STABILIZATION OF HIGHWAY BASES AND SUBGRADES WITH PORTLAND CEMENT AND STONE SCREENINGS

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STABILIZATION OF HIGHWAY BASES AND SUBGRADES

WITH PORTLAND CEMENT AND STONE SCREENINGS

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TABLE OF CONTENTS

		Page
ACKNOWLEDGEMENTS		ii
LIST OF TABLES		iv
LIST OF ILLUSTRATIONS		v
SUMMARY		vii
Chapter		
I.	INTRODUCTION	1
	General	1
	Methods of Soil Stabilization	1
II.	DESCRIPTION OF MATERIALS	3
	Soil	3
	Stone Screenings	3
	Portland Cement	6
III.	DESCRIPTION OF LABORATORY PROCEDURES AND TEST METHODS	8
	General	8
	Proportioning of Soil, Stone Screenings, and Portland Cement	8
	Moisture-Density Relationships	9
	Determination of Compressive Strength of Compacted Specimens	10
IV.	EVALUATION OF TEST RESULTS	19
	General	19
	Effect of Cement on Compressive Strength	25
	Effect of Stone Screenings on Compressive Strength	51
	Effect of Stone Screenings in Reducing Cement Content	53
	Establishment of Typical Design Curves	56
V.	SUMMARY OF RESULTS, CONCLUSIONS, AND RECOMMENDATIONS	62
	Summary of Results	62
	Conclusions	62
	Recommendations	63
BIBLIOGRAPHY		64

LIST OF TABLES

		Page
1.	Properties of Soils	4
2.	Analysis of Type I Normal Portland Cement	7
3.	Moisture-Density Data for Soils IV, V-A, VII, VIII and IX	11
4.	Summary of Compressive Strength Tests, Soil IV Combined with Stone Screenings and Portland Cement	26
5.	Summary of Compressive Strength Tests, Soil V-A Combined with Stone Screenings and Portland Cement	27
6.	Summary of Compressive Strength Tests, Soil VII Combined with Stone Screenings and Portland Cement	28
7.	Summary of Compressive Strength Tests, Soil VIII Combined with Stone Screenings and Portland Cement	29
8.	Summary of Compressive Strength Tests, Soil IX Combined with Stone Screenings and Portland Cement	30
9.	Effect of Stone Screenings on Strengths of Soils not Containing Portland Cement.	52
10.	Estimated Percentage of Cement Needed for a Compressive Strength of 300 lb./sq. in.	54

LIST OF ILLUSTRATIONS

		Page
1.	Grain Size Chart for Soils and Stone Screenings	5
2.	Equipment Used in Molding Samples for Strength Tests	14
3.	Sample being Molded for Strength Test	16
4.	Triaxial Shear Test in Progress	17
5.	Dry Density vs. Screenings Content, Soil IV	20
6.	Dry Density vs. Cement Content, Soil IV	20
7.	Dry Density vs. Screenings Content, Soil V-A	21
8.	Dry Density vs. Cement Content, Soil V-A	21
9.	Dry Density vs. Screenings Contents, Soil VII	22
10.	Dry Density vs. Cement Content, Soil VII	22
11.	Dry Density vs. Screenings Content, Soil VIII	23
12.	Dry Density vs. Cement Content, Soil VIII	23
13.	Dry Density vs. Screenings Content, Soil IX	24
14.	Dry Density vs. Cement Content, Soil IX	24
15.	Deviator Stress vs. Cement Content, Soil IV (No Screenings) .	31
16.	Deviator Stress vs. Cement Content, Soil IV + 25% Screenings.	32
17.	Deviator Stress vs. Cement Content, Soil IV + 50% Screenings.	33
18.	Deviator Stress vs. Cement Content, Soil IV + 75% Screenings.	34
19.	Deviator Stress vs. Cement Content, Soil V-A (No Screenings).	35
20.	Deviator Stress vs. Cement Content, Soil V-A + 25% Screenings	36
21.	Deviator Stress vs. Cement Content, Soil V-A + 50% Screenings	37

LIST OF ILLUSTRATIONS (Continued)

Page

22. Deviator Stress vs. Cement Content, Soil V-A + 75% Screenings . . 38

23. Deviator Stress vs. Cement Content, Soil VII (No Screenings) . . 39

24. Deviator Stress vs. Cement Content, Soil VII + 25% Screenings . . 40

25. Deviator Stress vs. Cement Content, Soil VII + 50% Screenings . . 41

26. Deviator Stress vs. Cement Content, Soil VII + 75% Screenings . . 42

27. Deviator Stress vs. Cement Content, Soil VIII (No Screenings). . 43

28. Deviator Stress vs. Cement Content, Soil VIII + 25% Screenings . 44

29. Deviator Stress vs. Cement Content, Soil VIII + 50% Screenings . 45

30. Deviator Stress vs. Cement Content, Soil VIII + 75% Screenings . 46

31. Deviator Stress vs. Cement Content, Soil IX (No Screenings) . . . 47

32. Deviator Stress vs. Cement Content, Soil IX + 25% Screenings . . 48

33. Deviator Stress vs. Cement Content, Soil IX + 50% Screenings . . 49

34. Deviator Stress vs. Cement Content, Soil IX + 75% Screenings . . 50

35. Design Curve, Soil IV Combined with Stone Screenings and Portland Cement 57

36. Design Curve, Soil V-A Combined with Stone Screenings and Portland Cement 58

37. Design Curve, Soil VII Combined with Stone Screenings and Portland Cement 59

38. Design Curve, Soil VIII Combined with Stone Screenings and Portland Cement 60

39. Design Curve, Soil VIII Combined with Stone Screenings and Portland Cement 61

SUMMARY

It was the purpose of this research to optimize the amounts of stone screenings and Portland cement to add to a soil in order to most economically produce a mixture having a given strength.

In the work, use was made of two common methods of soil stabilization, namely, mechanical stabilization and cementing. Stone screenings, obtained from rock-crushing operations, were utilized in mechanical stabilization in order to improve the particle size distribution and increase the angle of internal friction. Portland cement was added for the purpose of obtaining better cohesion through hydration of the cement with soil moisture.

Five different soils found in the State of Georgia were employed in this study. The percentages of stone screenings added were 25, 50, and 75 and the percentages of Portland cement used were 2, 4, 8, and 12.

Moisture-density relationships were determined for each soil alone and for each soil combined with the various percentages of stone screenings and Portland cement.

Use was made of the moisture-density relationships for molding samples for triaxial shear tests and unconfined compression tests. Eight samples were made for each of the twenty combinations of soil, stone screenings, and Portland cement for each of the five soils. Four of these samples were cured for 7 days before being tested and the other four were allowed to cure for 28 days.

The data obtained from the strength tests was used to construct some typical design curves which can be utilized to determine the most economical combinations of soil, stone screenings, and cement needed to produce a given compressive strength under certain conditions of curing and confining pressure.

An analysis of the data revealed that almost all of the gain in dry density caused by the addition of Portland cement and stone screenings was due to the stone screenings. In all soils tested, the addition of stone screenings was found to reduce the amount of cement required to develop the design compressive strength; however, adding only stone screenings to the soil did not cause the compressive strength to be increased. It was also found that the compressive strength of Soil VIII, considered to be the poorest soil, was improved much more than any other soil by the addition of stone screenings.

