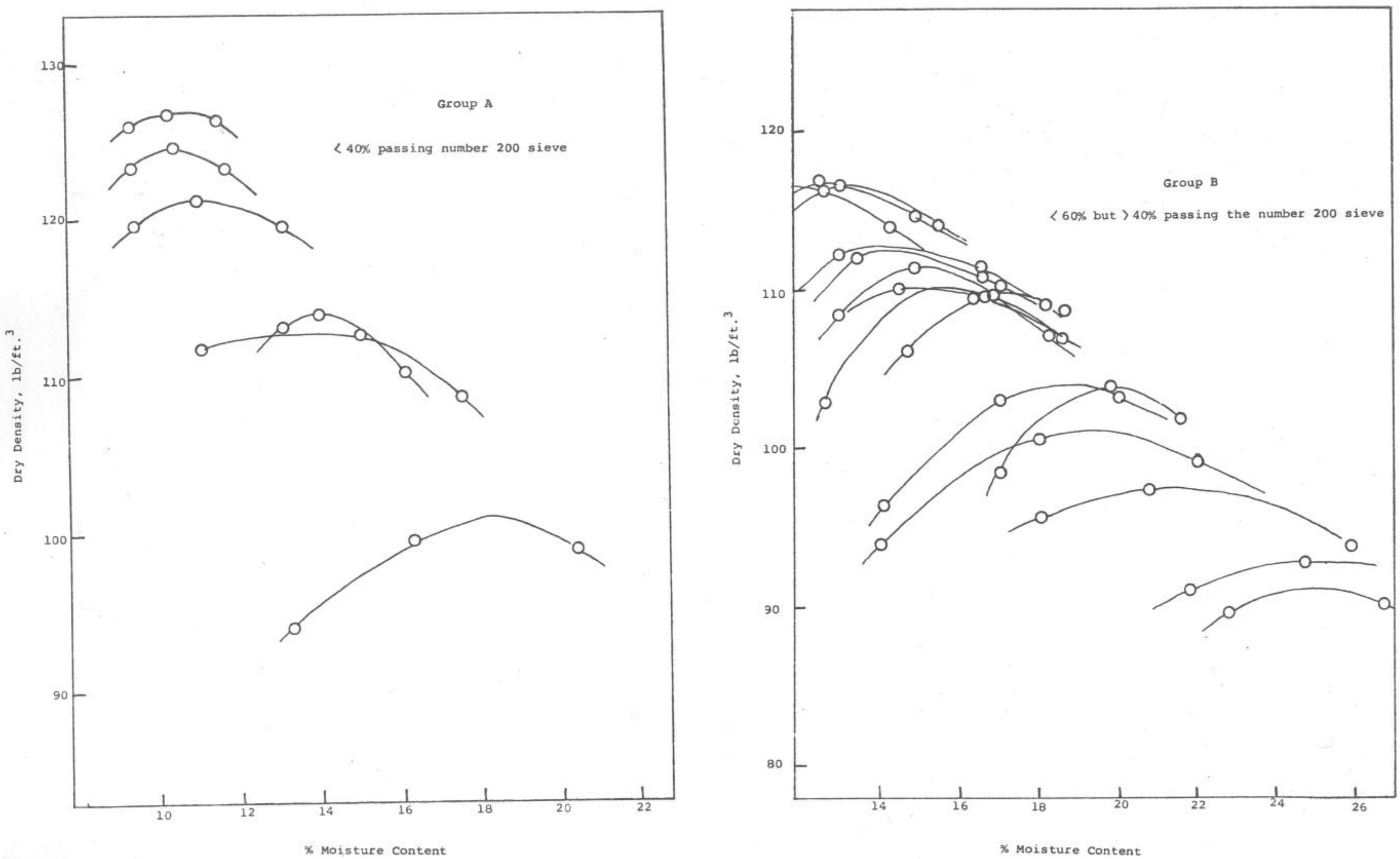

Figure 1. Compaction Curves for Clarksville Gravelly Clays

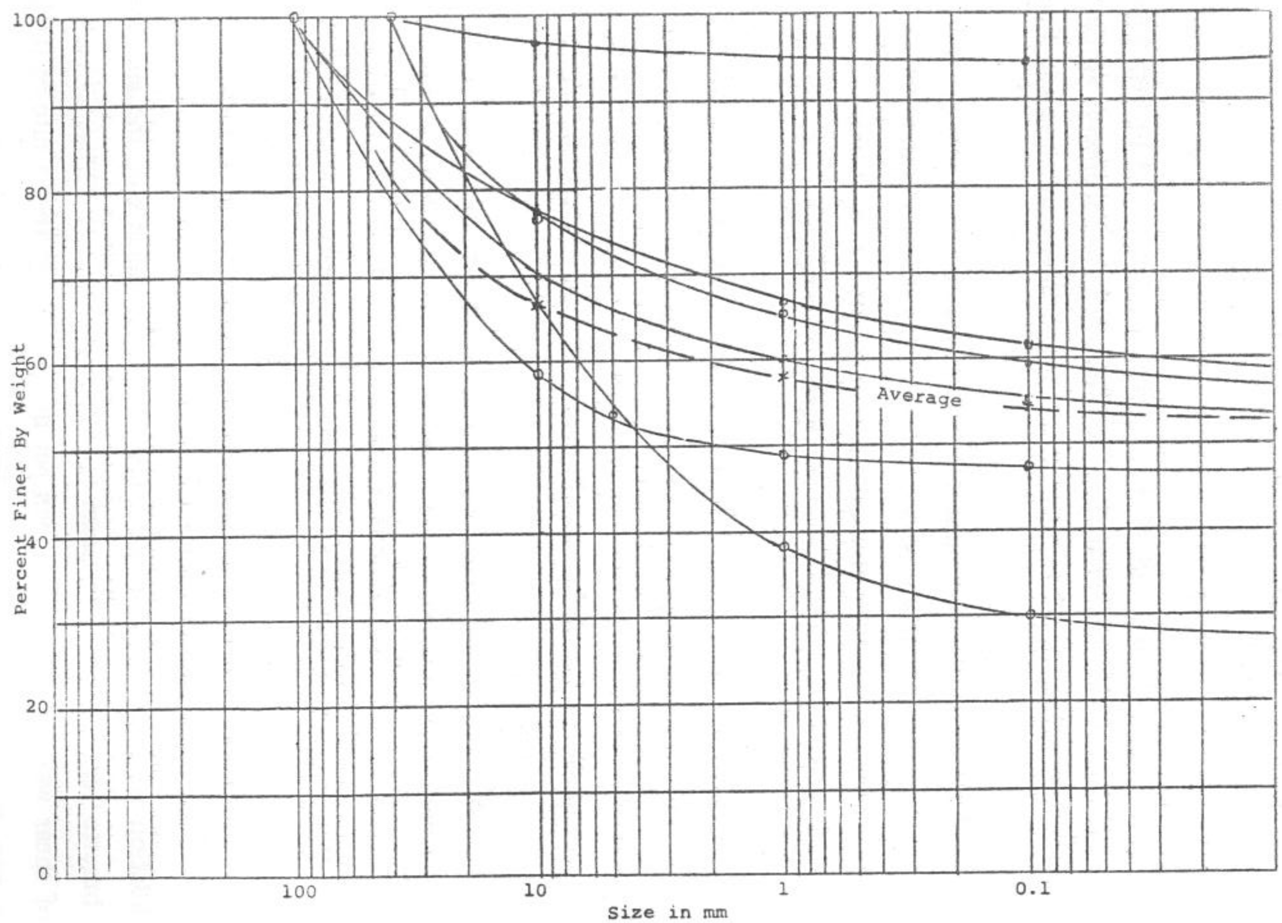

Figure 2. Gradation of Natural
Clarksville Gravelly Clays

PREPARATION AND TESTING

Gravel and clay mixtures were prepared with the amounts retained on the No. 10 sieve varied in increments of 5 percentage points from 10 to 50 percent. Additional fine granular content was added to produce gradations approximating natural Clarksville soils as closely as the maximum allowable particle sizes would permit. (See Figure 3.) The maximum particle size was limited to that passing the 1/4 inch sieve and retained on the No. 4 for 1.4 inch and 2 inch diameter triaxial test specimens, and to that passing the 3/8 inch and retained on the 1/4 inch sieve for the 2.75 inch diameter specimen. The resulting gradation curves for the 2.75 inch diameter specimens are shown in Figure 3.

Test specimens were statically compacted to the maximum extent practical on the wet side of optimum to obtain a nearly saturated specimen at approximately 95 percent of AASHTO T-99 maximum density for the soil fraction only (less the admixed granular portion). Thirty-three percent moisture was added based on weight of the soil less the admixed granular portion. The granular material was soaked for 24 hours, drained and blotted free of water before blending. All mixtures were cured 24 hours after adding water and before compaction. Triaxial specimens were prepared in 1.4 inch, 2 inch and 2.75 inch diameters, all having a 2 to 1 height to diameter ratio. Consolidated, undrained triaxial tests with pore pressure measurements ($\overline{R}$) were performed in conformance with AASHTO T-234-70 except that the ratio of specimen diameter to maximum particle size was about 7 to 1 instead of 10 to 1 for the 1.4 inch diameter specimens.

Differential confining pressures varied from 15 to 60 psi. Porous stones were used at both end caps with discontinuous filter strips to facilitate saturation by backpressuring in 5 psi increments with a 3 psi differential maintained across the membrane. Pore pressures were monitored using low displacement transducers. Saturation was considered complete when an immediate response in pore pressure was measured by the transducer after an increase in back pressure.

Consolidation was measured by both changes in the heights of the specimens and changes in burette readings with drainage.

Rate of shear was less than 0.002 inch per minute except that a rate of 0.0027 inch per minute was used with the 2.75 inch diameter specimens to permit achieving 15 percent strain in a normal work period encompassing 9 hours.

Membrane puncture by the sharp chert particles limited successful testing to 40 percent retained on the No. 10 sieve for 1.4 inch diameter specimens, to 45 percent for the 2 inch specimens and to 50 percent for the 2.75 inch specimens. Forty-five psi was the maximum differential confining pressure successfully applied to the 2.75 inch diameter specimens with 50 percent retained on the No. 10 sieve.

Triaxial test data was resolved by a computer program with automatic plotting of Mohr's circles and stress-strain data.

Specimens with 20, 30 and 45 percent retained on the No. 10 sieve were statically molded to one inch thickness for consolidation testing, with moisture content and density similar to that of the triaxial test specimens, for determination of permeability.

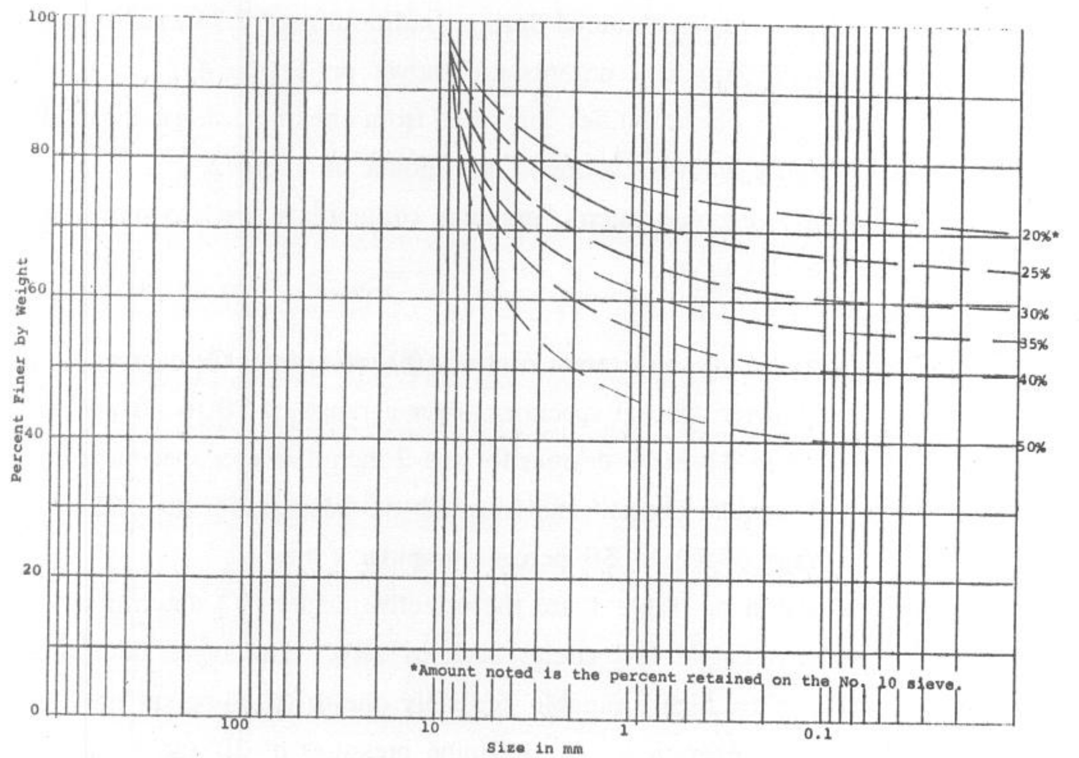

Figure 3. Gradation of Mixtures Prepared For 2.75 Inch Diameter Triaxial Specimens

ANALYSIS OF DATA

General

Results of triaxial tests are presented as Figures 5 through 40. Mohr's circles and plots of stress-strain relationships are included as alternate figures. Angles of effective and total stress envelopes for varying granular contents and specimen sizes are summarized in Table 1. Both averages and standard deviations are also listed. Tabulation of stress-strain relationship factors for varying granular contents and specimen sizes are presented on Tables 3, 4, 5 and 6.

Consolidation curves obtained during conditioning of 2.75 inch diameter triaxial specimens with varying granular contents are shown on Figure 4.

A summary of permeabilities computed from one dimensional consolidation tests performed with varying granular contents are shown in Table 2.

In the following discussion, "granular content" is used to mean that portion retained on the No. 10 sieve.

Effective Stresses

The effective angle of internal friction (ϕ') varies from 29 degrees to 34 degrees for the 1.4 inch diameter triaxial specimens over a range of 10 to 40 percent granular content. ϕ' varies from 31 to 34 degrees for the 2 inch diameter specimens over a range of 20 to 45 percent granular content and from 30 to 34 degrees for the 2.75 inch diameter specimen over a range of 10 to 50 percent granular content.

Also tabulated on Table 1 are the effective angles (ϕ') determined by striking lines tangent to individual Mohr's circles back to zero. The angles determined for 15 psi confining pressures are highly variable, probably due to the apparent pre-consolidation resulting from sample preparation. At confining pressures of 30 and 60 psi, the average angle is 30.9 degrees with granular content of less than 40 percent and 33.5 degrees with granular contents of 40 percent or greater.

Comparison of the effect of confining pressure on ϕ' indicates a consistent variation. With granular contents of less than 40 percent, the average angles are 31.6 degrees for 30 psi confining pressures and 30.2 degrees at 60 psi. For granular contents of 40 percent or greater, the averages are 34.5 degrees at 30 psi and 32.5 degrees at 60 psi. This average 1.5 degree variation as a function of confining pressure is believed due to apparent pre-consolidation effects at the lower confining pressures and, at higher pressures, to development on the shear plane of locally high pore pressures which cannot be accurately measured at the specimen ends.

The average angle (ϕ') is 31.8 degrees for all tests at granular contents of less than 40 percent. For 40 percent granular content, ϕ' is 32.5 degrees and, for 45 and

50 percent combined, the average is 35.3 degrees. The standard deviations of the test results are 2.7, 2.2 and 1.9 degrees respectively.

Total Stresses

Comparison of total stress envelopes indicates the available shear resistance of varying granular contents. The total stress strength increases dramatically at 40 percent granular content with an average increase in apparent cohesion (c) of 7.7 psi. The total stress angle (ϕ) averages 12.5 degrees, apparently without significant variation as a function of granular content. More variation is evident as a function of test specimen size with 2.75 inch diameter specimens indicating an average value of ϕ of 4.9 degrees greater than was determined for 1.4 inch specimens.

The increase in total stress occurring at approximately 40 percent granular content and above is believed due to internal pressure dissipation within the shear plane from dilatancy and to pressure equalization within the specimen as a function of the greatly increased permeability.

Triaxial Stress-Strain Related Factors

Factor $\frac{u-u_o}{\sigma 1-\sigma 3}$ is the ratio of the internal pore pressure measured to the added axial load applied to the specimen. This factor, included in the plots in alternate Figures 5 through 39, averages 0.8 to 1.0 through the 0 to 30 percent granular range but, significantly, drops as low as 0.3 for tests on specimens where granular content exceeds about 40 percent. At the higher contents, dilatancy effects are probably tending to relieve internal pore pressures at the shear plane in combination with increased permeability.

The factor $\frac{\sigma 1-u}{\sigma 3-u}$ is the ratio of the effective axial load to the effective confining load on the specimen. Plots of this factor are included in alternate Figures 5 through 39, for varying specimen sizes. There are no significant patterns to the variations of this factor throughout the range of tests. This suggests that rate of shear, drainage and monitored pressures are not significant variables through the range of specimen sizes and granular contents tested.

Permeability

Permeability data, obtained from consolidation tests on specimens with varying granular content, are tabulated on Table 2. The permeabilities shown are calculated from coefficients of consolidation and compressibility and from compression indices derived from one-dimensional consolidation tests.

This data shows the permeability of the specimen with 45 percent retained on the No. 10 sieve to have a 50 fold increase in permeability over a sample having 30 percent retained on the No. 10 sieve.

Time curves, plotted from consolidation of 2.75 inch diameter triaxial specimens at varying granular contents, are shown in Figure 4. Due to the complex drainage and indeterminate time factors associated with use of discontinuous filter strips, coefficients of consolidation were not calculated. However, a comparison of these curves indicates that the time for 50 percent consolidation, which is inversely proportionate to the coefficient of consolidation, decreases as the percent granular content increases. At 40 percent granular content, the time for 50 percent consolidation is in the one to ten minute range as compared to 50 minutes for specimens with lower granular content. This corresponds to the changes in permeability computed from consolidation data.

All data and observations indicate that at about 40 percent granular content, a substantial increase occurs in permeability.