CHAPTER I

INTRODUCTION

General.--The success of any highway pavement is primarily dependent on two factors (1): 1) the ability of the pavement system to withstand the worst conditions of loading imposed on it, and 2) protection of the pavement components against the elements of nature to such a degree that the desirable properties of the structure are maintained throughout its design life.

The base and subgrade courses usually are the most critical components of the pavement system as they should for economy reasons, be composed mostly of local soil. Since good, natural roadbuilding materials are not in abundance in many parts of the world, it is often necessary to improve the physical properties of the available material in order to fulfill the first requirement named above. For soils which have adequate strength under normal conditions but lose strength during periods of inundation, such as are caused by a high water table, it is necessary to use protective measures. The processes used to improve the strengths of natural soils or to preserve the natural strength properties of a soil come under the general heading of "stabilization."

Methods of Soil Stabilization.--Many different methods of stabilization have been used successfully in the past. Some of these methods are still in the development stages, with economy being the biggest hindrance to practical usage. The most commonly used methods of soil stabilization today (1,2) are: 1) mechanical stabilization, in which the gradation of the soil is altered by the blending in of other soil or crushed stone, thus producing a more compact and stable mixture; 2) cementing, in which Portland cement or bituminous material is used to increase the cohesion; and 3) moisture resistance, in which bituminous material is mixed into the soil as a waterproofing agent in order to prevent loss of strength or minimize swell. In the state of Georgia, mechanical stabilization and cementing are the most widely used methods of stabilizing soils.

The three methods of soil stabilization described above have been used with or without success, successful efforts often being due to a high factor of safety. Also, there is a tendency to apply design and construction procedures which have been used elsewhere to local conditions. Because of the infinite variety of soils and climatic conditions existing, such generalizations should not be made in the field of soil stabilization.

CHAPTER II

DESCRIPTION OF MATERIALS

Soil.--Five different soils were utilized in this research. These soils were designated as Soils IV, V-A, VII, VIII, and IX.

Soil IV is a red, silty, clayey sand; Soil V-A is a yellowish brown, clayey, sandy silt; Soil VII is a brown, silty, clayey sand; Soil VIII is a red, sandy, clayey silt; and Soil IX is a reddish brown, sandy, silty clay.

The determinations of the liquid limit, plastic limit, specific gravity, and grain-size distribution were made according to the standard methods of test of the American Association of State Highway Officials (3). The values that were obtained are shown in Table 1, along with other pertinent data on the soils. Figure 1 shows the grain-size curves for these soils.

Stone Screenings.--The stone screenings referred to in this study are collected from rock-crushing operations; there are approximately thirty such operations in the state of Georgia. The material is classified geologically as gneissoid porphyritic granite.

Two different batches of stone screenings were obtained during the course of this work. The first batch was from the Weston and Brooker Company quarry in Camak, Georgia. The second batch was obtained from the Thames quarry in Fulton County, Georgia.

The specific gravity of the screenings from each batch was determined to be 2.65. The particle size distribution, shown in Figure 1, was found to be almost identical for both batches of screenings.

Table 1. Properties of Soils.

Soil No.	IV	V-A	VII	VIII	IX
% Passing U. S. Standard Sieve No.:					
4	100	100	100	100	100
10	97	99	99	98	99
40	81	84	70	93	94
60	72	77	53	89	86
100	63	71	44	85	76
200	54	65	39	83	69
% Sand	46	35	61	17	31
% Silt	27	51	9	48	34
% Clay	27	14	30	35	35
Liquid Limit	29	42	24	64	47
Plasticity Index	6	Non-plastic	10	16	3
Specific Gravity	2.70	2.77	2.59	2.67	2.67
AASHO Classification	A-4(4)	A-5(6)	A-4(1)	A-7-5(15)	A-5-7
Location (County)	Fulton	Fulton	Clayton	Putnam	Putnam

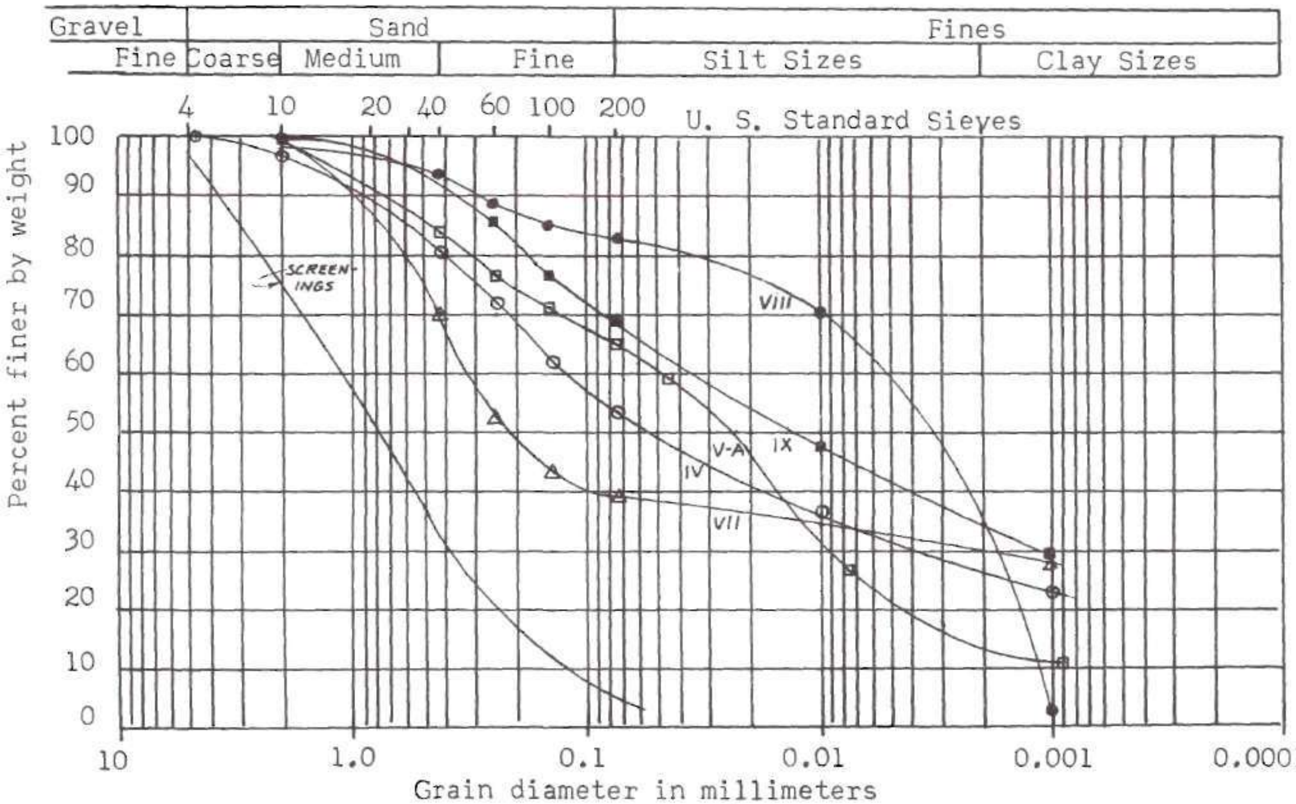

Figure 1. Grain Size Chart for Soils and Stone Screenings

Portland Cement.--The Portland cement used was Type I Normal. The significant properties of this material are given in Table 2.

Table 2. Analysis of Type I Normal Portland Cement.