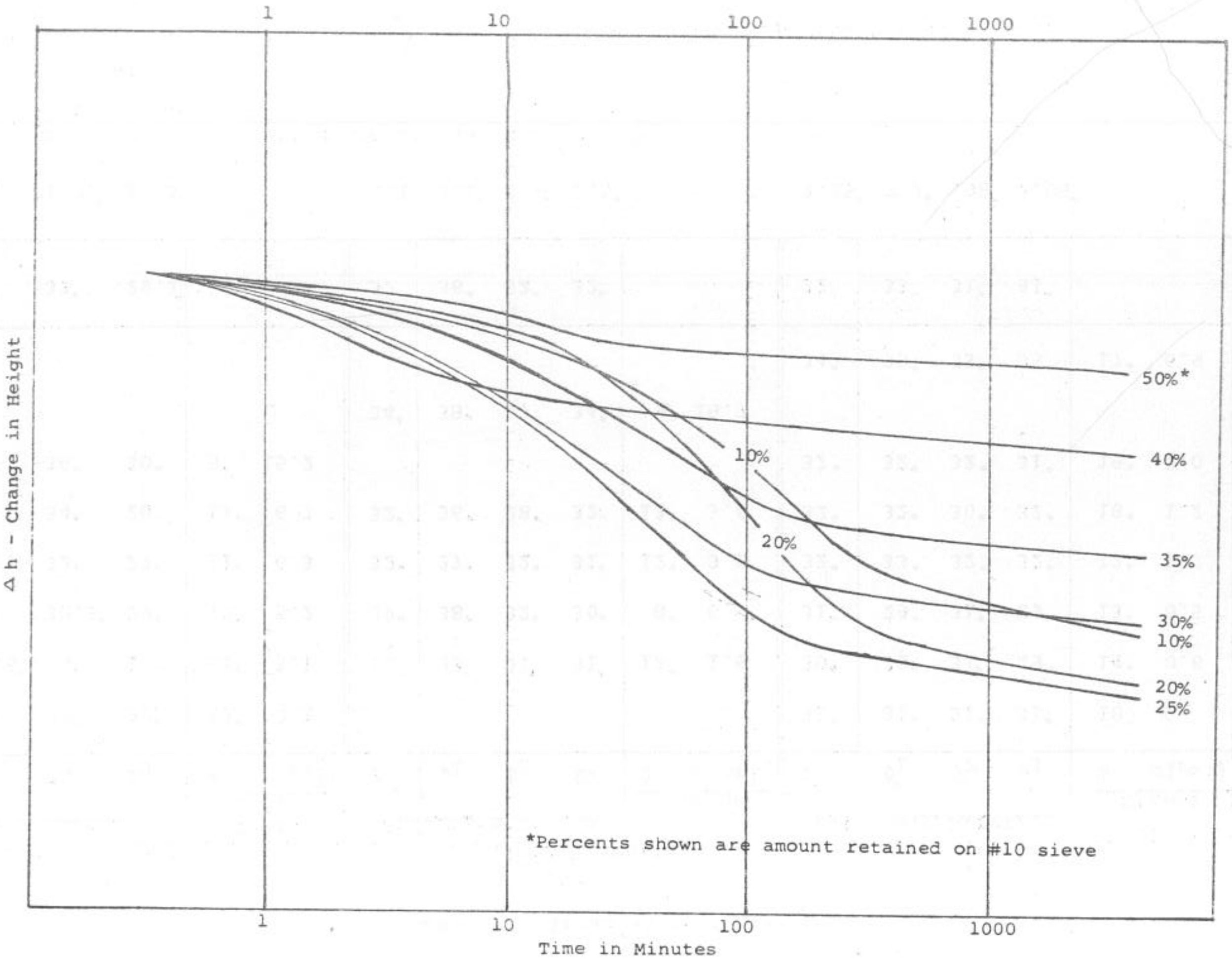

Figure 4. Consolidation Curves for 2.75 Inch Diameter Triaxial Specimens at 60 psi Lateral Pressure

TABLE 1

Summary Of Triaxial Test Data

% Granular Content**	1.4" Specimen Diameter: Effective Stress				Total Stress		2.0" Specimen Diameter: Effective Stress				Total Stress		2.75" Specimen Diameter: Effective Stress				Total Stress		Averages		
	ϕ'^*	ϕ'_1	ϕ'_2	ϕ'_3	ϕ	c(psi)	ϕ'^*	ϕ'_1	ϕ'_2	ϕ'_3	ϕ	c(psi)	ϕ'^*	ϕ'_1	ϕ'_2	ϕ'_3	ϕ	c(psi)	ϕ'^*	ϕ	c(psi)
10	32°	36°	32°	32°	13°	2.1							31°	31°	31°	31°	18°	0	32°	15.5°	1.1
20	30°	30.5°	34°	30°	13°	3.1	31°	33°	31°	31°	13°	1.6	30°	39°	31°	29°	14°	0.6	32°	13.3°	1.8
25	31°	33°	30.5°	29°	12°	5.2	32°	38°	32°	30°	8°	6	31°	29°	31°	29°	13°	0.5	31°	11°	3.9
30	32°	34.5°	32°	27°	11°	6.3	32°	37°	32°	31°	12°	3.8	32°	33°	32°	32°	12°	1.7	32°	12°	3.9
35	29°	30°	34°	28°	11°	6.7	32°	36°	28°	32°	13°	3.6	32°	32°	30°	32°	18°	1.2	31°	14°	3.8
40	34°	34°	36°	30°	5°	15.2							32°	32°	32°	31°	18°	2.0	33°	11.5°	8.6
45							34°	38°	37°	34°	9°	18.7							34°		
50													34°	35°	33°	35°	17°	6.9	34°		
Average	31°	33°	33°	29.3°			32°	36°	32°	32°			32°	33°	31°	31°			32°		
Standard Deviation	1.75°	2.35°	1.96°	1.75°			1.1°	2.1°	3.2°	1.5°			1.25°	3.2°	.98°	2.06°			2.8°		

* Average tangent to Mohr's circles - effective stress (case c' = 0)

ϕ'_1 Confining pressure = 15 psi (c'= 0)

ϕ'_2 Confining pressure = 30 psi (c'= 0)

ϕ'_3 Confining pressure = 60 psi (except for 50% granular where the confining pressure = 45 psi) (c'= 0)

** Amount retained on No. 10 sieve

TABLE 2

Summary of Permeability Data Determined by One-Dimensional Consolidation Tests

Granular Content*	Coefficient of Consolidation** $Ft.^2/Day \times 10^{-2}$	Permeability*** $X10^{-5}$ Ft./Day
10%	2	7.5
20%	1.5	5.9
30%	1.5	4.7
45%	60	250

*Amount retained on No. 10 sieve
**4, 8 and 16 Tsf loading average
***At 4 ton loading in consolidometer

TABLE 3

Averages Of Pore Pressure Factor $\frac{(u-u_o)}{(\sigma 1-\sigma 3)}$ Vs. Varying Granular Content

% Granular Content#

$\sigma 1 - \sigma 3$	10*	20	25	30	35	40	45**	50***
				At 3% Strain				
15 psi	.925	.94	.89	.57	.63	.45	.1	.3
30 psi	.925	.96	1.0	.87	.80	.6	.35	.4
60 psi	1.025	1.08	1.1	1.11	.9	.78	.4	.5##
				At 8% Strain				
15 psi	.81	.79	.65	.44	.44	.29	0	.05
30 psi	.8	.93	.83	.75	.82	.51	.18	.03
60 psi	.97	1.0	.98	1.13	.94	.76	.32	.42

* 1.4" and 2.75" diameter specimens only
** 2" diameter specimen only
*** 2.75" diameter specimen only
\# Amount retained on No. 10 sieve
\## $\sigma 1-\sigma 3$ = 45 psi

TABLE 4

Effective Stress Factor $\frac{(\sigma^1-u)}{(\sigma^3-u)}$ Vs. Varying Granular Content

For 1.4 Inch Diameter Triaxial Specimens

$\sigma^1 - \sigma^3$	% Granular Content# 10	20	25	30	35	40	Average	Standard Deviation
				At 3% Strain				
15 psi	3.2	2.5	3.3	3.75	2.7	3.3	3.13	.45
30 psi	2.8	3.35	3.05	3.55	3.4	3.8	2.93	1.24
60 psi	2.4	2.8	2.7	2.5	2.6	2.8	2.63	.16
Average	2.8	2.88	3.02	3.27	2.9	3.3	3.03	
Standard Deviation	0.4	.43	.3	.67	.44	.5	.46	
				At 8% Strain				
15 psi	3.55	2.6	3.3	3.5	2.8	3.3	3.18	.39
30 psi	3.3	3.5	3.1	3.6	3.6	3.5	3.3	.32
60 psi	2.55	2.85	2.8	2.8	2.7	2.9	2.78	.14
Average	3.13	2.98	3.1	3.3	3.1	3.23	3.14	
Standard Deviation	.52	.46	.25	.49	.44	.31	.41	

Amount retained on No. 10 sieve

TABLE 5

Effective Stress Factor $\left(\frac{\sigma_1 - u}{\sigma_3 - u}\right)$ Vs. Varying Granular Content

For 2.0 Inch Diameter Triaxial Specimens

$\sigma_1 - \sigma_3$	20	25	30	35	45	Average	Standard Deviation
	% Granular Content#						
	At 3% Strain						
15 psi	2.2	4.3	4.0	4.2	4.0	3.7	.87
30 psi	2.8	3.1	3.1	2.5	3.9	3.2	.48
60 psi	2.4	2.7	2.8	3.0	3.4	2.9	.37
Average	2.47	2.1	3.4	3.3	3.2	2.9	
Standard Deviation	.31	1.44	.83	.8	.76	.8	
	At 8% Strain						
15 psi	2.3	2.8	3.4	3.4	3.6	3.1	.54
30 psi	3.2	3.0	2.8	2.7	3.5	3.0	.32
60 psi	2.7	2.9	3.0	3.2	3.2	3.0	.21
Average	2.73	2.9	3.1	3.70	3.4	3.0	
Standard Deviation	.45	.10	.31	.26	.21	.27	

Amount retained on No. 10 sieve

TABLE 6

Effective Stress Factor $\frac{(\sigma^1 - u)}{(\sigma^3 - u)}$ Vs. Varying Granular Content

For 2.75 Inch Diameter Triaxial Specimens

% Granular Content#

$\sigma^1 - \sigma^3$	10	20	25	30	35	40	50*	Average	Standard Deviation
					At 3% Strain				
15 psi	3.0	3.4	2.9	3.2	3.6	3.2	3.6	3.3	.28
30 psi	2.9	2.7	3.1	2.9	2.9	3.3	3.3	3.0	.23
60 psi	2.7	2.7	2.7	2.4	3.0	3.0	3.5*	2.86	.35
Average	2.87	2.93	2.9	2.8	3.2	3.2	3.5	3.1	
Standard Deviation	.15	0.4	.2	.4	.28	.15	.15	.25	
					At 8% Strain				
15 psi	2.7	4.2	2.7	3.2	3.5	3.2	3.4	3.3	.5
30 psi	3.0	3.0	3.1	3.2	3.3	3.3	3.2	3.2	.13
60 psi	3.0	3.0	2.9	2.5	3.3	3.1	3.5	3.0	.32
Average	3.0	3.4	2.9	3.0	3.4	3.2	3.4	3.1	
Standard Deviation	.06	.7	.2	.4	.12	.1	.15	.25	

*45 psi loading only
#Amount retained on No. 10 sieve

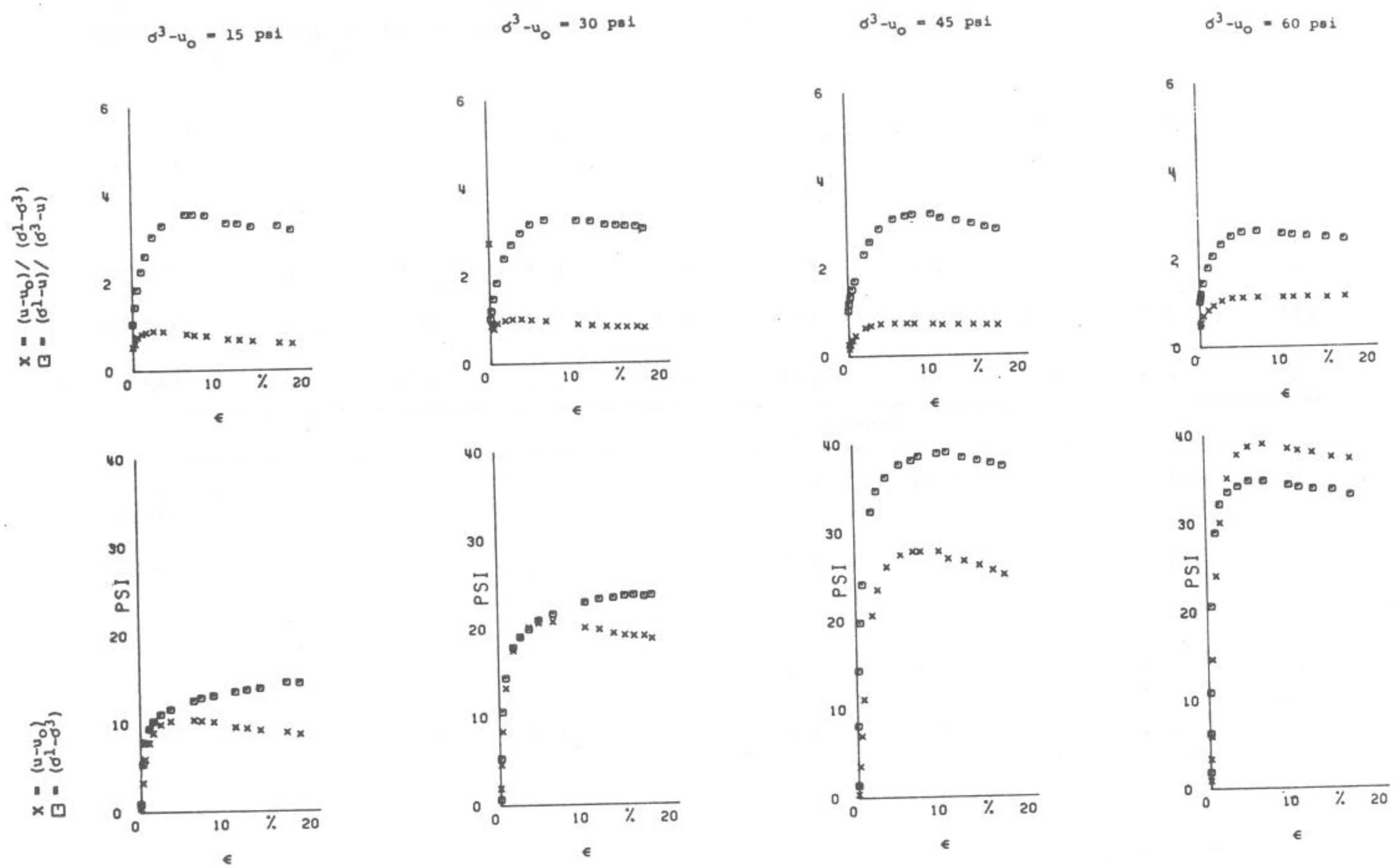

Figure 5 . Stress - Strain Relationships of 1.4 Inch Diameter Specimens With 10 Percent Retained On Number 10 Sieve

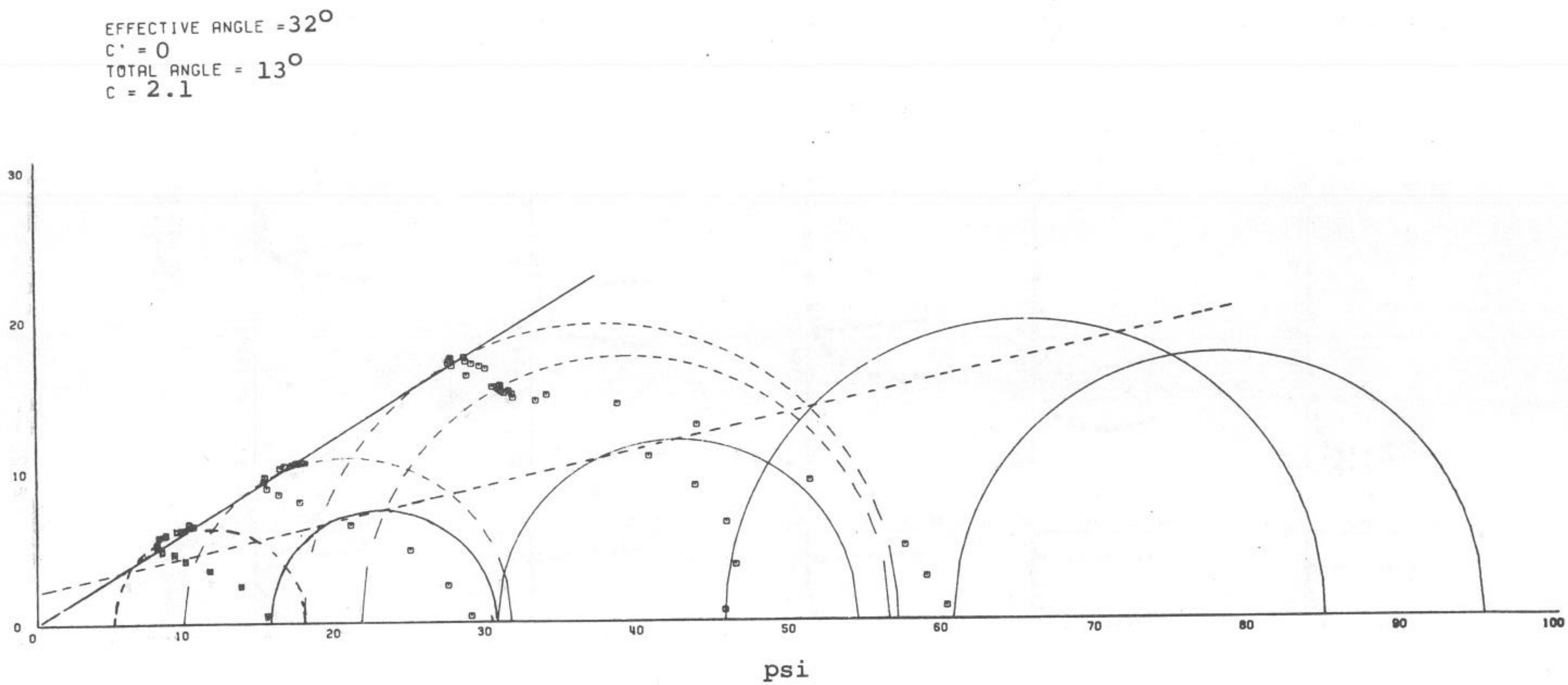

Figure 6. Triaxial Shear Strength Envelope For 1.4 Inch Diameter Specimens With 10 Percent Retained On Number 10 Sieve

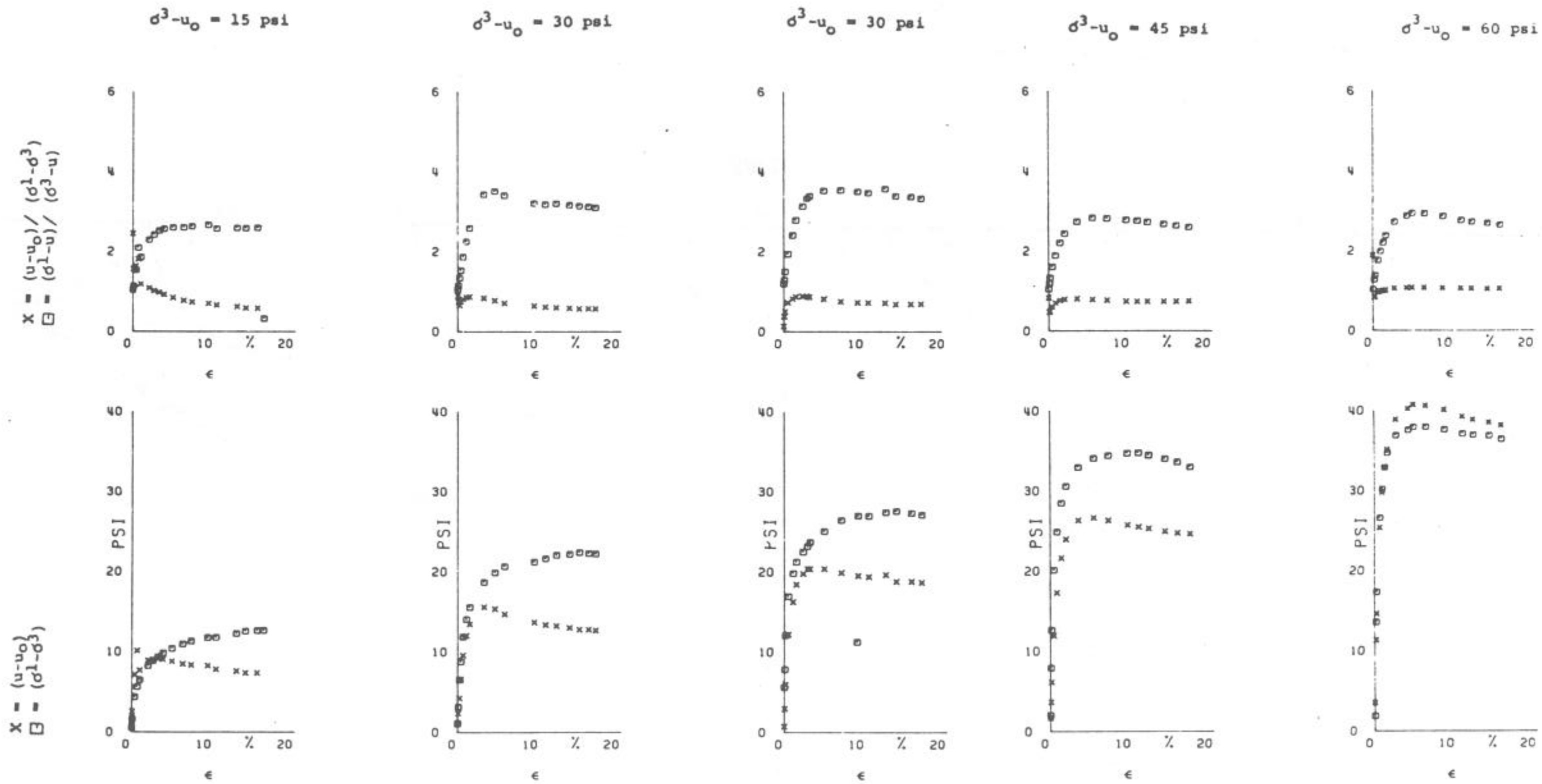

Figure 7 . Stress - Strain Relationships of 1.4 Inch Diameter Specimens With 20 Percent Retained On Number 10 Sieve

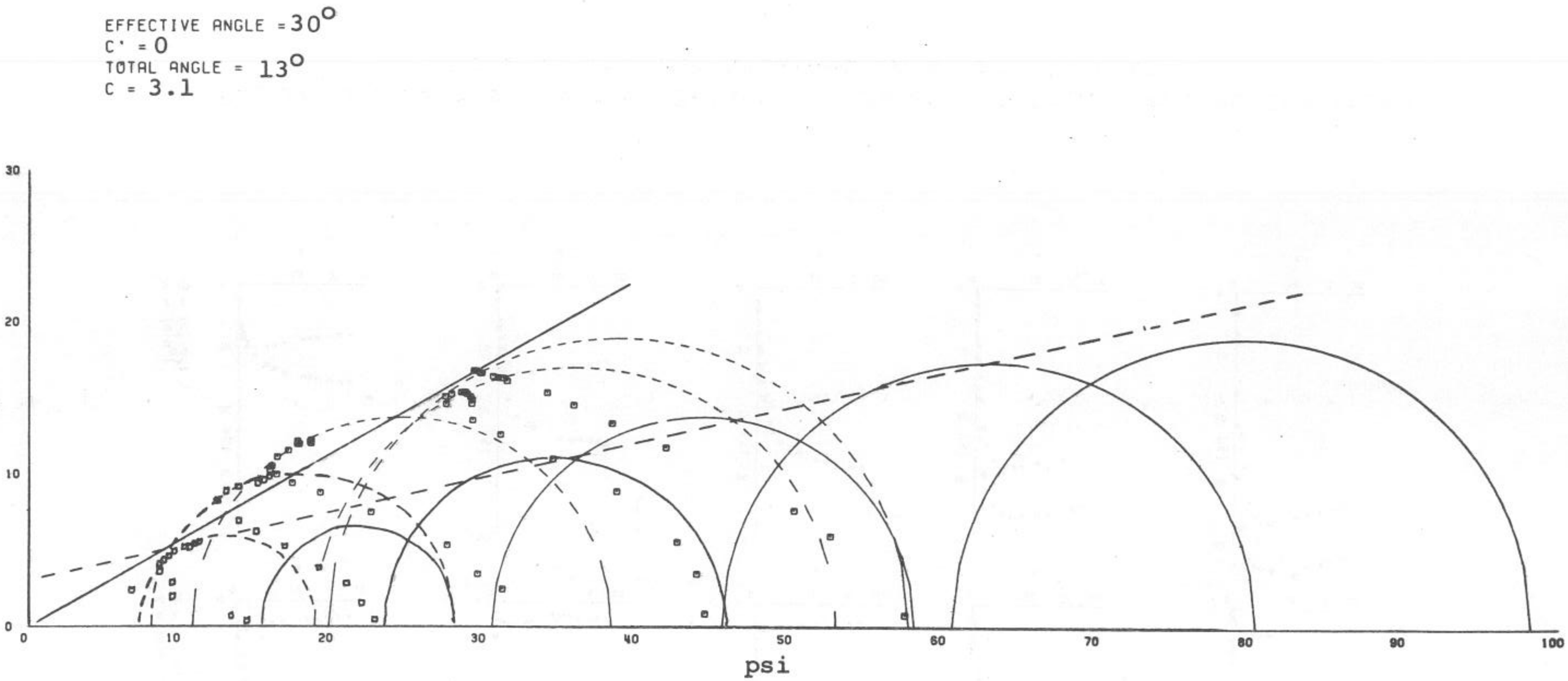

Figure 8. Triaxial Shear Strength Envelope For 1.4 Inch Diameter Specimens With 20 Percent Retained On Number 10 Sieve

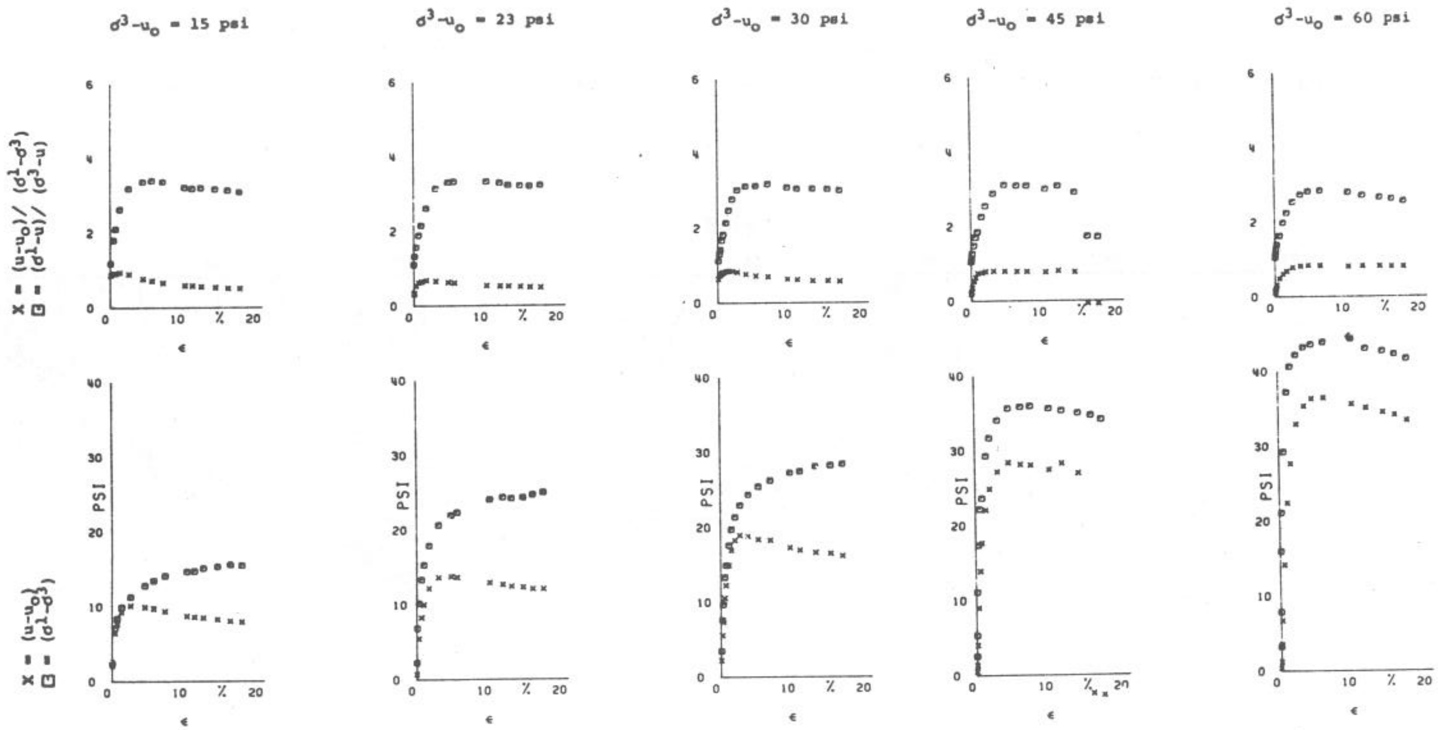

Figure 9 . Stress - Strain Relationships of 1.4 Inch Diameter Specimens
With 25 Percent Retained On Number 10 Sieve

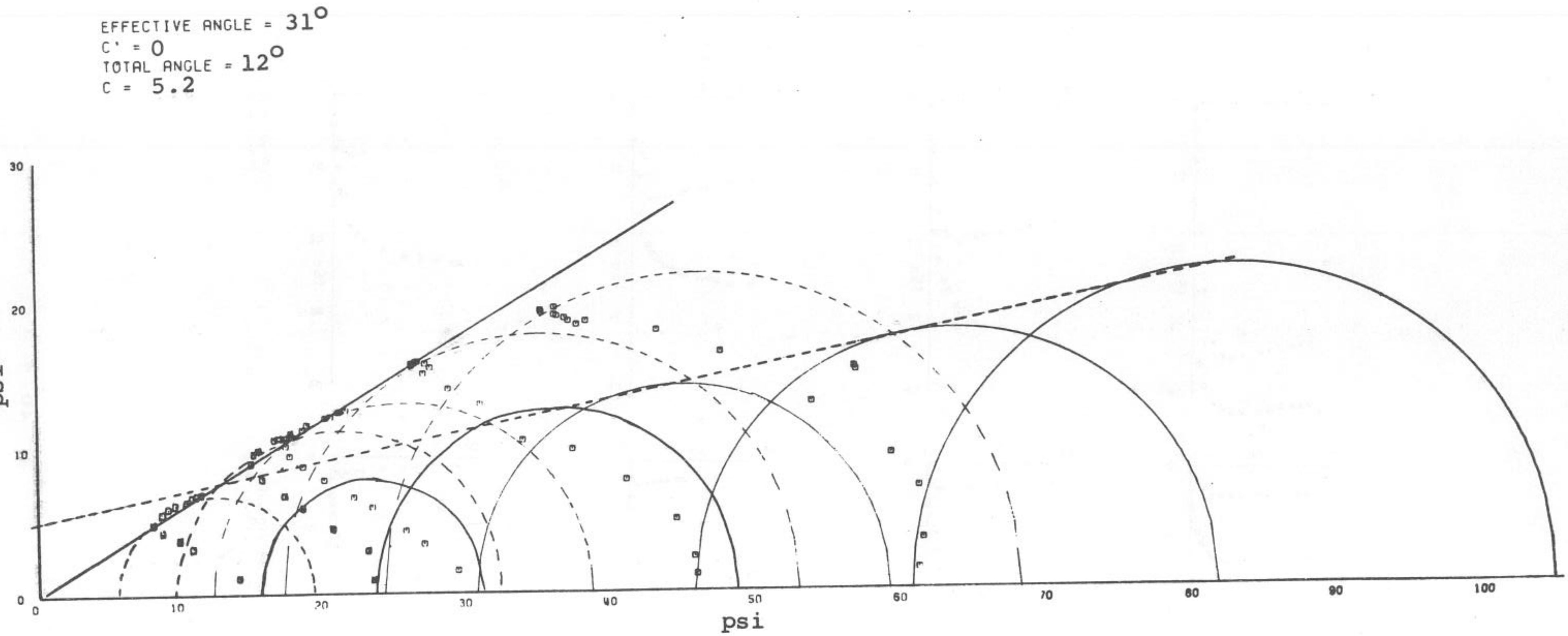

Figure 10. Triaxial Shear Strength Envelope For 1.4 Inch Diameter Specimens With 25 Percent Retained On Number 10 Sieve

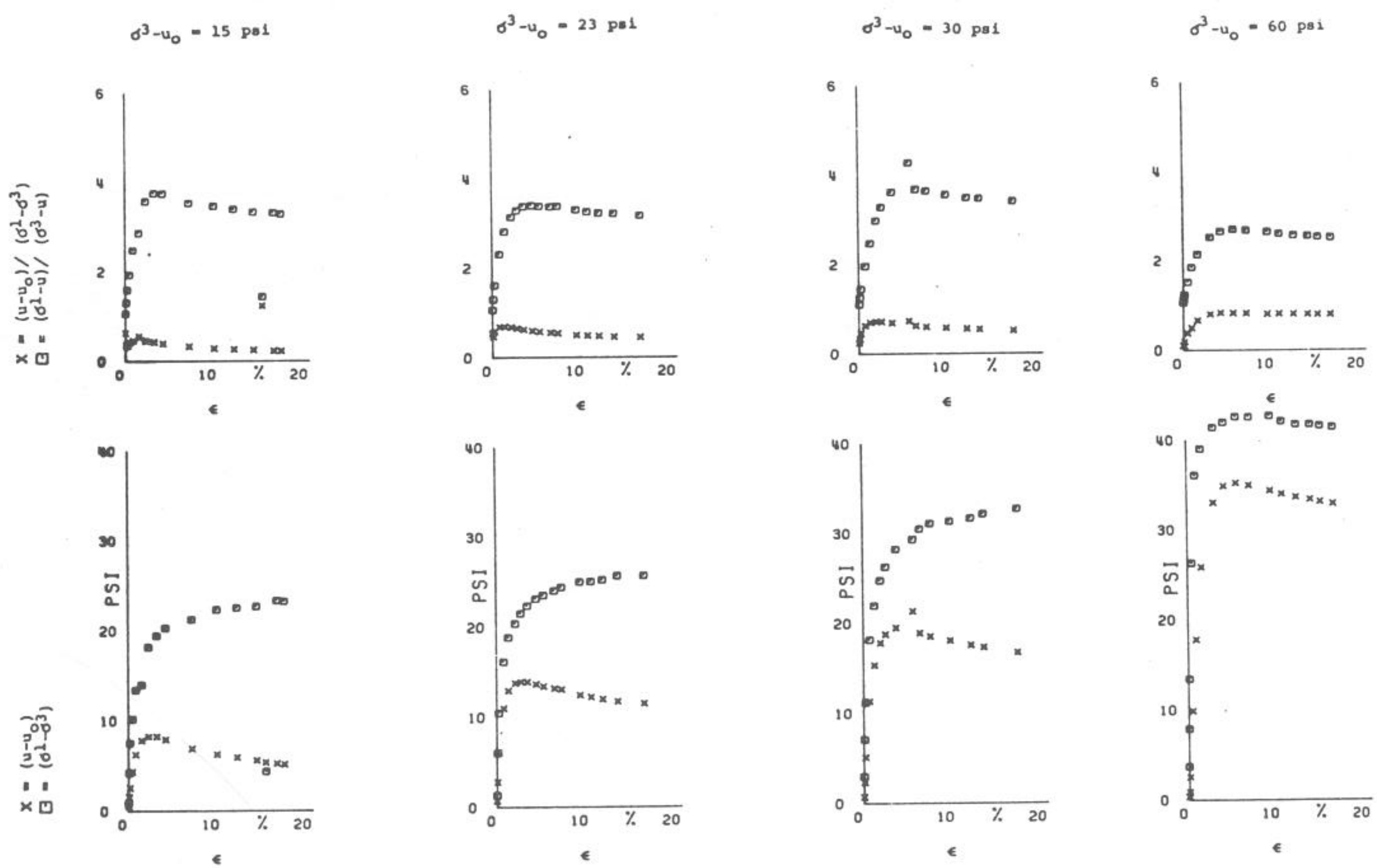

Figure 11. Stress - Strain Relationships of 1.4 Inch Diameter Specimens With 30 Percent Retained On Number 10 Sieve

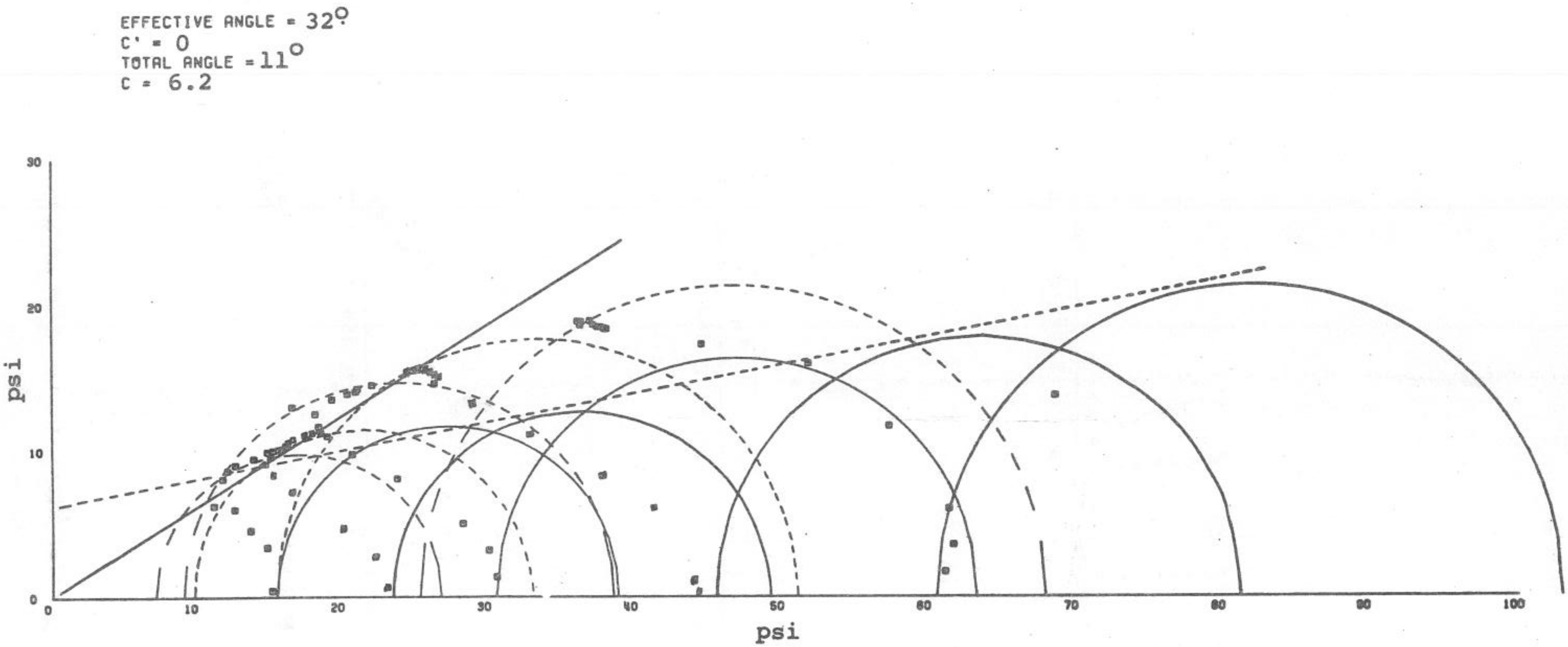

Figure 12. Triaxial Shear Strength Envelope For 1.4 Inch Diameter Specimens
With 30 Percent Retained On Number 10 Sieve