Chemical Composition, %	
Silicon dioxide, $Si\ O_2$	20.46
Ferric oxide, $Fe_2\ O_3$	2.44
Aluminum oxide, $Al_2\ O_3$	5.90
Sulpher trioxide, SO_3	2.08
Calcium oxide, Ca O	62.87
Magnesium oxide, Mg O	4.18
Insoluble residue	0.30
Loss on Ignition	1.38
Specific surface area, Blaine (sq.cm./gm.)	3464

CHAPTER III

DESCRIPTION OF LABORATORY PROCEDURES AND TEST METHODS

General.--All soil brought to the laboratory for testing was stored in barrels. Soil to be used the following day in testing was passed through a No. 4 sieve, placed in a large pan, and allowed to air-dry. Clay lumps were broken down to pass the No. 4 sieve and thoroughly mixed in with the soil while roots were discarded.

The first testing performed on a new batch of soil was the grain size analysis. This test was conducted as specified in AASHO (American Association of State Highway Officials) Designation: T 88-57.

The specific gravity of the soil was then determined according to AASHO Designation: T 100-60.

Next, the moisture-density relationship was obtained as specified in AASHO Designation: T 99-57.

The liquid and plastic limits were determined according to AASHO Designations: T 89-60 and T 90-56, respectively.

Proportioning of Soil, Stone Screenings, and Portland Cement.--Stone screenings were added to each of Soils IV, V-A, VII, VIII, and IX as a percentage of total weight of oven dry soil plus screenings. For example, a 10-pound batch of soil and screenings said to contain 25 per cent screenings was composed of 7.5 pounds of dry soil and 2.5 pounds of screenings.

For all the above soils except Soil IX, the addition of Portland cement was based on a percentage of total weight of dry soil plus stone screenings. In other words, a typical batch containing "25 per cent screenings plus 2 per cent cement" would consist of 7.5 pounds of dry soil, 2.5 pounds of screenings, and 0.2 pounds of cement. Portland cement was added to Soil IX, the first soil tested, as a percentage of dry soil only. In this case, "25 per cent screenings plus 2 per cent cement" meant 7.5 pounds of dry soil, 2.5 pounds of screenings, and 0.15 pounds of cement. In order to compare the effects of these admixtures on the different soils, it was necessary to adjust the data obtained in the tests utilizing Soil IX.

The screenings contents used were 0, 25, 50 and 75 per cent. The cement percentages were 0, 2, 4, 8 and 12. This resulted in 20 different combinations of soil, stone screenings, and cement for each soil.

Moisture-Density Relationships.--Moisture-density relationships were determined for each of the 20 combinations described above.

The procedure used for preparing and compacting a moisture-density sample was as follows:

1. The hygroscopic moisture of the soil was estimated by the use of a "Speedy" Moisture Tester manufactured by the Alpha Lux Co., Inc. In this method, a six-gram sample of soil is placed in the tester body with a specified amount of calcium carbide. The gas pressure created by the chemical reaction of the reagent and water in the soil activates a gage which directly gives the percentage of water in the soil sample. The amount of water to be added to attain the desired water content was then found.
2. The desired amounts of soil, screenings and cement were weighed to the nearest 0.1 pound, while the desired volume of water to be added was measured to the nearest 10 milliliters.

3. The solid components of the mix were placed in a 10-quart capacity mixing bowl and mixed manually until a fairly uniform mix was obtained.
4. The ingredients were then mixed mechanically by a Hobart C-100 mixer with a flat blade. After the mixer had been running for a few seconds, the water was added. All ingredients were mixed for a total of ten minutes, the mixing being interrupted once or twice to scrape the blade and the inside of the mixing bowl clean. Upon completion of mixing, a moisture sample of about 100 grams was taken from the bowl.
5. The mix was compacted according to the method outlined in AASHO Designation: T 99-57.
6. The moisture sample was dried in an oven at 230° F for 24 hours and the actual water content determined. If the actual water content was more than ± 0.3% different from the desired water content, a new mix was made up.

At least six different water contents were used for each combination of soil, screenings, and cement. After a mix had been compacted, it was not used again. The results of the moisture-density tests are summarized in Table 3.

Determination of Compressive Strength of Compacted Specimens.--The compressive strength was determined for each combination of soil, stone screenings, and cement, utilizing the optimum water content and the corresponding maximum dry density.

Eight samples, 2.8 inches in diameter and 5.6 inches high, were molded for each combination. Four of these samples were cured for 7 days prior to testing while the remaining four were cured for 28 days.

Table 3. Moisture-Density Data for Soils IV, V-A, VII, VIII, and IX

Percent Screenings	Percent Cement	Soil IV		Soil V-A		Soil VII		Soil VIII		Soil IX	
		M.D.D.*	O.M.C.**	M.D.D.	O.M.C.	M.D.D.	O.M.C.	M.D.D.	O.M.C.	M.D.D.	O.M.C.
0	0	114.2	14.6	95.7	20.3	116.1	14.0	88.7	30.9	100.4	22.4
0	2	112.4	15.5	94.2	25.0	114.8	13.9	90.3	30.7	101.9	22.0
0	4	111.6	16.6	94.9	23.9	115.2	14.2	90.4	30.3	101.0	21.7
0	8	112.3	15.8	95.8	24.0	116.1	13.8	90.0	30.9	101.5	21.5
0	12	114.2	15.1	96.2	23.4	117.3	13.4	90.6	30.5	103.3	20.5
25	0	118.8	13.0	102.7	21.2	121.0	11.5	96.6	24.6	108.0	18.0
25	2	115.4	14.4	102.8	21.0	120.1	12.0	98.0	24.0	109.1	17.6
25	4	117.1	13.9	105.6	19.8	120.7	12.1	98.5	23.5	109.2	17.3
25	8	118.2	13.0	106.0	19.8	121.0	11.9	100.0	23.5	109.3	17.7
25	12	118.0	13.0	105.7	19.4	121.8	11.6	100.1	23.4	109.3	18.6

*M.D.D. = Maximum Dry Density

**O.M.C. = Optimum Moisture Content

(Continued)

Table 3.(Continued). Moisture-Density Data for Soils IV, V-A, VII, VIII, and IX

Percent Screenings	Percent Cement	Soil IV		Soil V-A		Soil VII		Soil VIII		Soil IX	
		M.D.D.*	O.M.C.**	M.D.D.	O.M.C.	M.D.D.	O.M.C.	M.D.D.	O.M.C.	M.D.D.	O.M.C.
50	0	126.3	10.9	114.3	14.6	125.2	9.5	107.7	18.7	115.0	14.0
50	2	125.3	10.9	114.7	13.1	123.5	10.8	108.0	18.5	115.8	14.5
50	4	124.0	11.9	115.0	14.7	123.7	10.7	108.6	18.6	114.8	14.5
50	8	125.1	10.6	115.3	14.6	124.6	10.5	109.3	17.7	115.0	14.3
50	12	126.5	10.8	114.2	13.2	125.0	10.5	109.7	17.5	117.0	14.0
75	0	132.5	8.2	126.7	9.6	126.0	10.0	121.1	11.2	122.8	10.2
75	2	132.6	8.8	126.3	9.3	126.3	9.4	120.2	11.5	124.0	10.5
75	4	133.5	8.8	126.8	10.5	127.2	9.2	122.8	11.1	125.6	10.5
75	8	133.8	8.6	126.8	9.5	129.5	8.9	122.5	11.3	122.8	10.5
75	12	132.4	8.8	128.0	9.7	130.0	8.8	122.7	11.8	125.0	10.1

*M.D.D. = Maximum Dry Density

**O.M.C. = Optimum Moisture Content

The procedure used for preparing the strength-test specimens was as follows:

1. A calculation was made of the amount of each ingredient necessary to yield a batch sufficient for four molded specimens at the maximum dry density and optimum moisture content. The calculated batch weights were then increased enough to provice two moisture samples of about 100 grams each.
2. The adjusted amount of each ingredient was weighed to the nearest 0.1 pound and the constituents blended and mixed in the same manner as used for the moisture-density mixes.