3.36

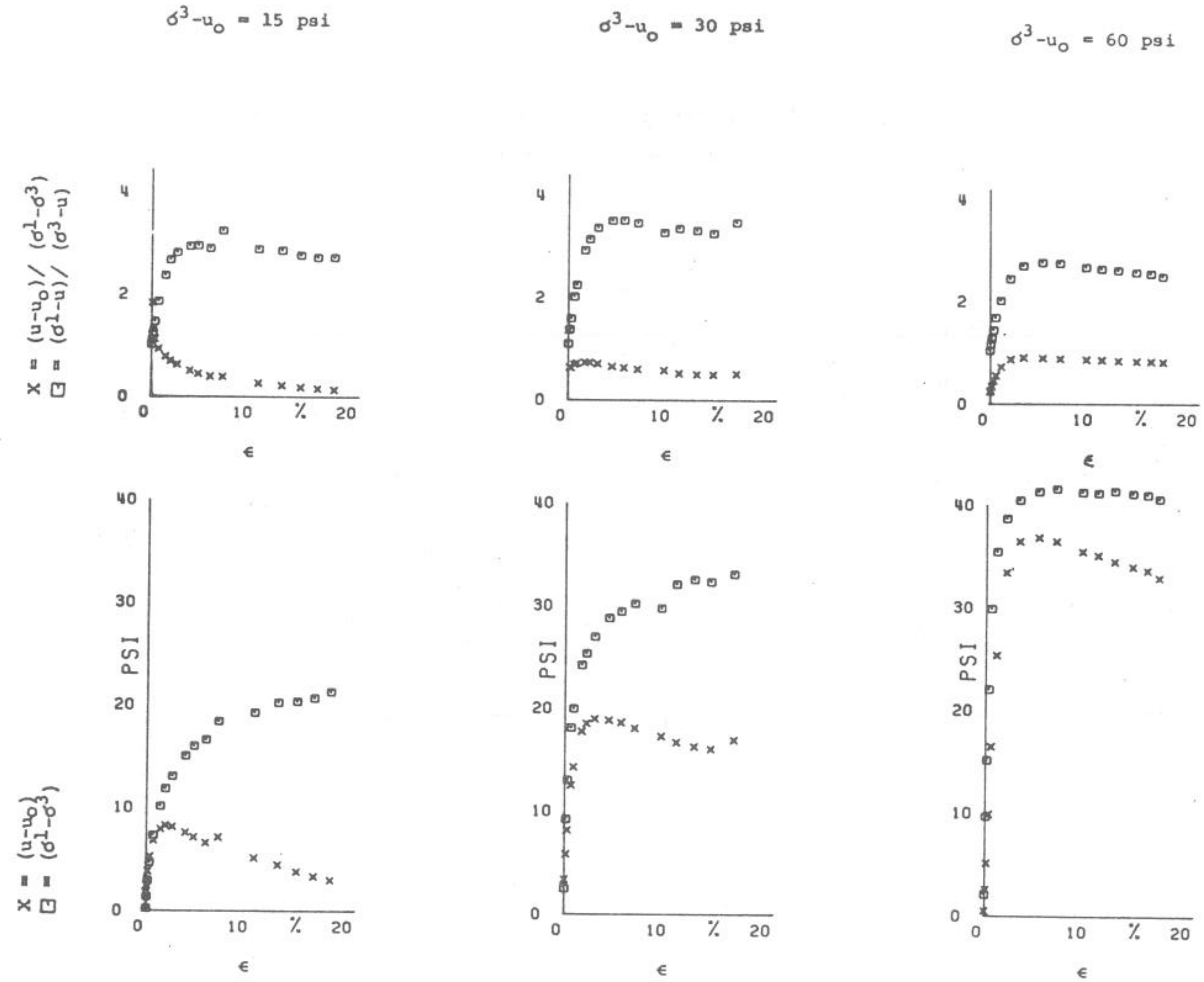

Figure 13. Stress - Strain Relationships of 1.4 Inch Diameter Specimens With 35 Percent Retained On Number 10 Sieve

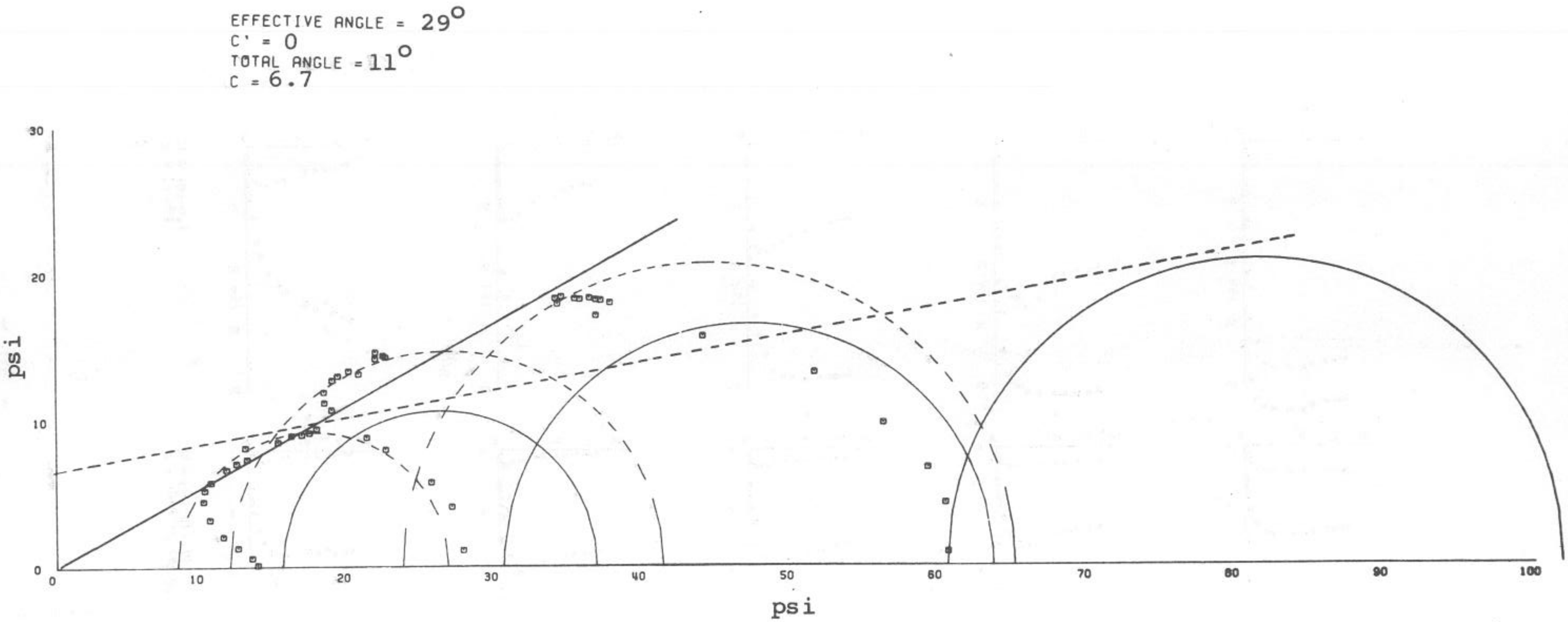

Figure 14. Triaxial Shear Strength Envelope For 1.4 Inch Diameter Specimens With 35 Percent Retained On Number 10 Sieve

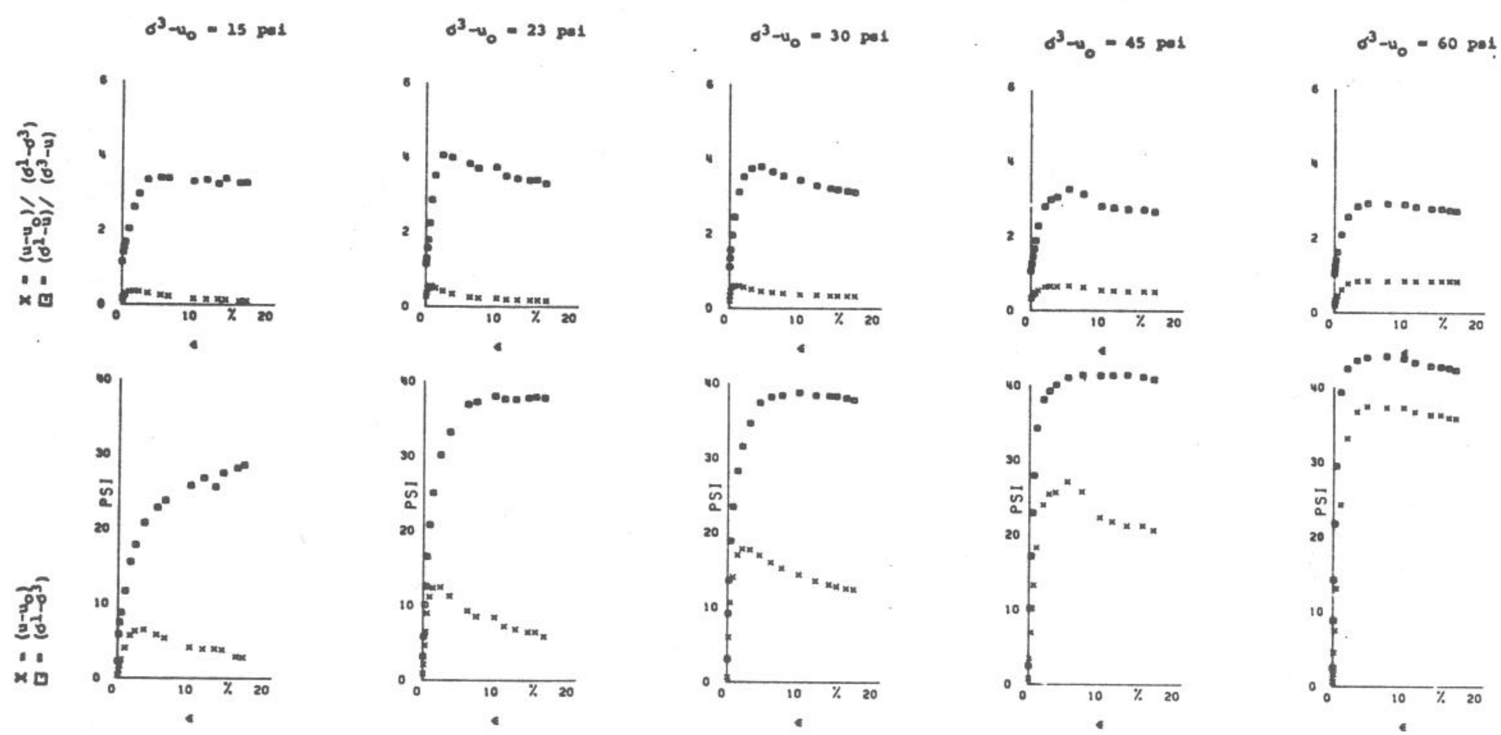

Figure 15 . Stress - Strain Relationships of 1.4 Inch Diameter Specimens
With 40 Percent Retained On Number 10 Sieve

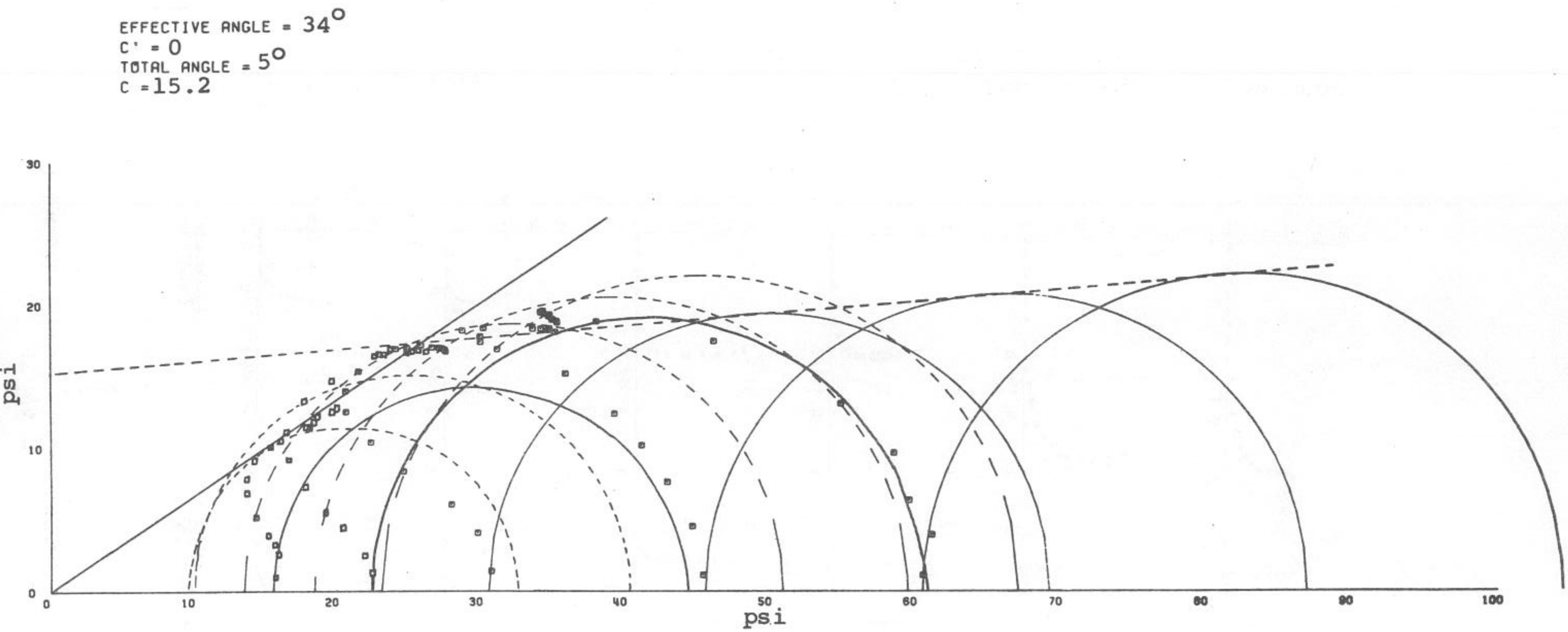

Figure 16. Triaxial Shear Strength Envelope For 1.4 Inch Diameter Specimens With 40 Percent Retained On Number 10 Sieve

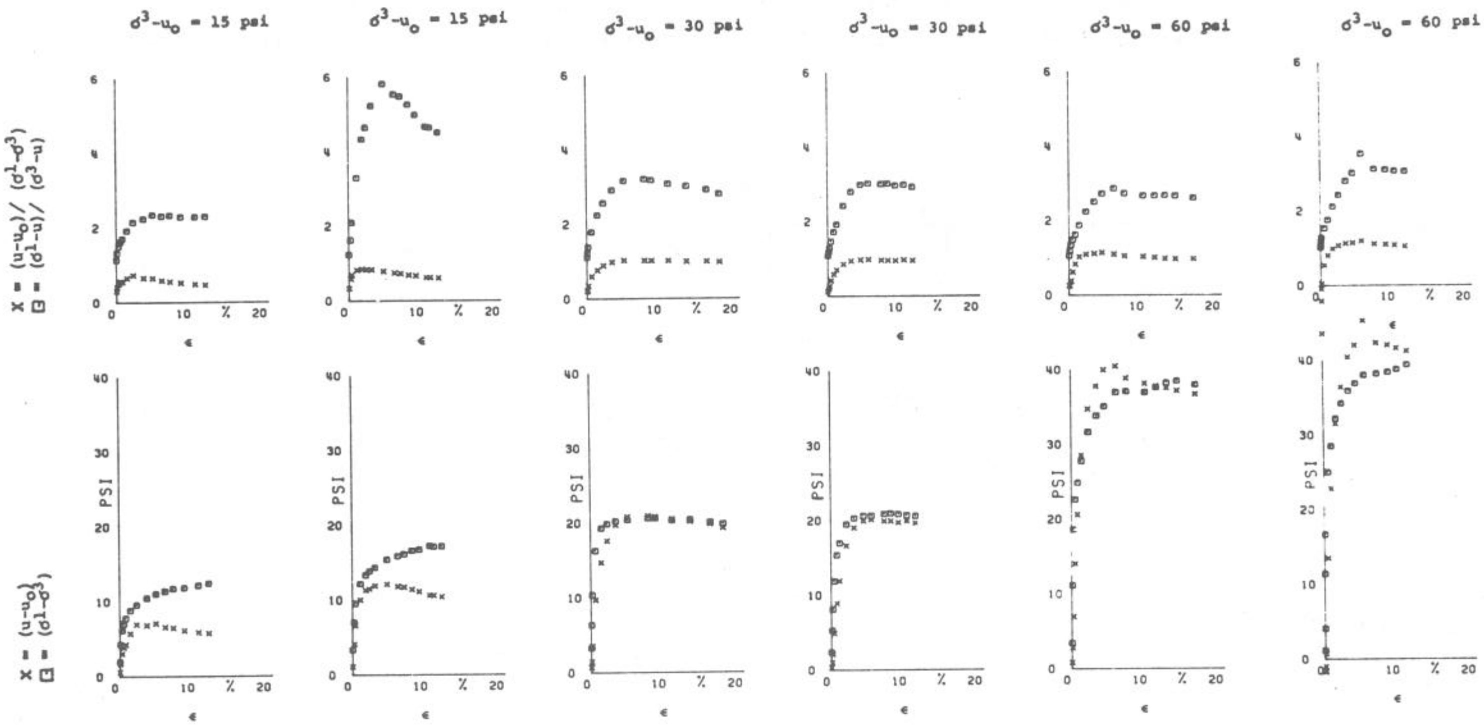

Figure 17. Stress - Strain Relationships of 2.0 Inch Diameter Specimens With 20 Percent Retained On Number 10 Sieve

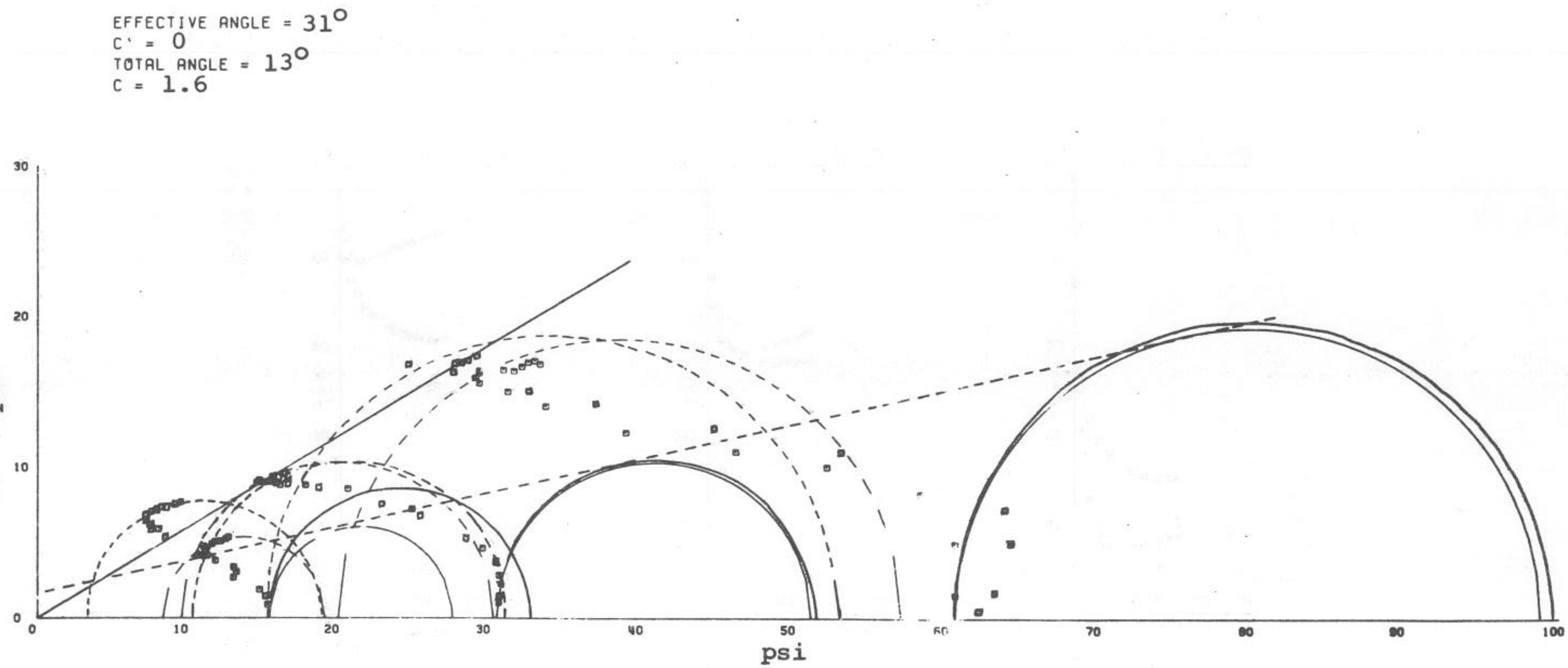

Figure 18. Triaxial Shear Strength Envelope For 2.0 Inch Diameter Specimens With 20 Percent Retained On Number 10 Sieve

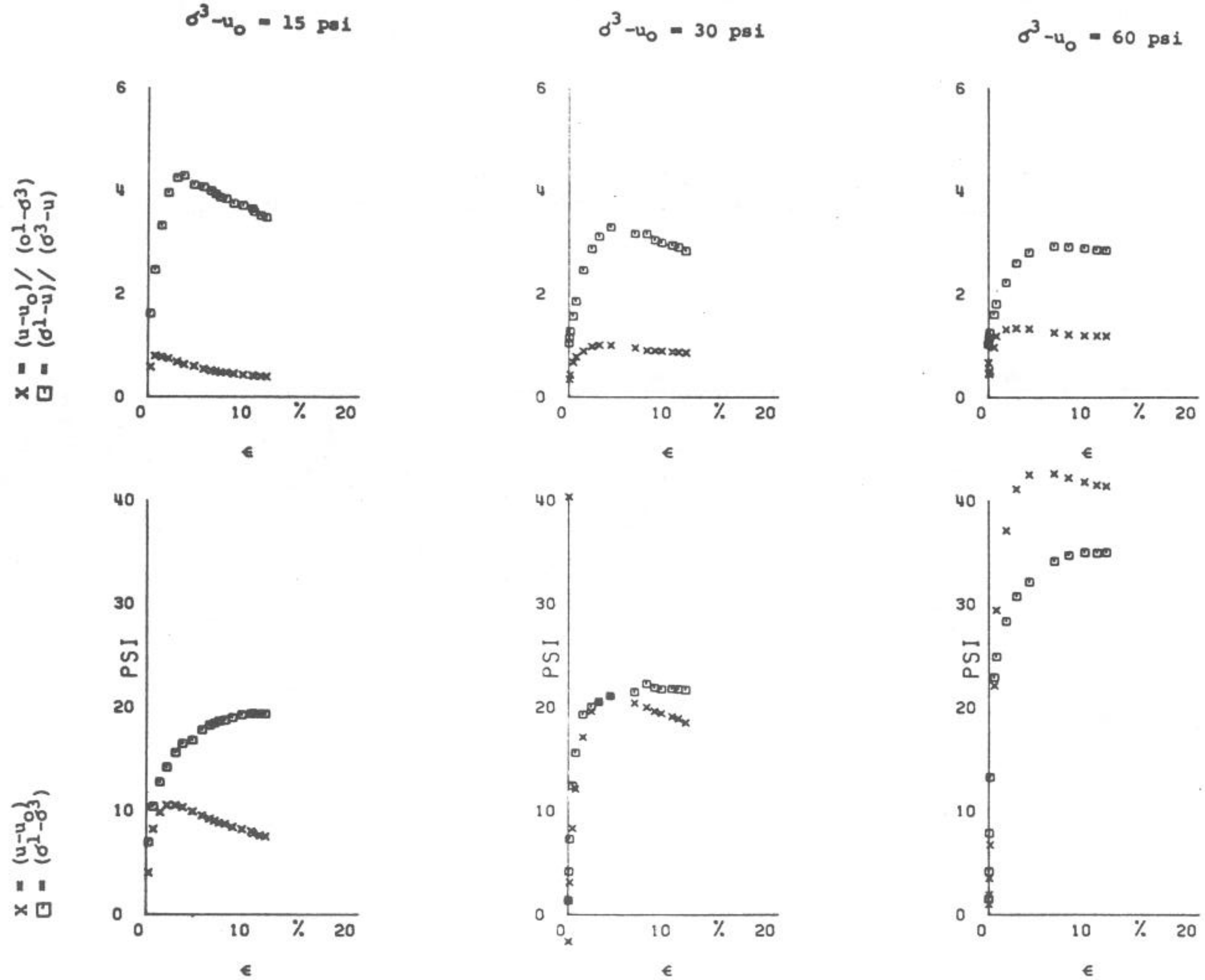

Figure 19. Stress - Strain Relationships of 2.0 Inch Diameter Specimens With 25 Percent Retained On Number 10 Sieve

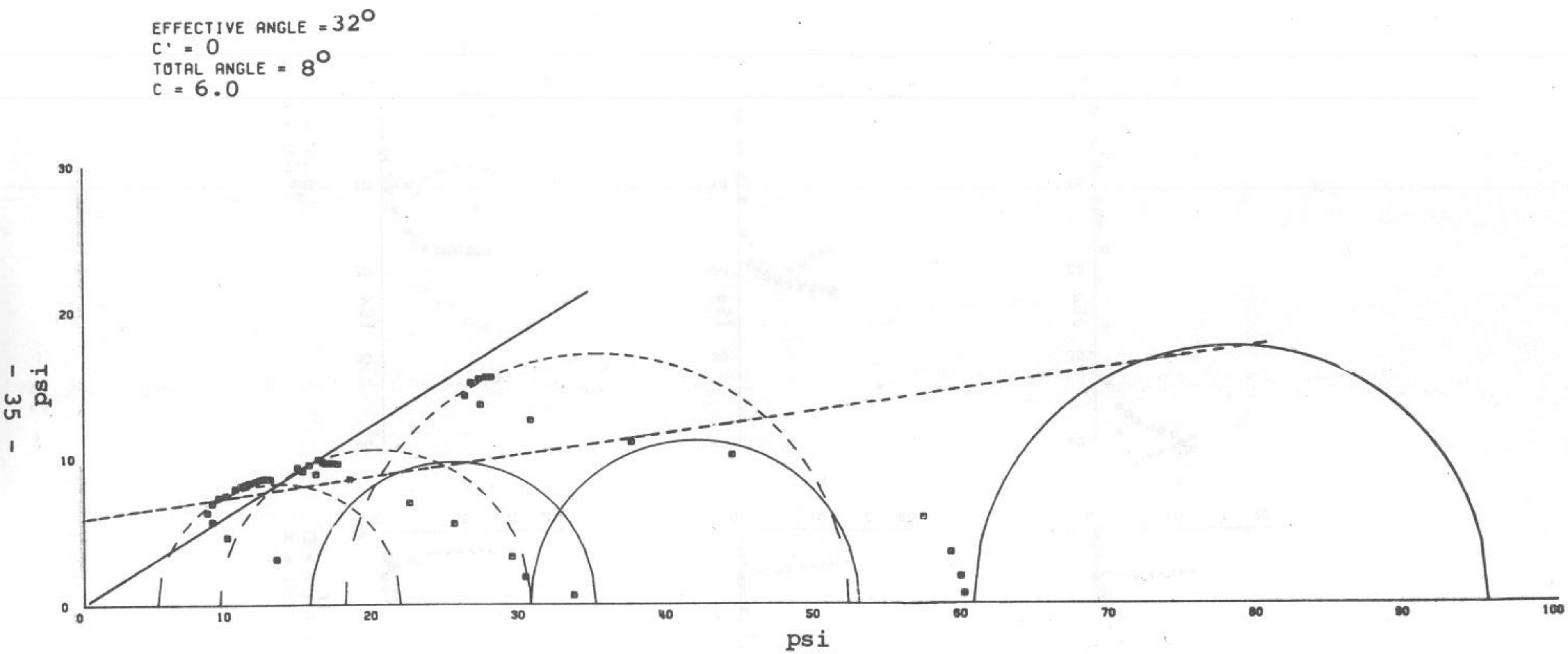

Figure 20. Triaxial Shear Strength Envelope For 2.0 Inch Diameter Specimens With 25 Percent Retained On Number 10 Sieve

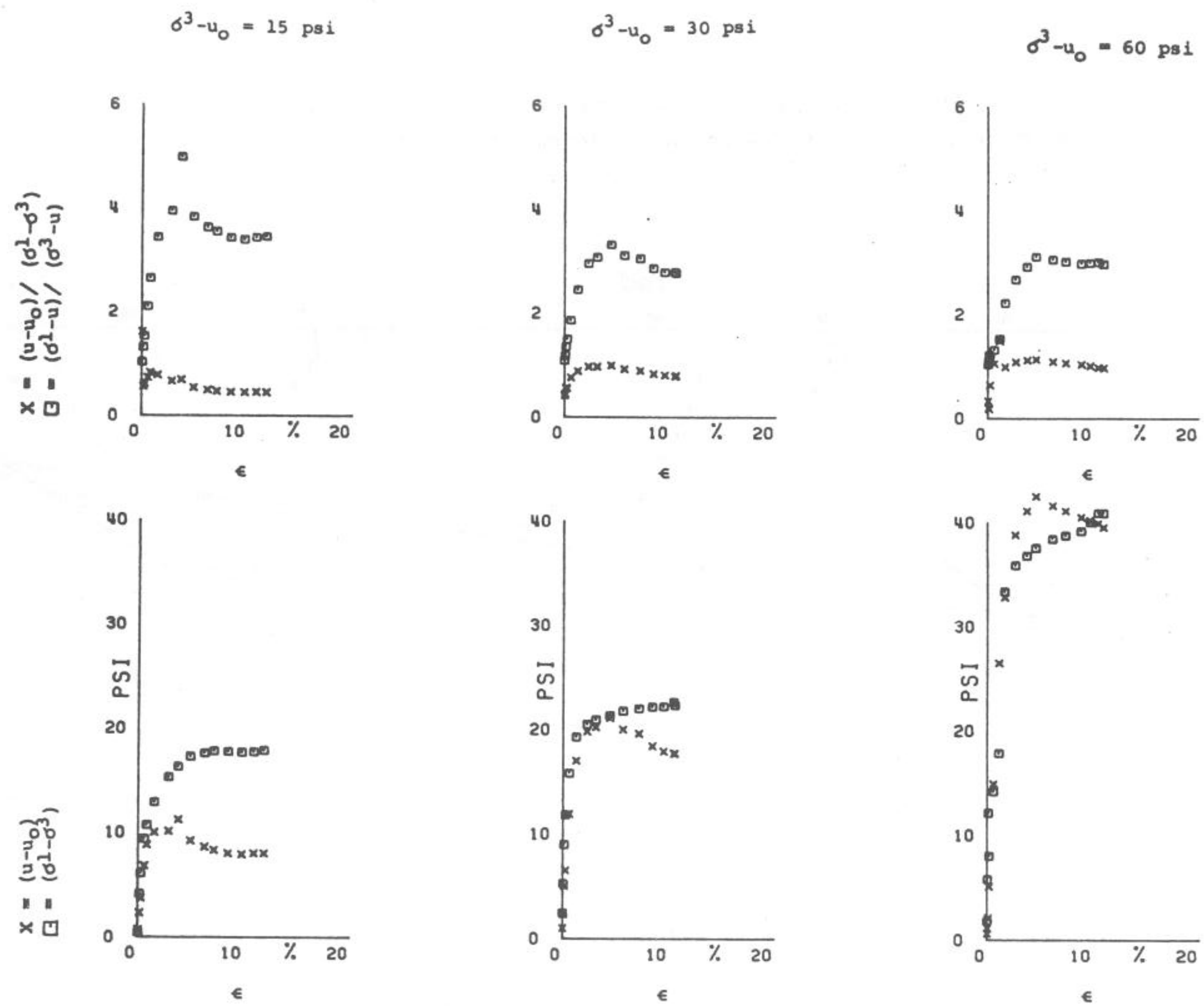

Figure 21. Stress - Strain Relationships of 2.0 Inch Diameter Specimens
With 30 Percent Retained On Number 10 Sieve

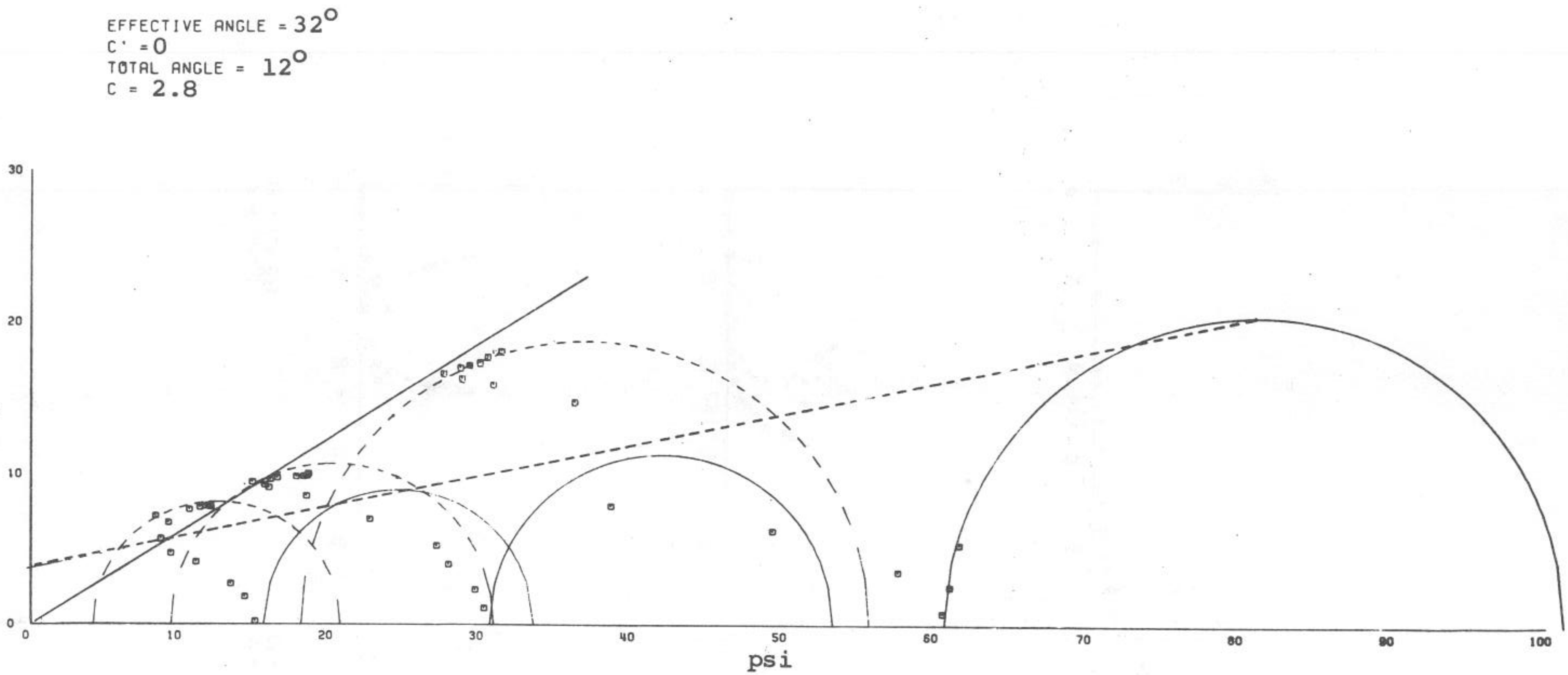

Figure 22. Triaxial Shear Strength Envelope For 2.0 Inch Diameter Specimens With 30 Percent Retained On Number 10 Sieve

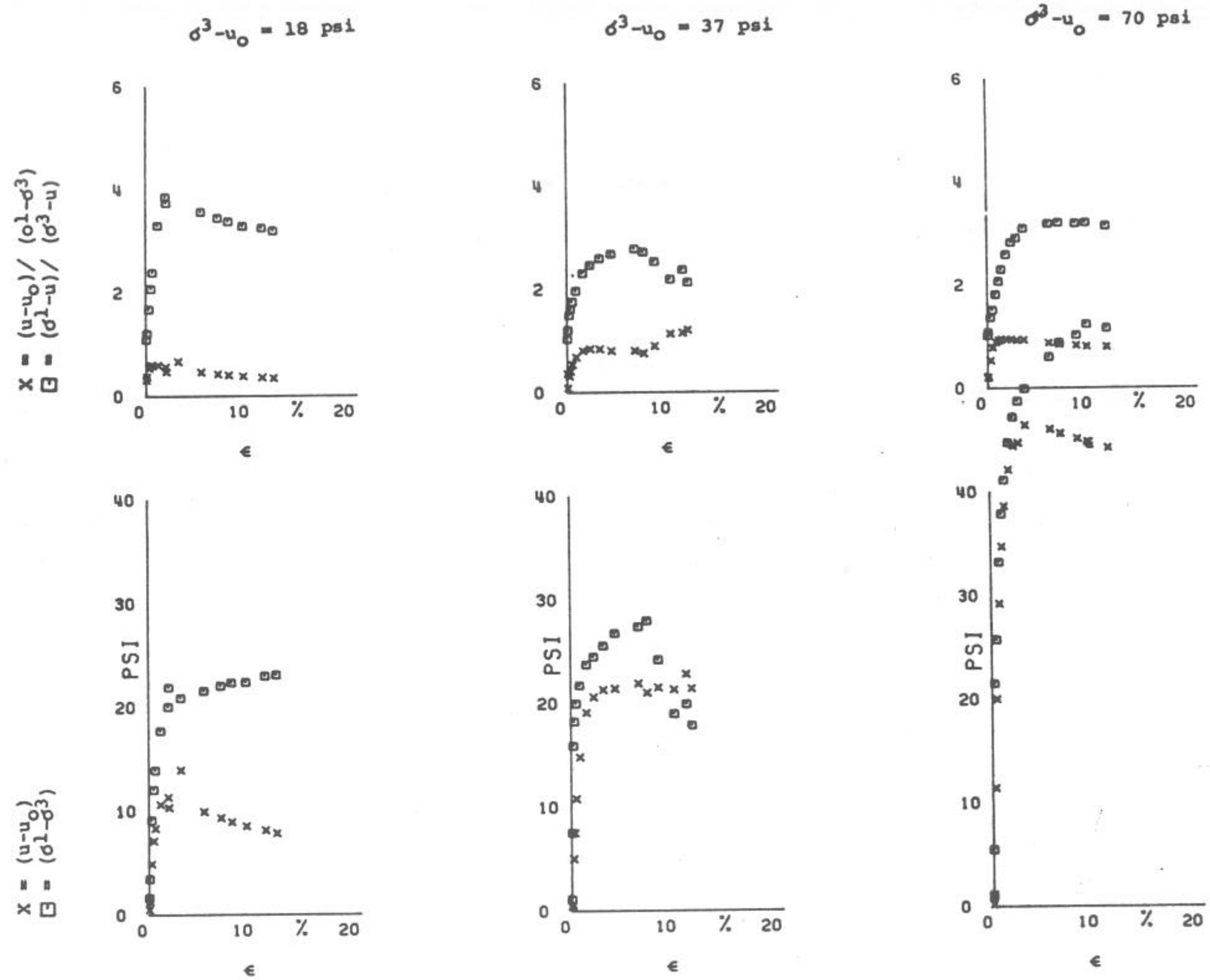

Figure 23. Stress - Strain Relationships of 2.0 Inch Diameter Specimens With 35 Percent Retained On Number 10 Sieve