Molding of the specimens was begun as soon after completion of the mixing process as possible. The equipment used for molding the specimens is shown in Figures 2 and 3. The procedure followed in the molding and extruding of the compressive-strength samples was as follows:

1. The spacers were positioned around the lower piston and the bottom sleeve placed on top of the spacers.
2. About one-third of the weight of mixture necessary for one specimen was placed in the sleeve and rodded 20 times with the tamping rod.
3. The spacers were removed (friction holding the bottom sleeve stationary) and the remainder of the mix needed for this sample placed in the sleeve and rodded 20 times.
4. The bottom piston, with the bottom sleeve containing the mix still stationary, was aligned under the upper piston assembly which was secured to the upper head of the testing machine (Figure 3).

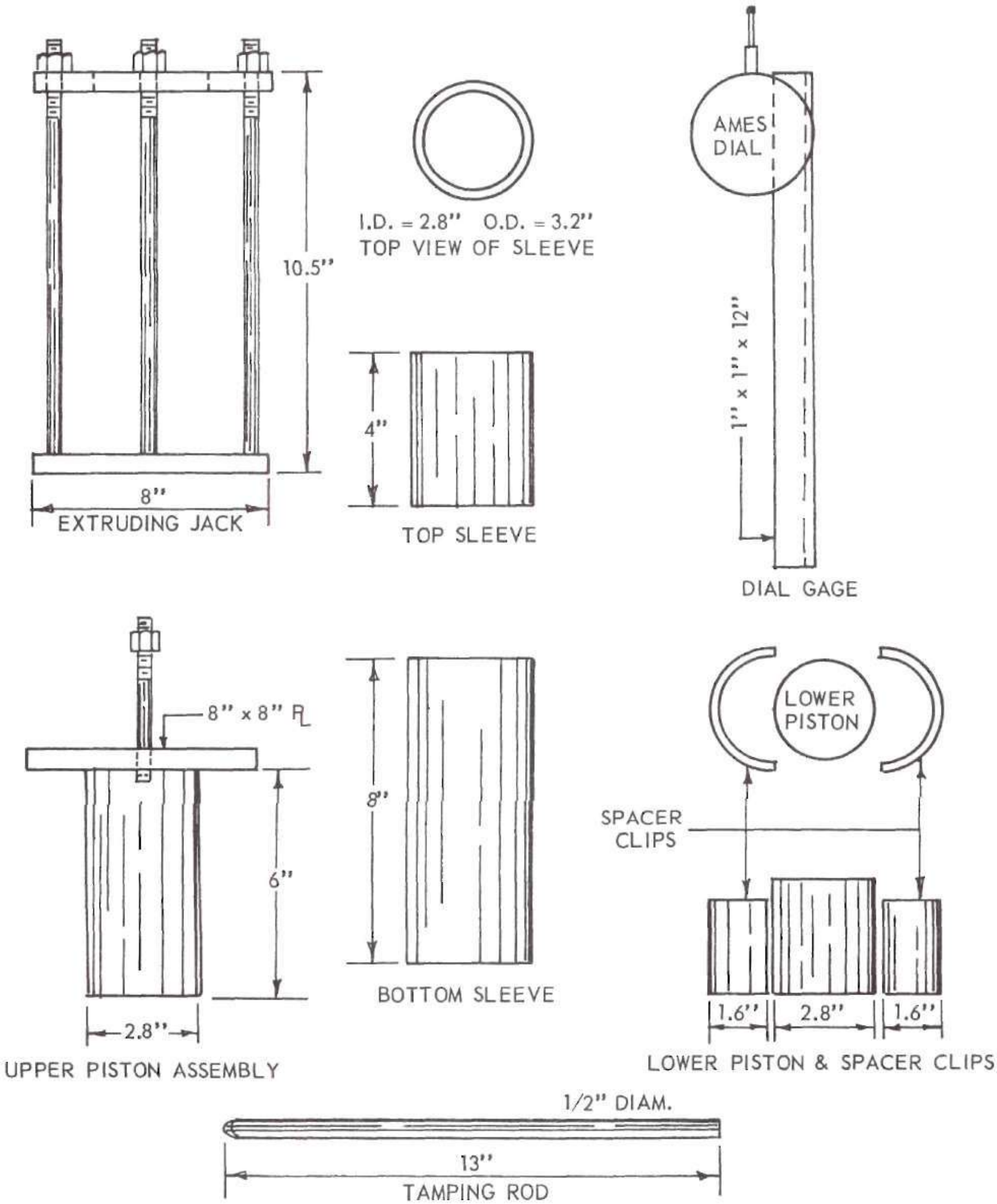

Figure 2. Equipment Used in Molding Samples for Strength Tests.

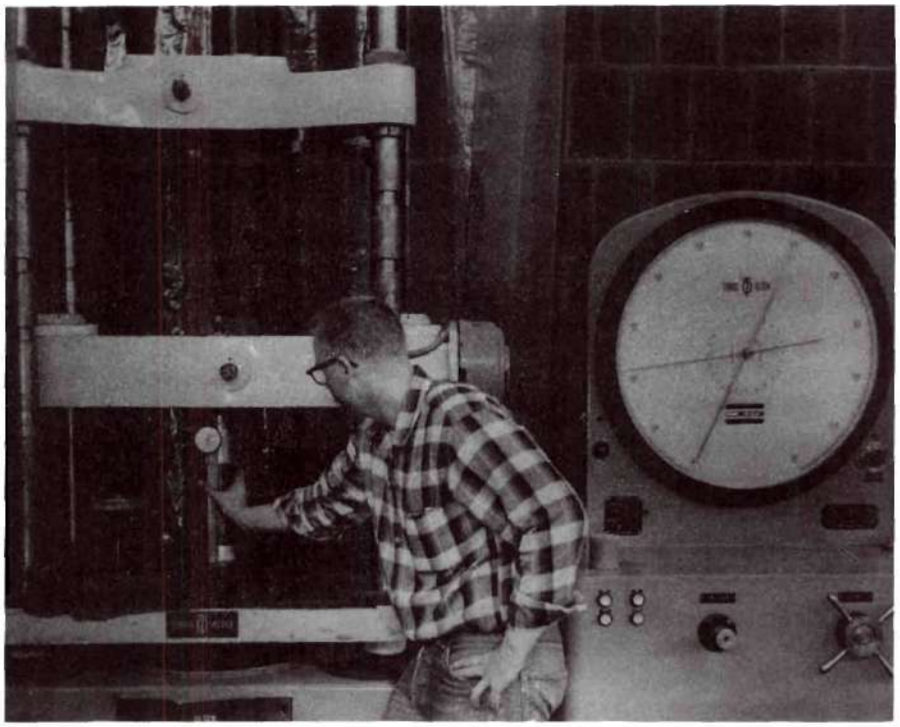

Figure 3. Sample Being Molded for Strength Test.