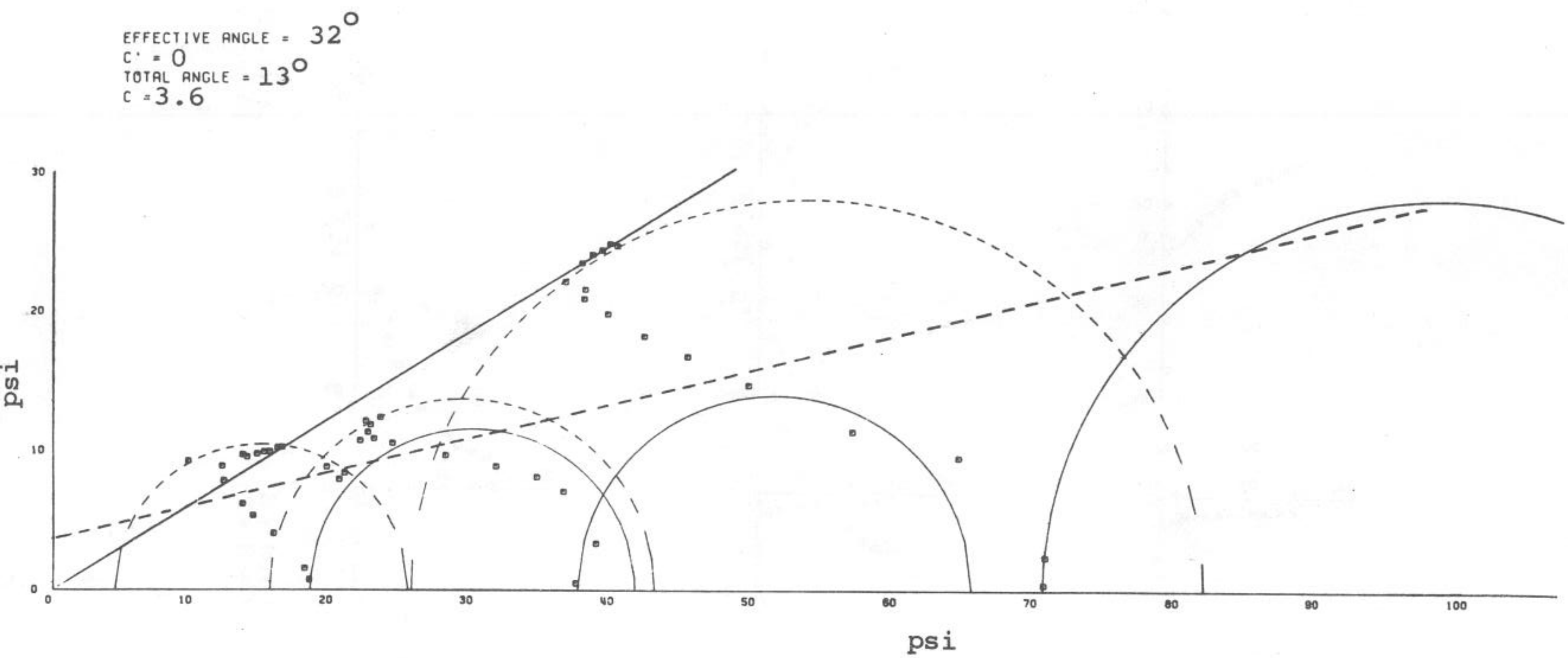

Figure 24. Triaxial Shear Strength Envelope For 2.0 Inch Diameter Specimens With 35 Percent Retained On Number 10 Sieve

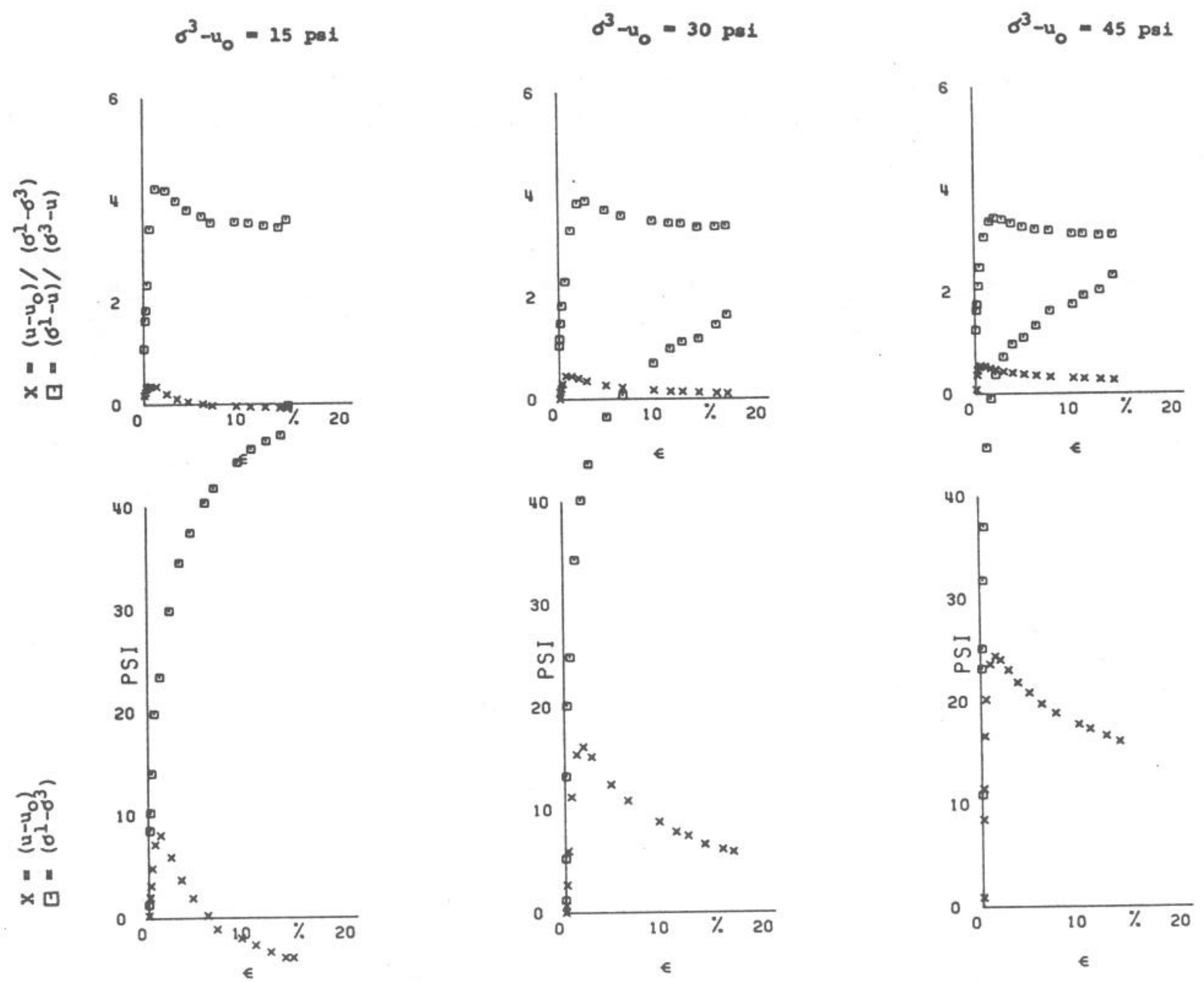

Figure 25. Stress - Strain Relationships of 2.0 Inch Diameter Specimens With 45 Percent Retained On Number 10 Sieve

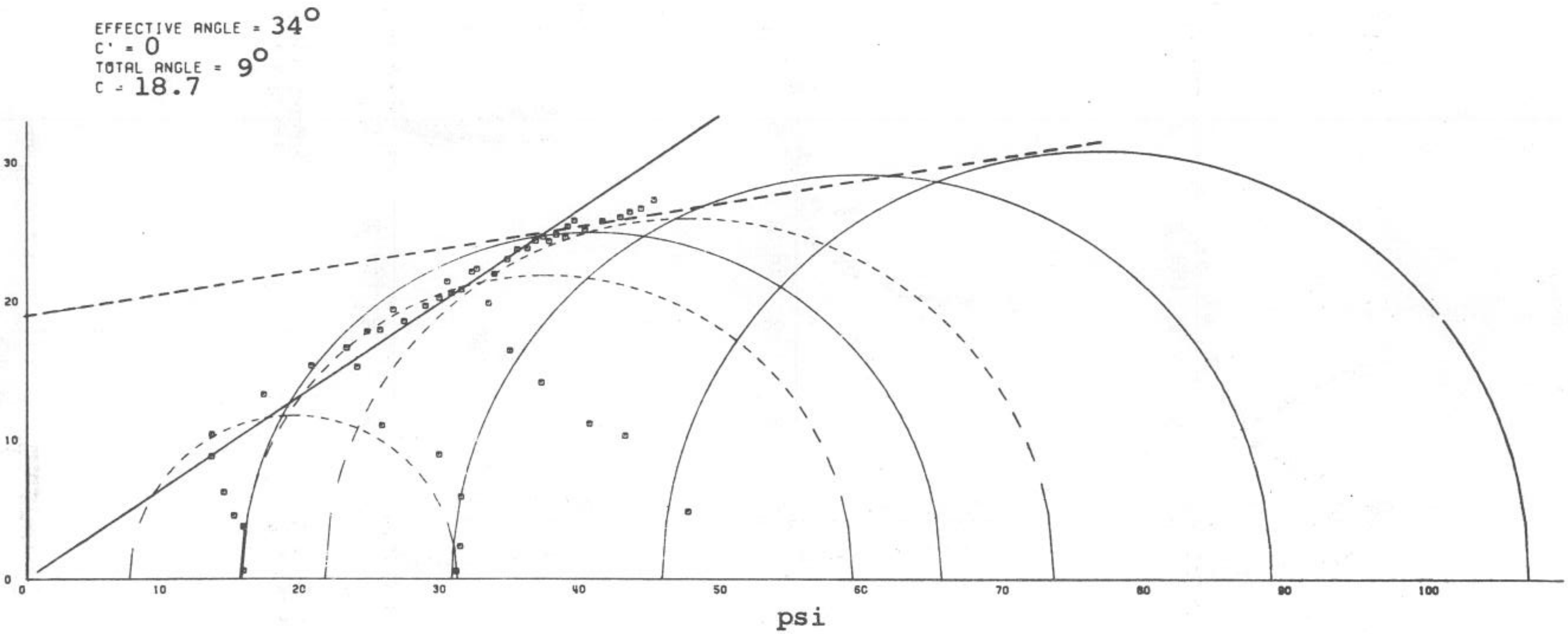

Figure 26. Triaxial Shear Strength Envelope For 2.0 Inch Diameter Specimens With 45 Percent Retained On Number 10 Sieve

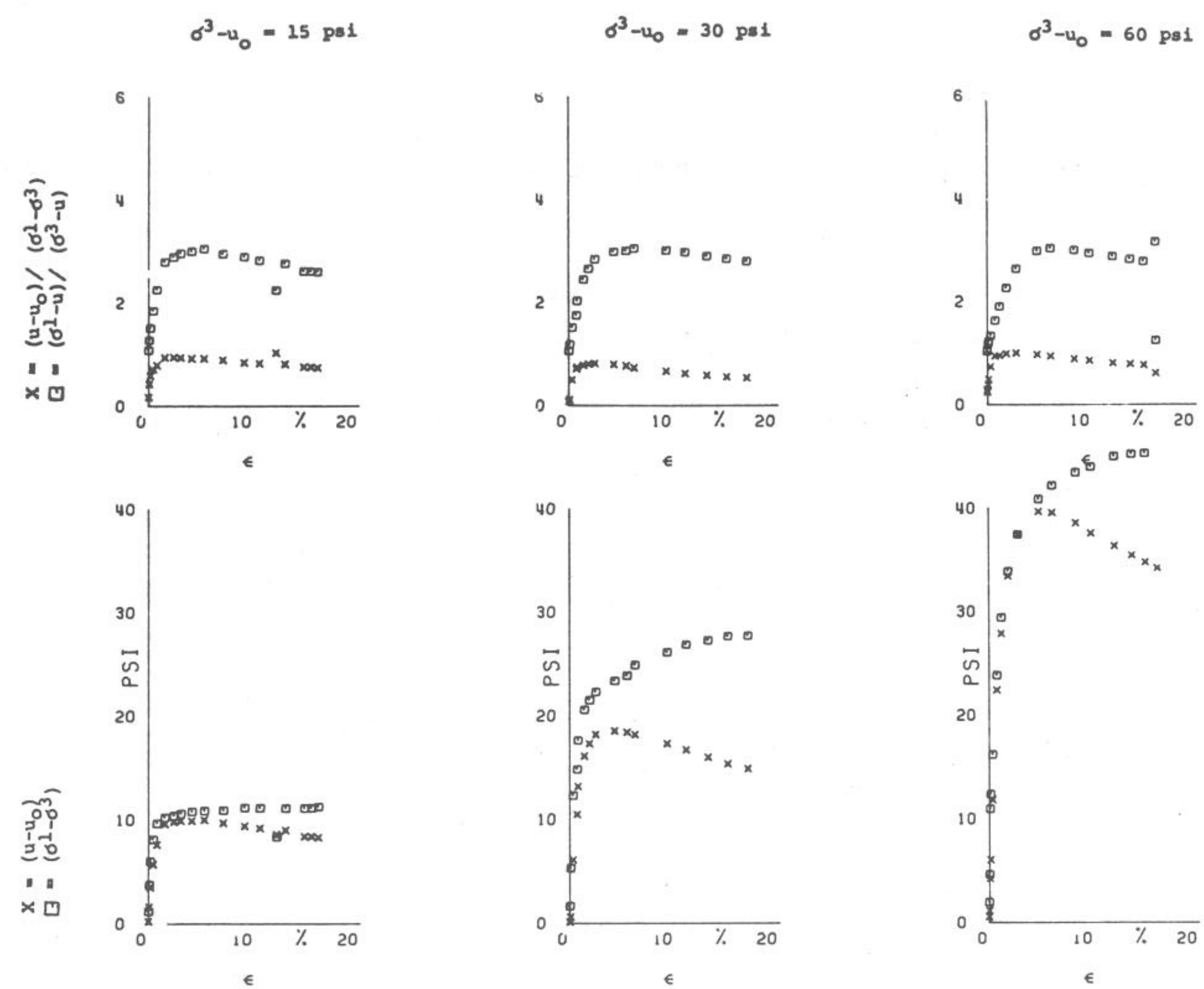

Figure 27. Stress - Strain Relationships of 2.75 Inch Diameter Specimens With 10 Percent Retained On Number 10 Sieve

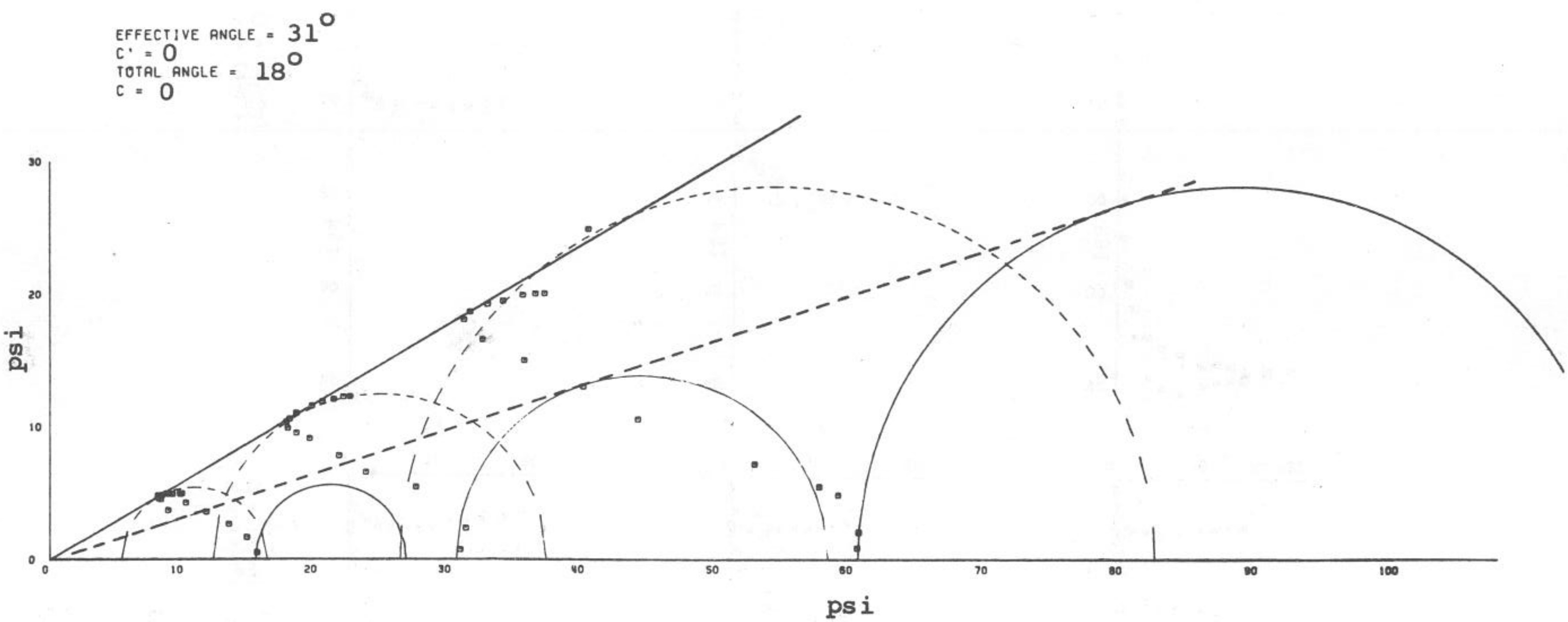

Figure 28. Triaxial Shear Strength Envelope For 2.75 Inch Diameter Specimens With 10 Percent Retained On Number 10 Sieve

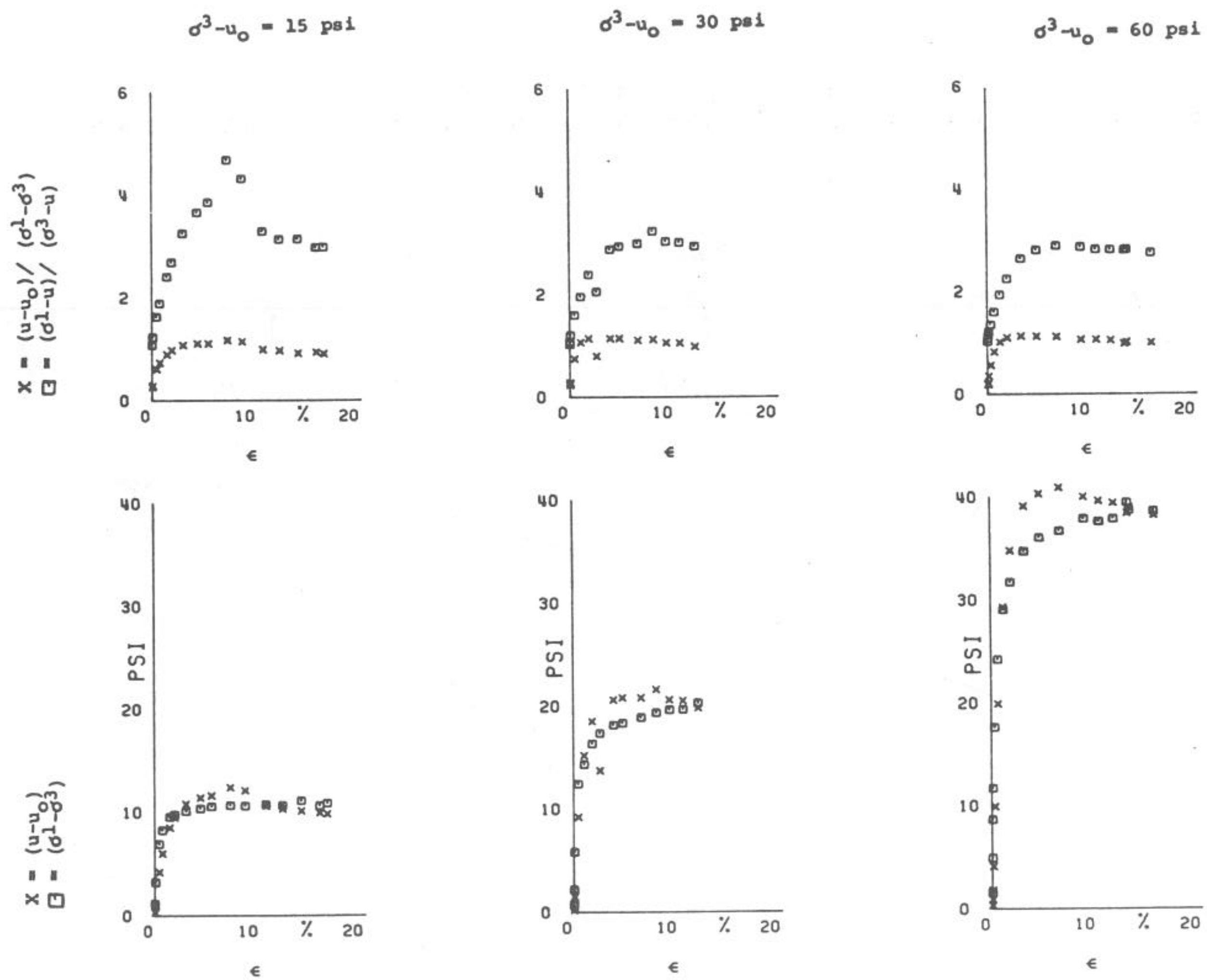

Figure 29. Stress - Strain Relationships of 2.75 Inch Diameter Specimens With 20 Percent Retained On Number 10 Sieve

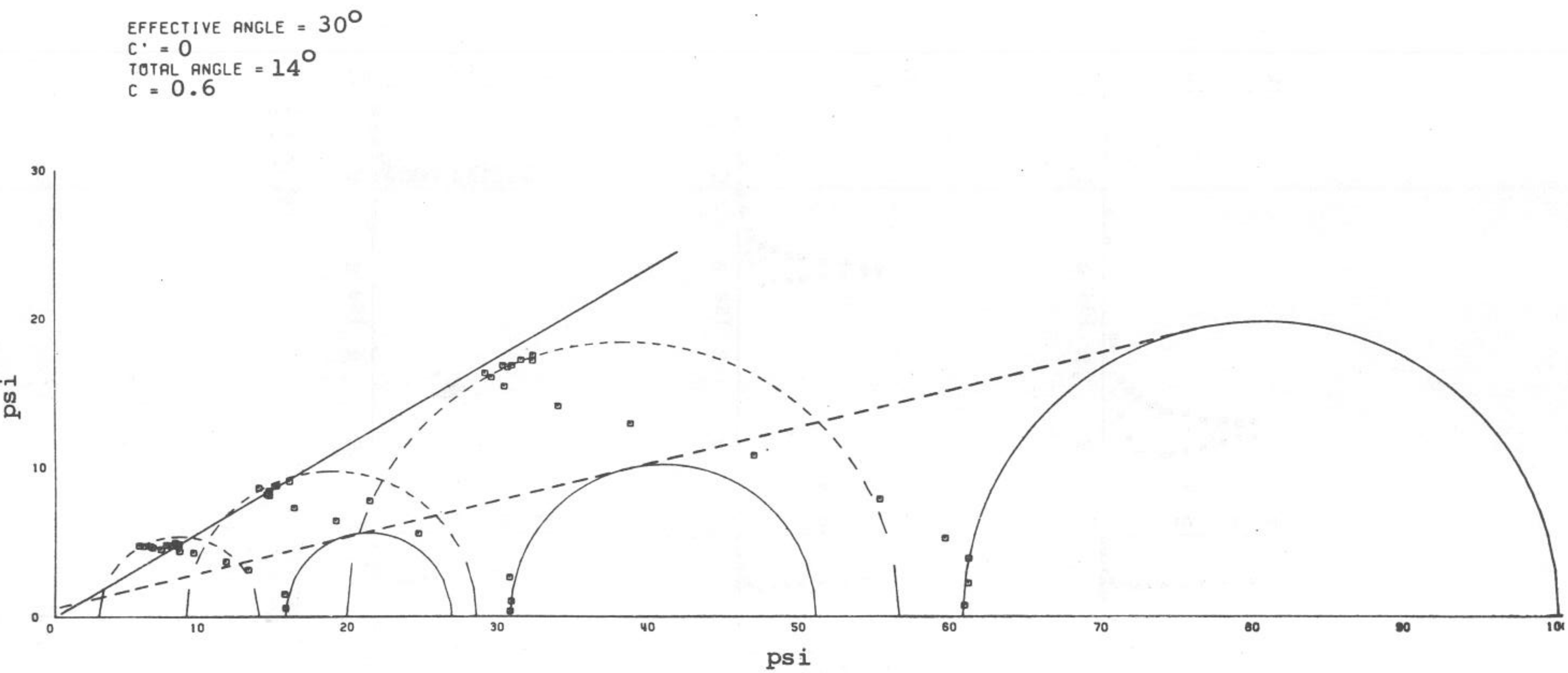

Figure 30. Triaxial Shear Strength Envelope For 2.75 Inch Diameter Specimens With 20 Percent Retained On Number 10 Sieve

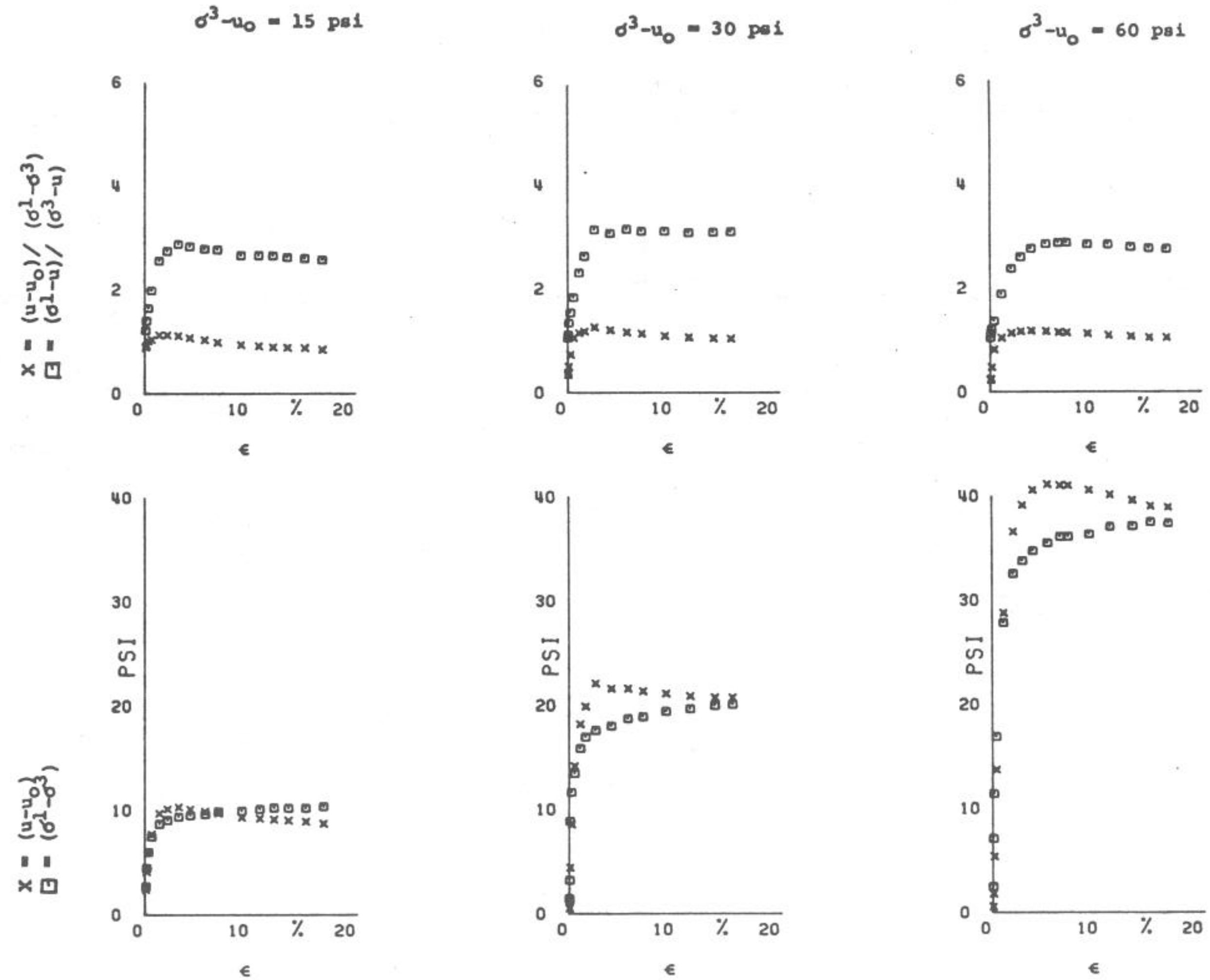

Figure 31. Stress - Strain Relationships of 2.75 Inch Diameter Specimens With 25 Percent Retained On Number 10 Sieve

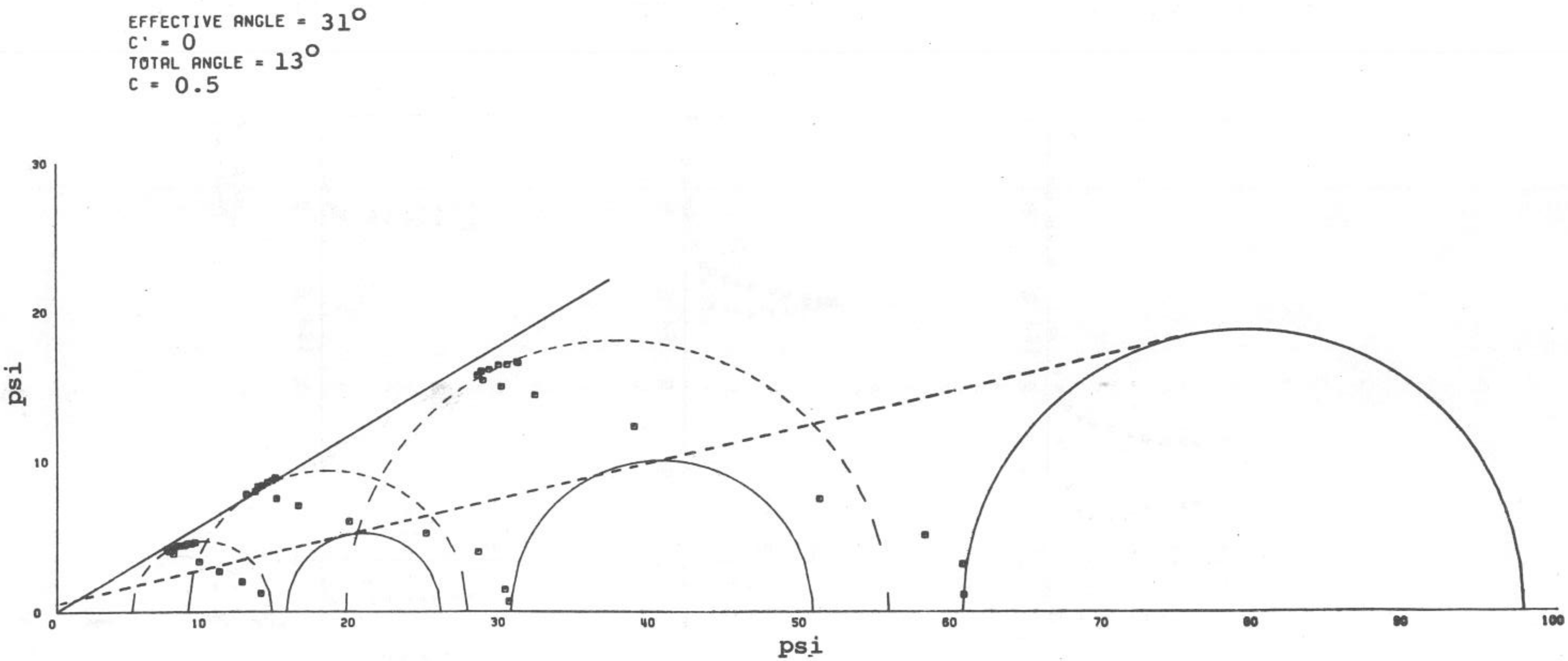

Figure 32. Triaxial Shear Strength Envelope For 2.75 Inch Diameter Specimens
With 25 Percent Retained On Number 10 Sieve

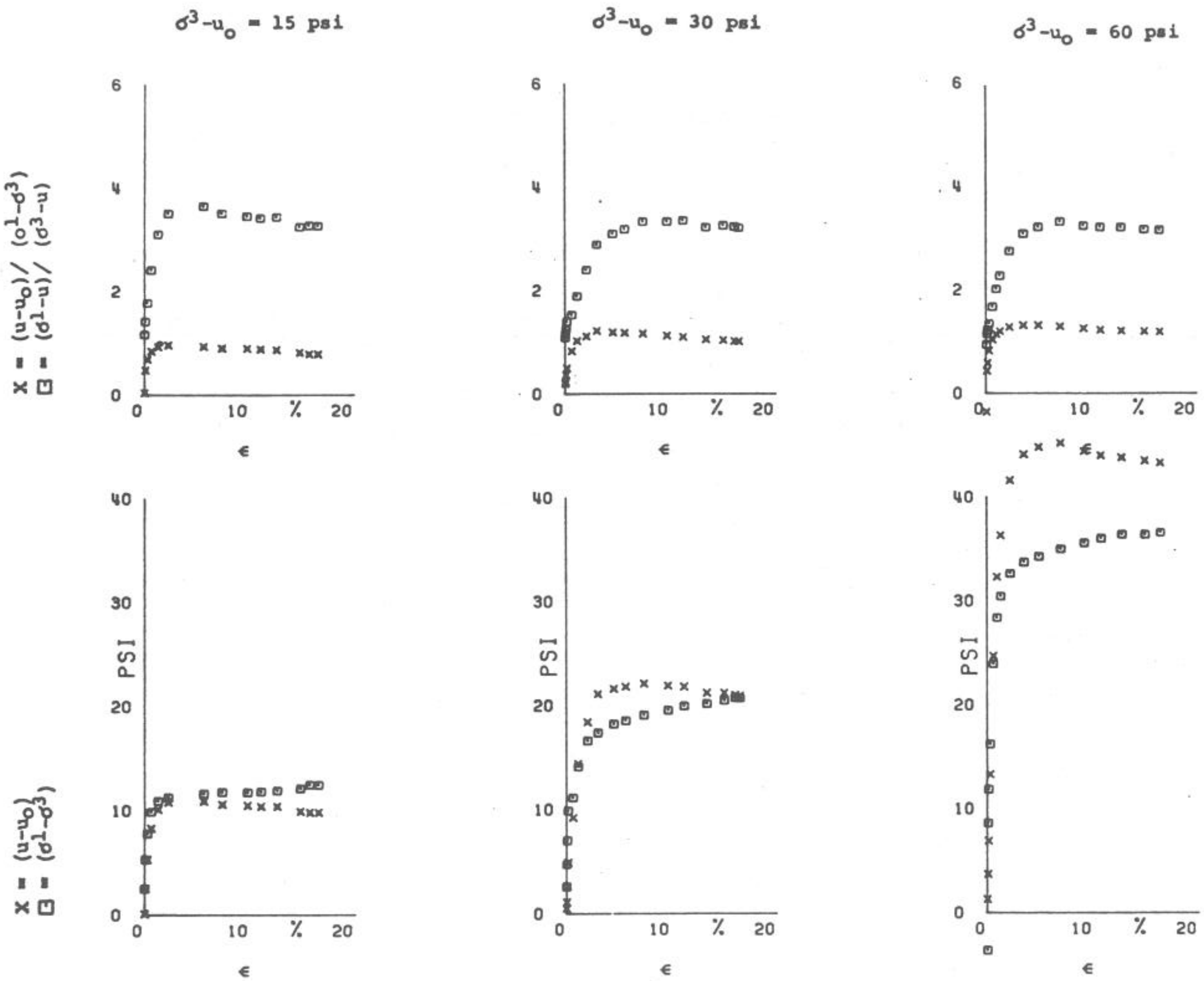

Figure 33. Stress - Strain Relationships of 2.75 Inch Diameter Specimens With 30 Percent Retained On Number 10 Sieve

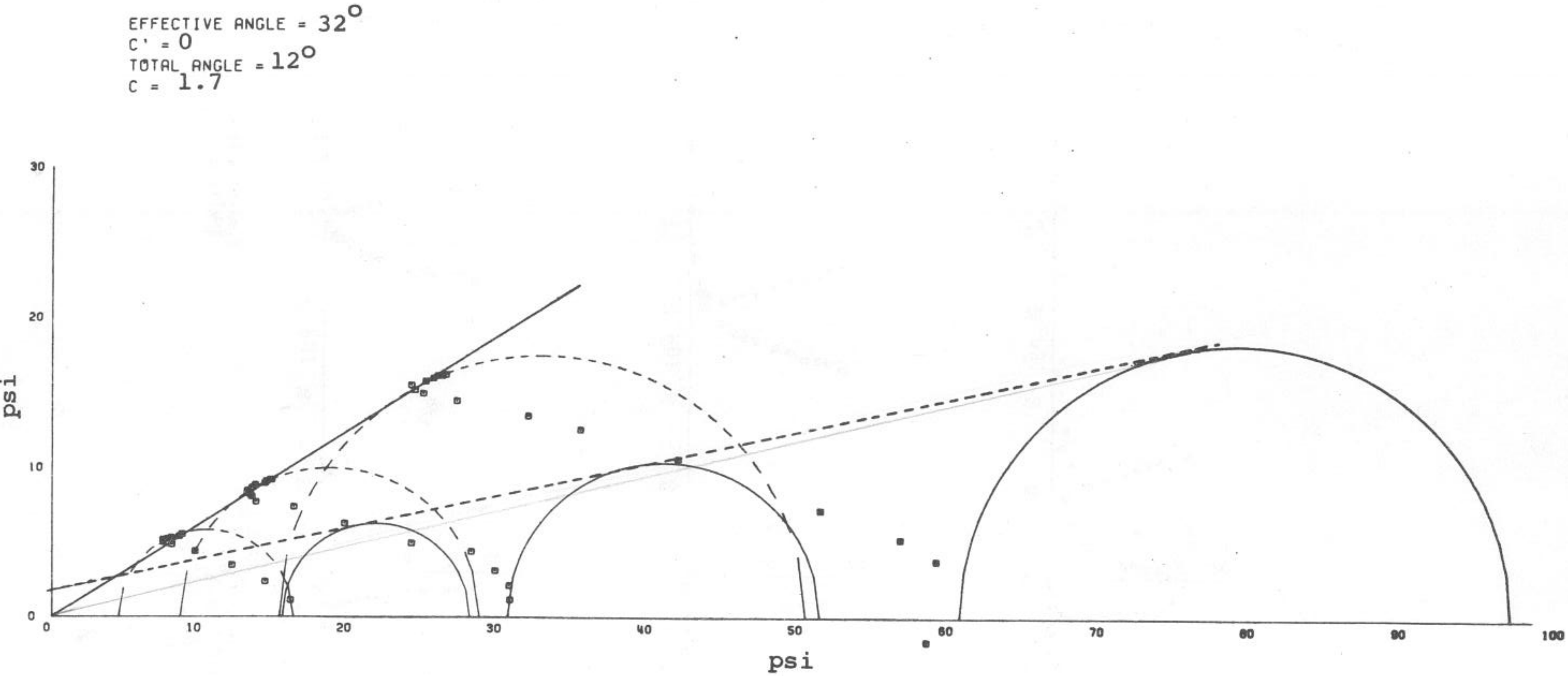

Figure 34. Triaxial Shear Strength Envelope For 2.75 Inch Diameter Specimens With 30 Percent Retained On Number 10 Sieve