5. The dial gage assembly was held against the bottom sleeve and the sample compacted at a rate of strain of 0.035 inch per minute.
6. When the dial gage reading was such that it corresponded to a height of sample of 5.6 inches, the machine was immediately stopped. Allowance was made for rebound of the sample, the exact amount depending on the type of mix being compacted.
7. The compacted sample was extruded from the bottom sleeve by placing the bottom sleeve in the extruding jack, aligning the bottom sleeve with the upper piston, and then pushing the sample down by means of pressure exerted by the upper piston.
8. The sample height was checked and the sample immediately sealed in a polyethylene freezer-bag.

For each batch, moisture samples were taken just before molding the first sample and immediately following molding of the fourth sample. Only samples molded within 1 per cent of optimum moisture were used.

The sealed samples were placed in a storage cabinet and allowed to cure. The four samples from each batch were cured for either 7 days or 28 days.

At the end of the prescribed curing period, the samples were tested for compressive strength. Two of the samples were tested without confining pressure and the other two were subjected to a lateral pressure of 20 pounds per square inch during the loading period. Figure 4 shows a triaxial shear test in progress.

After the sample was removed from the polyethylene bag, it was placed in the triaxial cell. For confined samples, a thin rubber membrane was placed over the sample so that the air pressure would not be exerted on

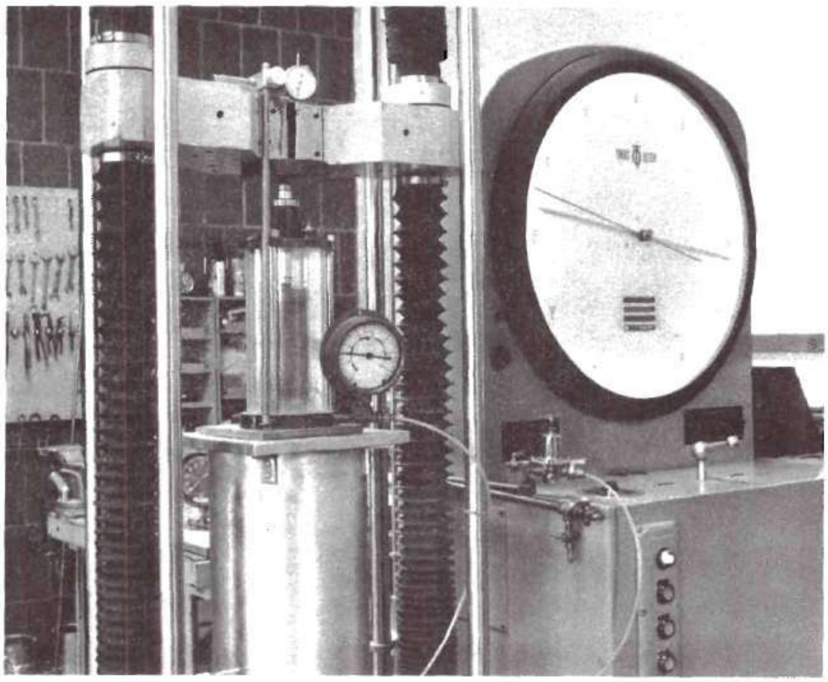

Figure 4. Triaxial Shear Test in Progress.

the soil itself. The top cap was placed on the sample and the top of the cell secured to the lucite cylinder. The shaft was inserted through the top of the cell until it gently rested on the top cap.

The triaxial cell was then aligned under the upper head of a constant-strain load machine, a dial gage being attached to the upper head. Load was applied at a rate of 0.075 inch per minute of vertical head-travel. A load reading was taken and recorded for each 0.025 inch increment of strain.

Immediately following failure of the sample, the sample was removed from the cell and a moisture sample taken.

The compressive strength was taken as the average deviator stress obtained from the failure-load readings of the two samples.

CHAPTER IV

EVALUATION OF TEST RESULTS

General.--In this chapter, an evaluation will be made of the effects of various screenings contents and cement contents on each individual soil. Also, a comparison of the relative effects on the five different soils will be made. In this way the feasibility of using a certain combination of these admixtures for a certain soil will become more evident.

It can be seen from Figures 5, 7, 9, 11, and 13 that for a constant cement content, the dry density increased appreciably with increasing screenings content. For a constant screenings content, however, no such broad statement can be made about the effect of increasing the cement content (see Figures 6, 8, 10, 12, and 14); in fact, increasing the cement content had very little effect on the dry density. It can be concluded, then, that the greater portion of increase in dry density can be attributed to the addition of the stone screenings. This is due to the increasing amount of well graded, angular-shaped stone present in the mix. Greater and greater amounts of soil having maximum dry densities less than that of these stone screenings (121.8 lb./cu.ft.) are being replaced with screenings. It is important to note here that the percentage increase in maximum dry density due to the addition of screenings increases with decreasing original maximum dry density of the soils. In other words, the greatest increase in maximum dry density due to adding 75 per cent screenings occurred with Soil VIII while the least increase took place with Soil VII (See Table 3). On the other hand, for a constant screenings content,

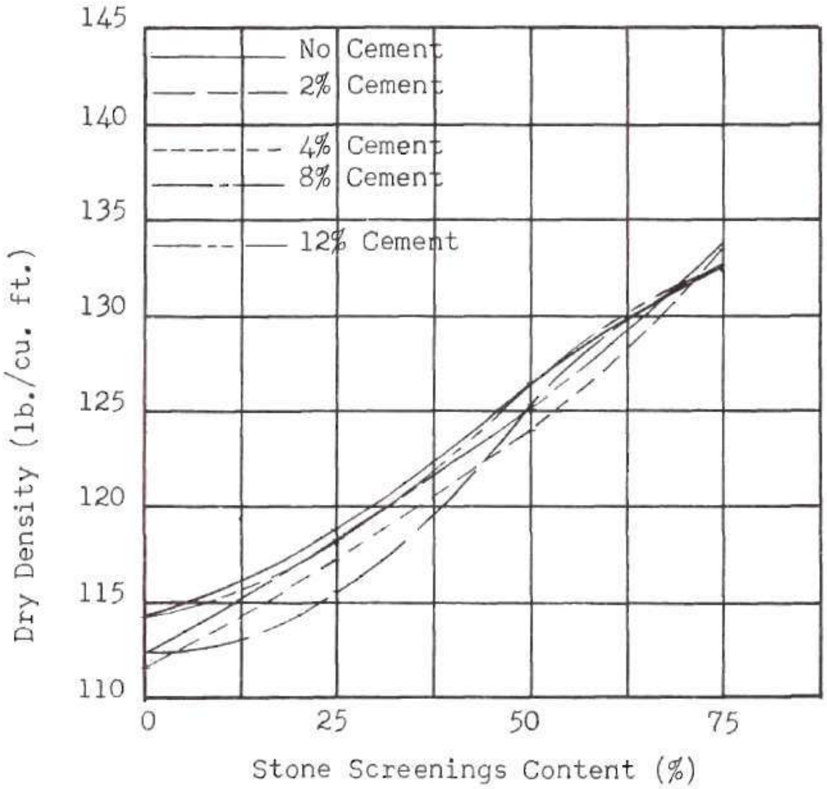

Figure 5. Dry Density vs. Screenings Content, Soil IV

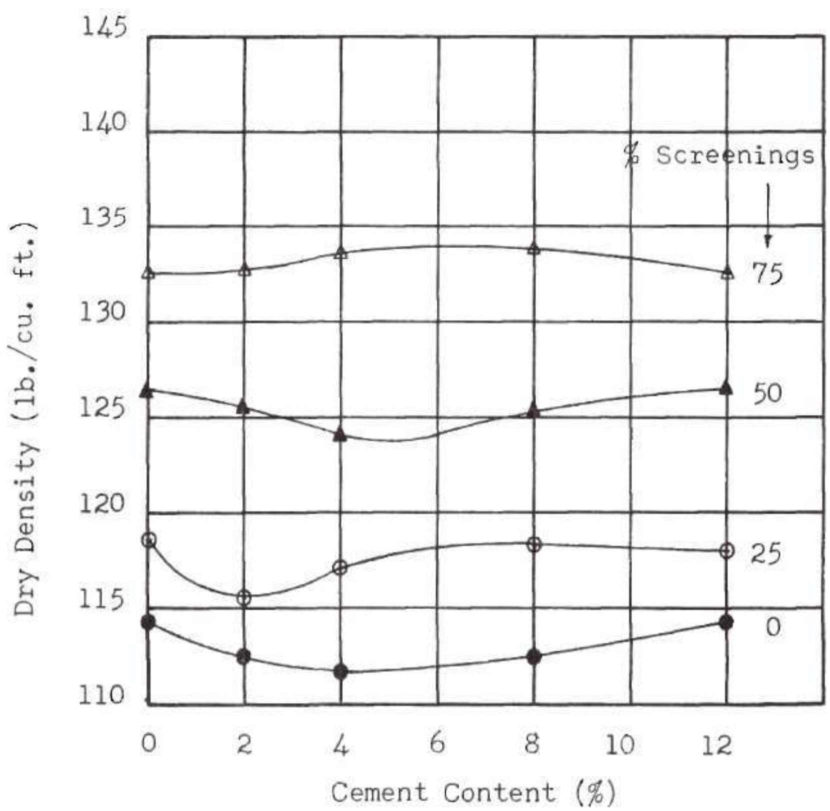

Figure 6. Dry Density vs. Cement Content, Soil IV

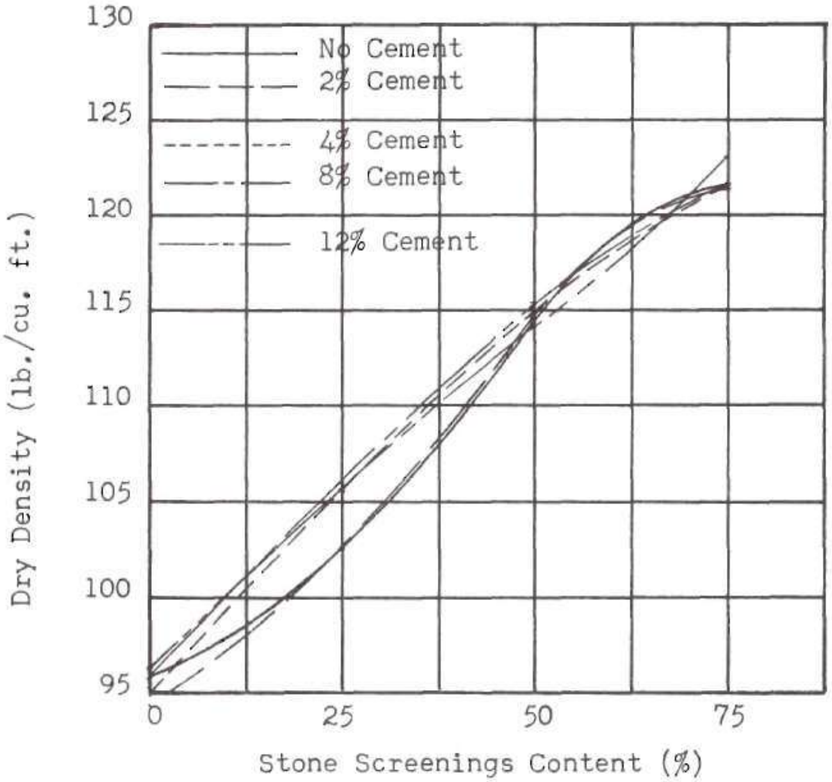

Figure 7. Dry Density vs. Screenings Content, Soil V-A

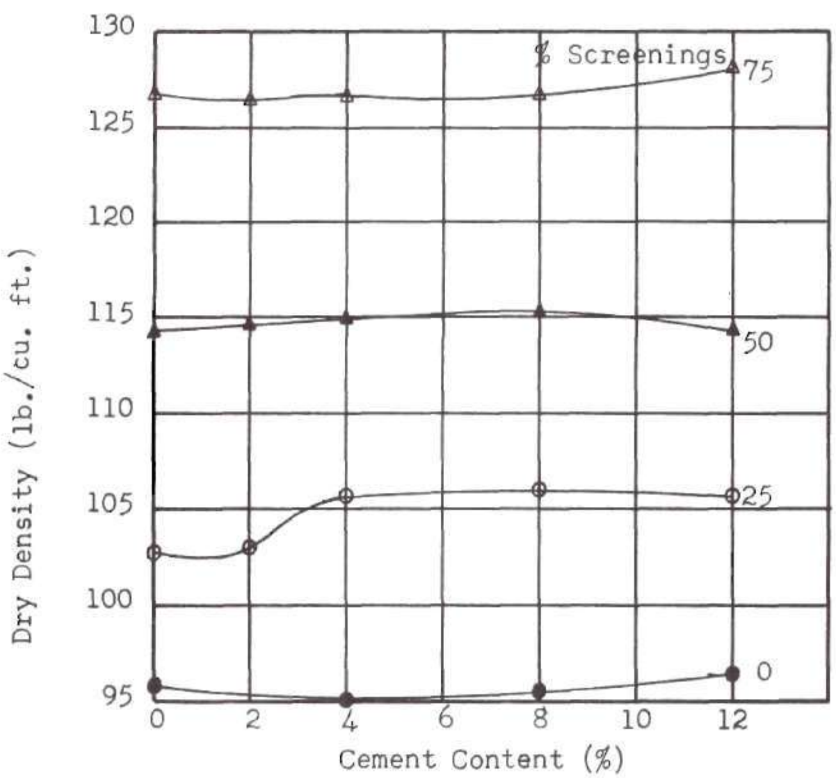

Figure 8. Dry Density vs. Cement Content, Soil V-A

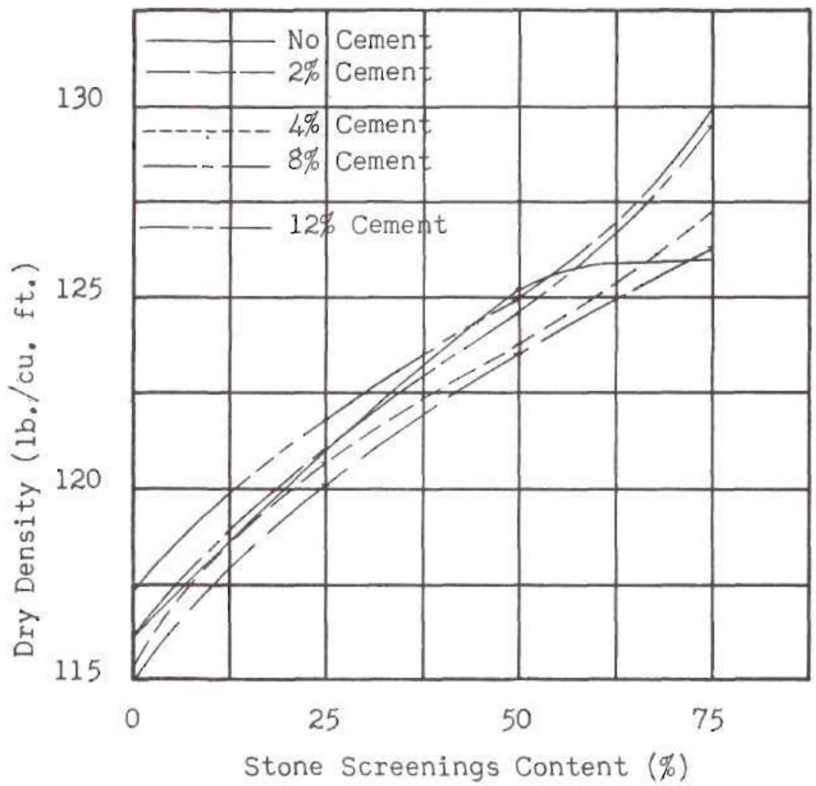

Figure 9. Dry Density vs. Screenings Content, Soil VII

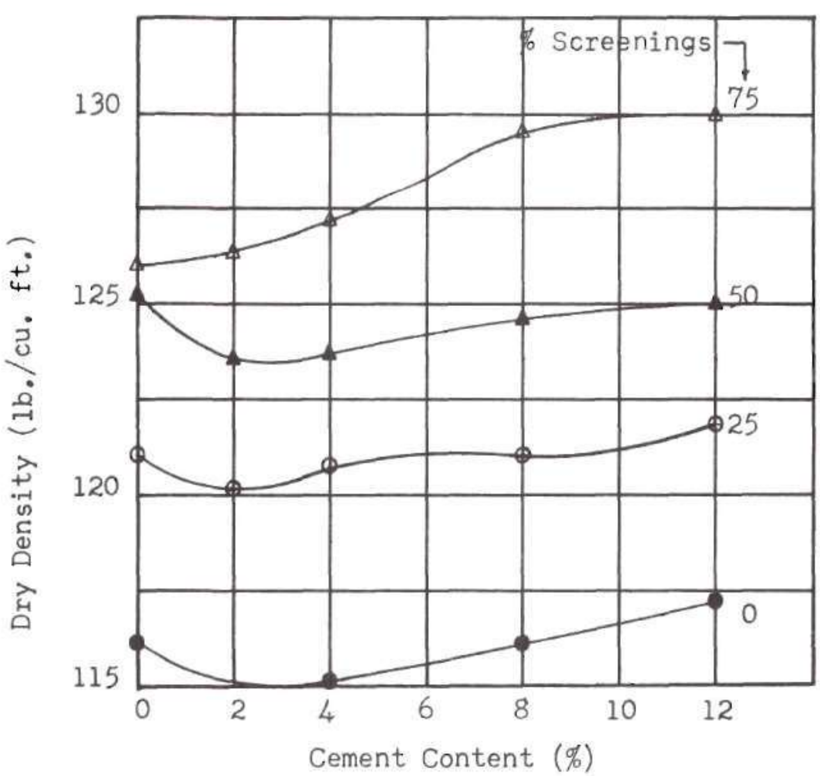

Figure 10. Dry Density vs. Cement Content, Soil VII

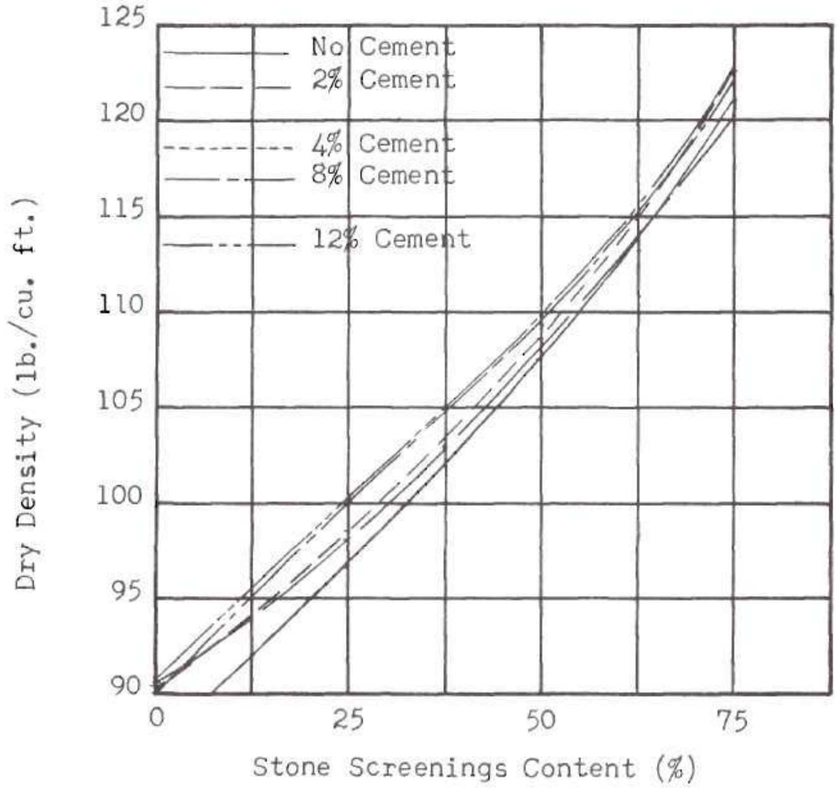

Figure 11. Dry Density vs. Screenings Content, Soil VIII

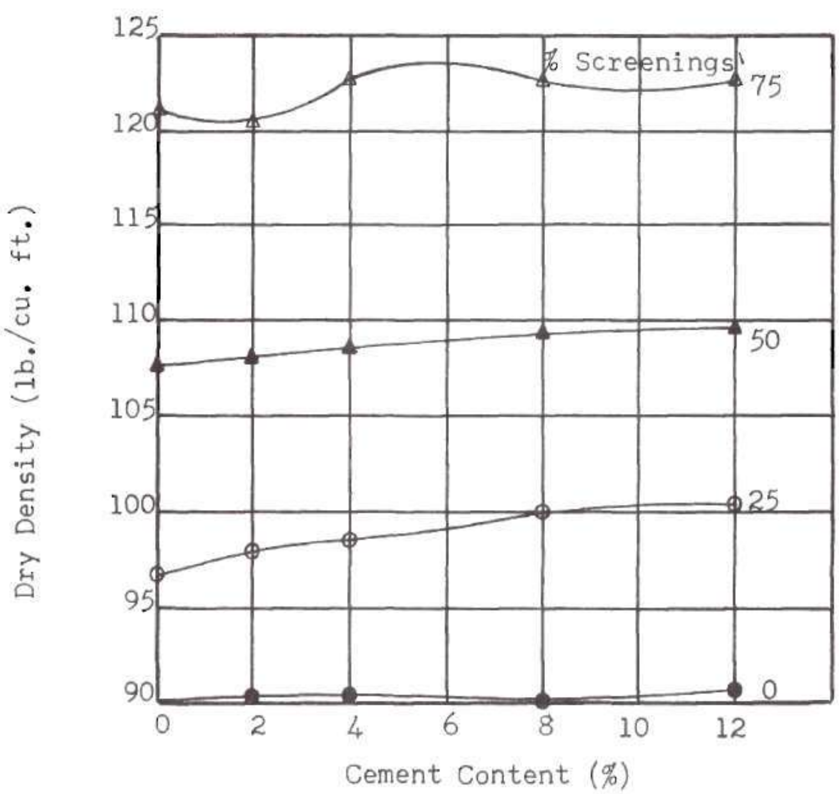

Figure 12. Dry Density vs. Cement Content, Soil VIII

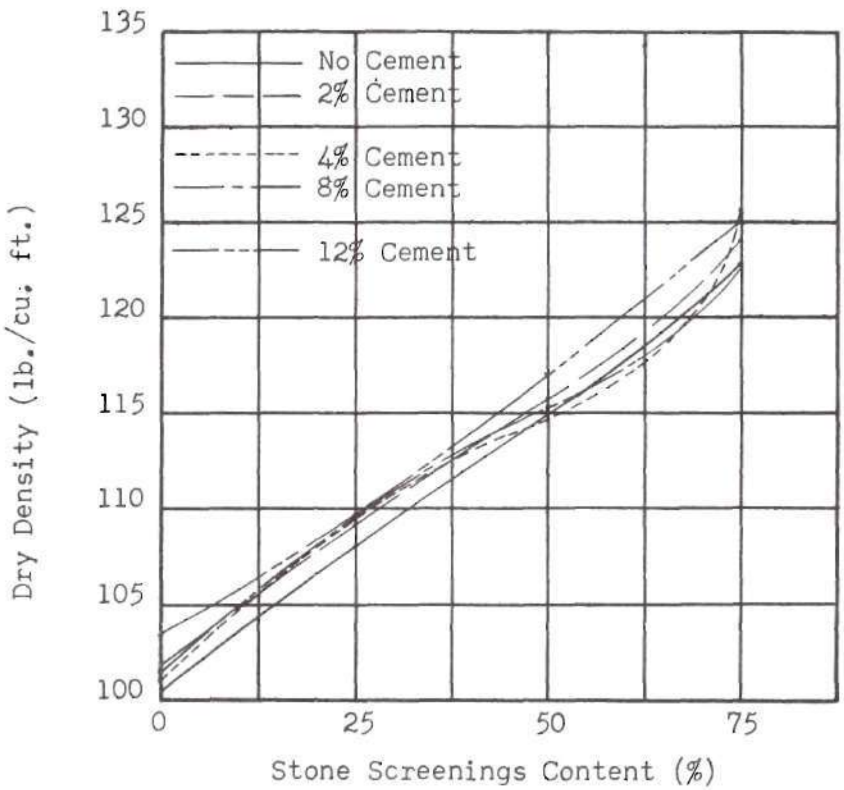

Figure 13. Dry Density vs. Screenings Content, Soil IX

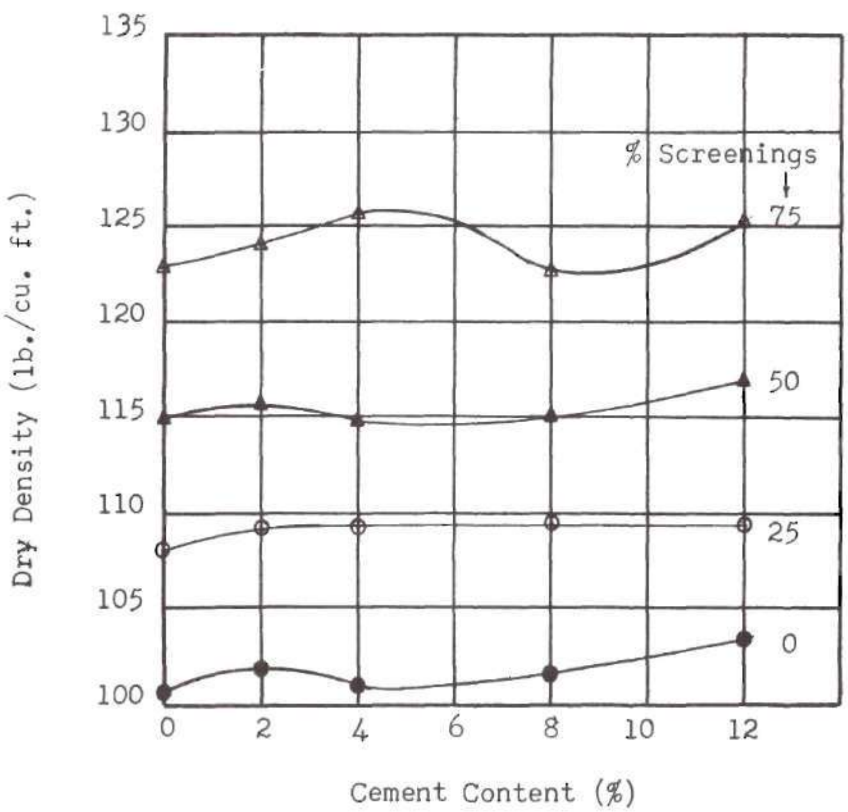

Figure 14. Dry Density vs. Cement Content, Soil IX

only a small amount of soil is replaced when cement is added and so any increase in maximum dry density is difficult to detect.