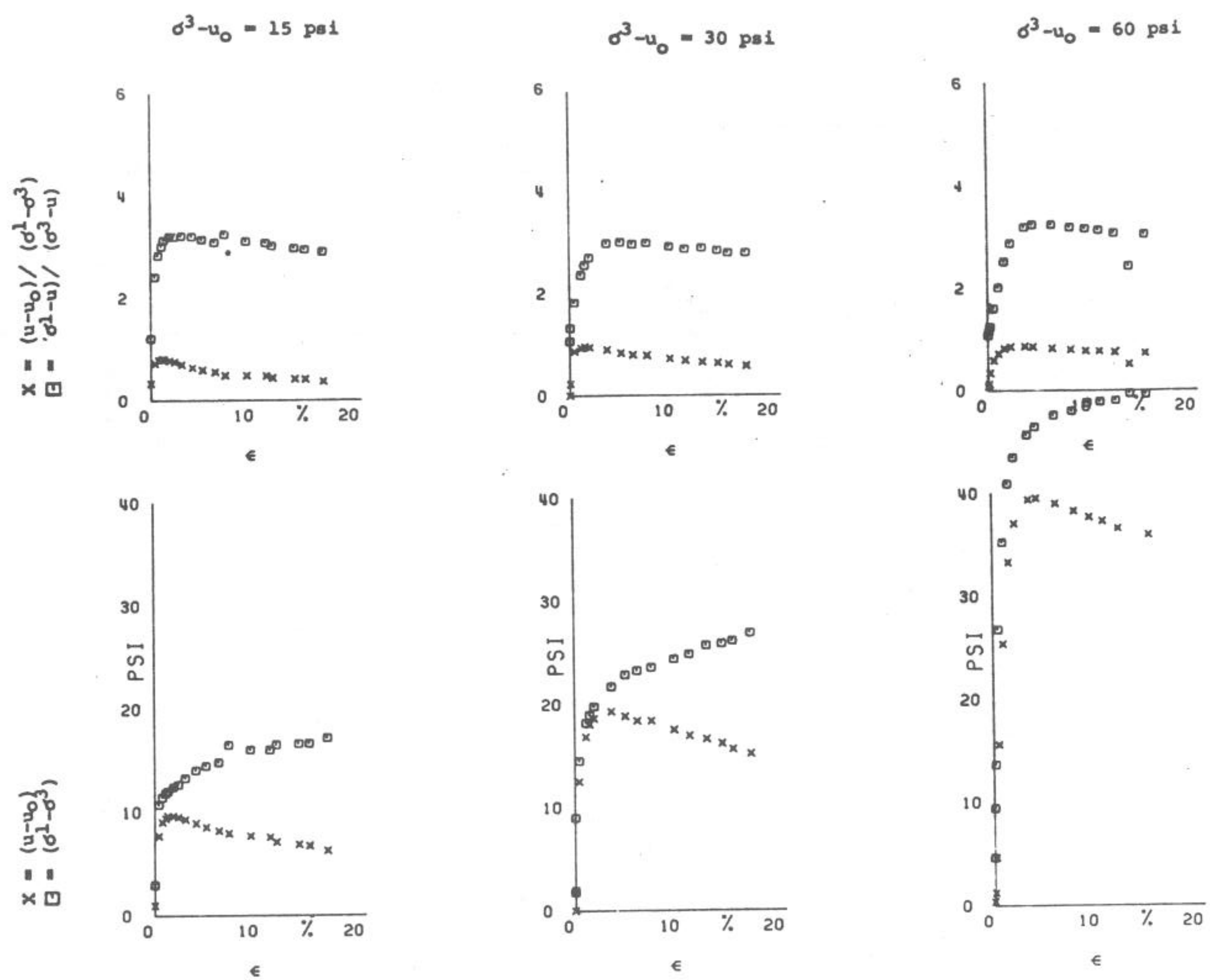

Figure 35. Stress - Strain Relationships of 2.75 Inch Diameter Specimens With 35 Percent Retained On Number 10 Sieve

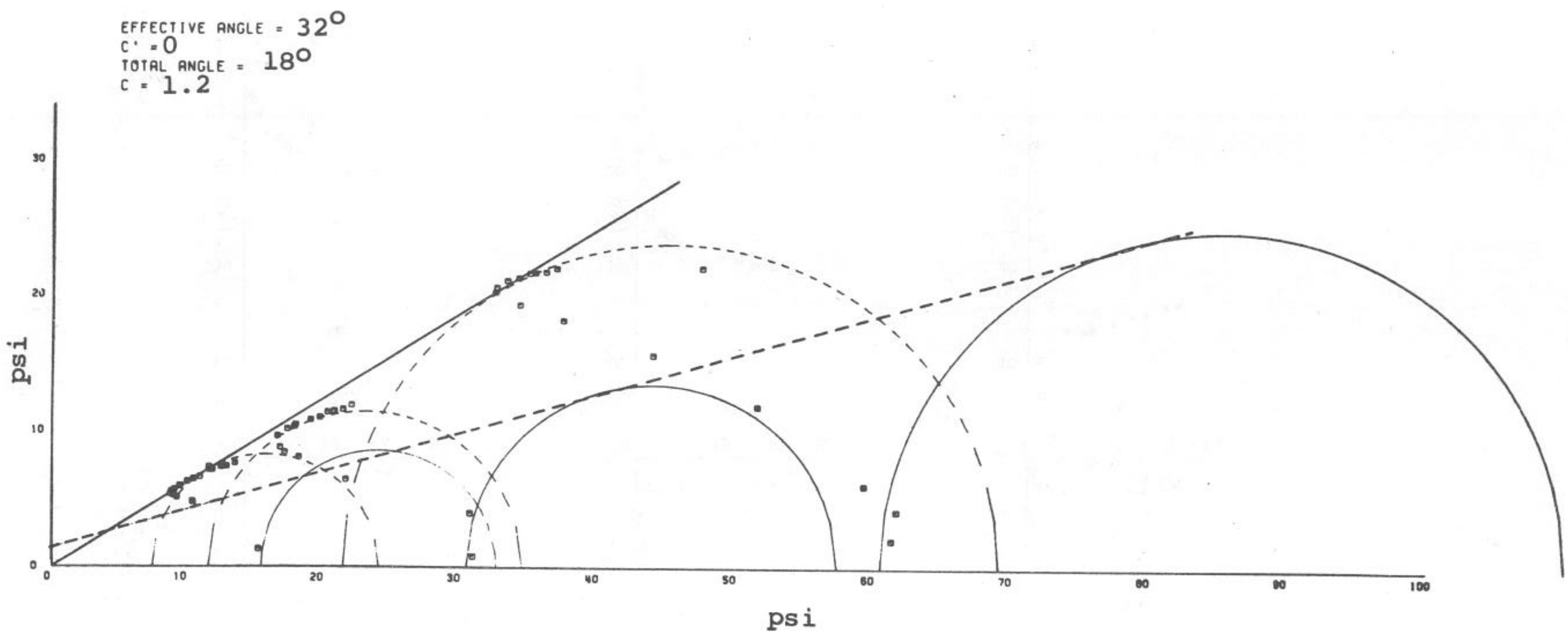

Figure 36. Triaxial Shear Strength Envelope For 2.75 Inch Diameter Specimens With 35 Percent Retained On Number 10 Sieve

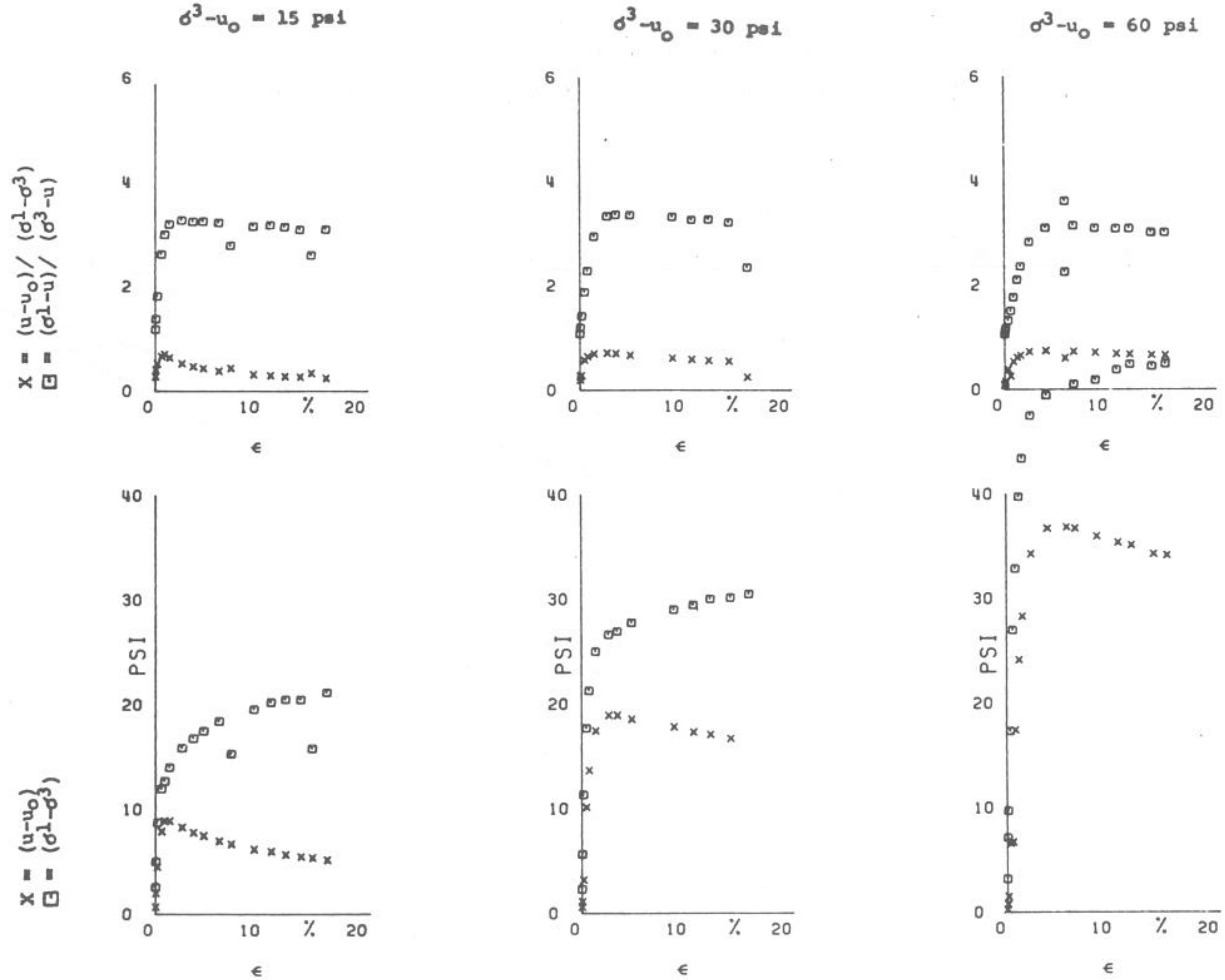

Figure 37. Stress - Strain Relationships of 2.75 Inch Diameter Specimens With 40 Percent Retained On Number 10 Sieve

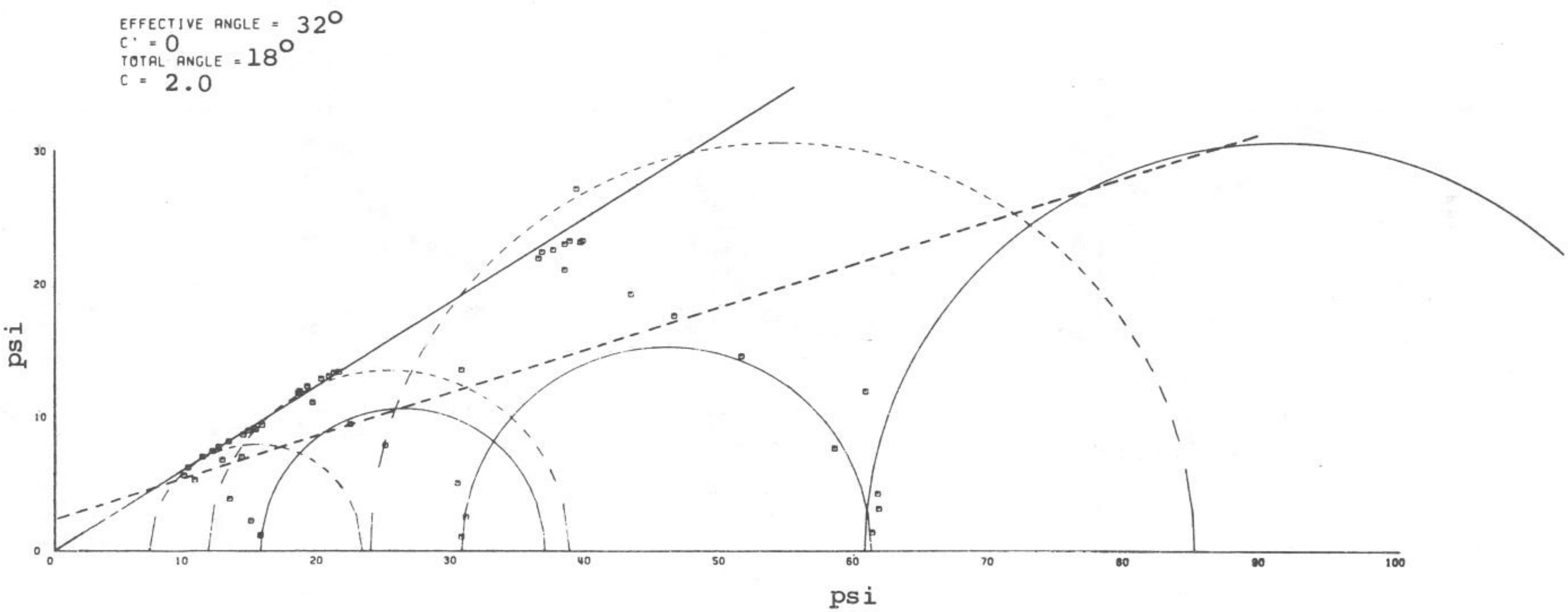

Figure 38. Triaxial Shear Strength Envelope For 2.75 Inch Diameter Specimens With 40 Percent Retained On Number 10 Sieve

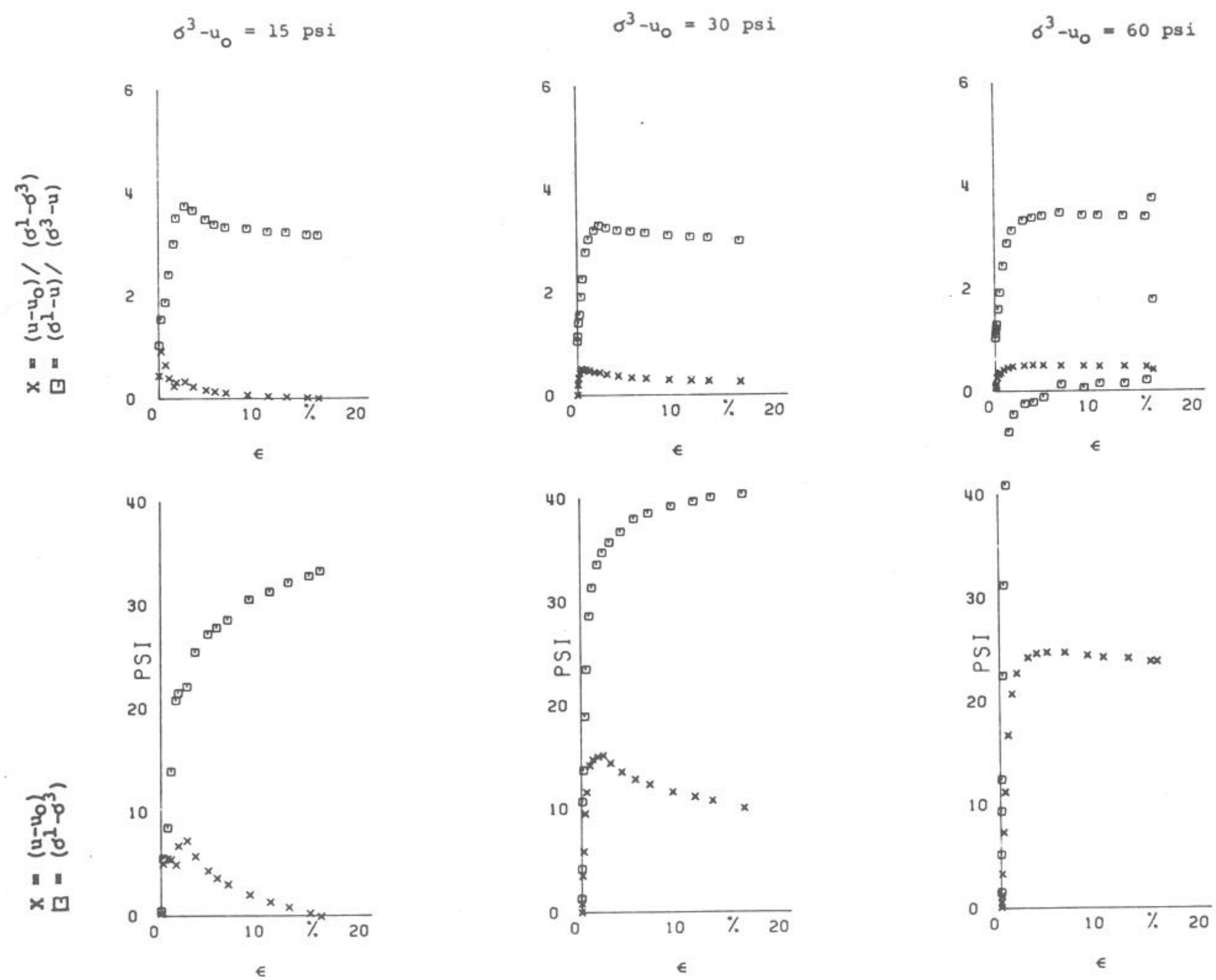

Figure 39. Stress - Strain Relationships of 2.75 Inch Diameter Specimens With 50 Percent Retained On Number 10 Sieve

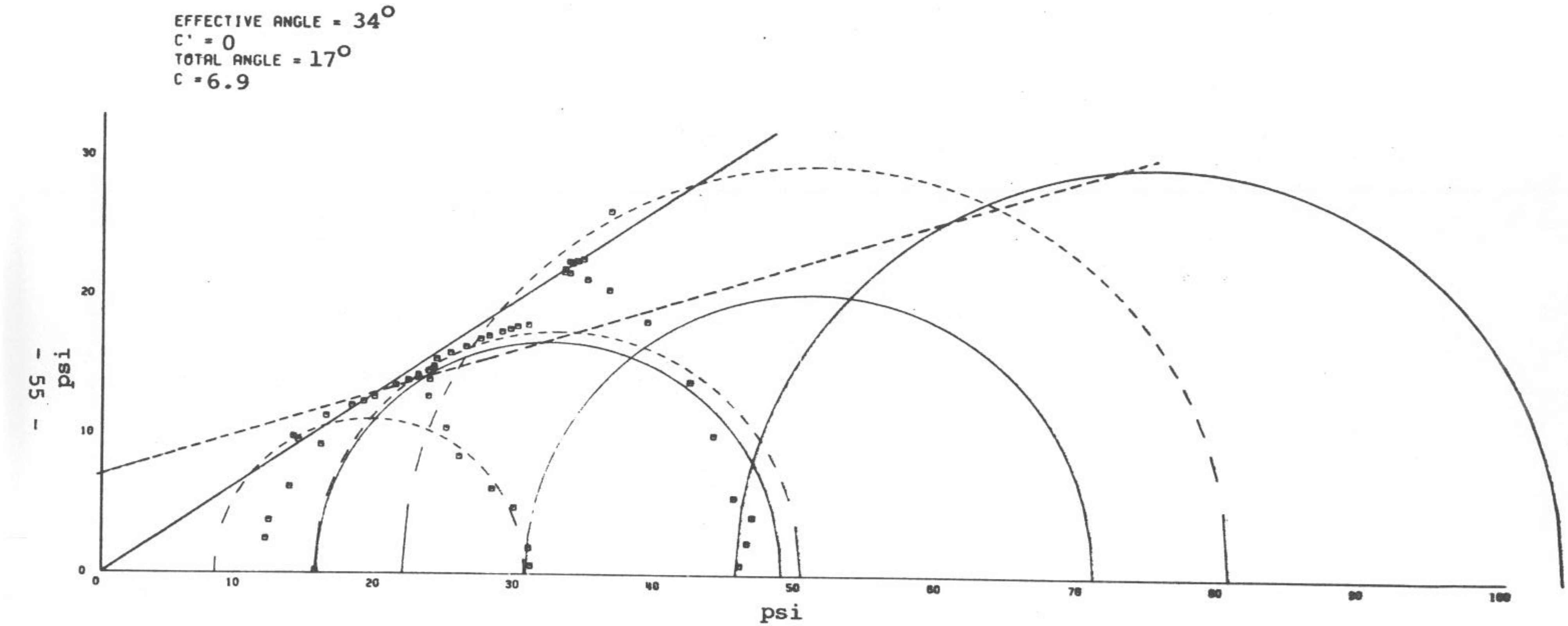

Figure 40. Triaxial Shear Strength Envelope For 2.75 Inch Diameter Specimens
With 50 Percent Retained On Number 10 Sieve