Effect of Cement on Compressive Strength.--The influence of cement content on compressive strength, for a fixed screenings content, can be found from Tables 4 through 8 and Figures 15 through 34. These data indicate that, for any given curing period and lateral pressure, increasing the cement content caused an increase in the deviator stress.

For Soils IV, VII, and IX without screenings the greatest gains in strength, within any cement content range of four per cent, were obtained in the range from 0 to 4 per cent. For Soils V-A and VIII without screenings the largest per cent increases were found to be in the cement content range between 4 and 8 per cent. This information was derived from Tables 4 through 8 and is plotted in Figures 15 through 34. For soils containing 25% screenings, the same tables show that the highest strength gains for Soil IV were between 0 and 4 per cent. This range was also the most beneficial for Soils VII and IX. For Soil V-A, the greatest increase occurred between 4 and 8 per cent cement content. Soil VIII shows an increase in deviator stress that is constant throughout the entire cement content range. However, the gains in strength of Soil VIII are less than those of the other soils. This is probably due to the greater amount of binder (minus No. 200 sieve material) in this soil.

The values of deviator stress for soils containing 50% screenings indicate that the greatest increases in strength for all soils except Soil V-A occurred in the 0-4 per cent cement content range. Increasing the cement content from 4 to 8 per cent doubled the strength of Soil V-A giving that soil its largest increase for any 4 per cent range.

Table 4. Summary of Compressive Strength Tests, Soil IV Combined with Stone Screenings and Portland Cement.

		Normal Stress δ_1 (psi)			
Length of Cure (days)		7	28	7	28
Lateral Pressure, δ_3 (psi)		20	20	0	0
% Screenings	% Cement				
0	0	58.0	73.0	33.0	38.0
0	2	137	169	104	109
0	4	270	347	241	284
0	8	333	493	327	387
0	12	457	588	460	539
25	0	29.9	48.4	19.1	23.9
25	2	189	246	148	199
25	4	429	557	362	501
25	8	611	887	528	755
25	12	724	989	590	823
50	0	50.0	60.3	16.8	18.8
50	2	287	333	206	258
50	4	418	557	376	464
50	8	656	742	515	589
50	12	882	1048	757	830
75	0	73.5	68.0	9.5	11.0
75	2	289	375	157	238
75	4	438	498	292	360
75	8	684	818	525	635
75	12	906	1058	756	850

Table 5. Summary of Compressive Strength Tests, Soil V-A Combined with Stone Screenings and Portland Cement.

		Normal Stress δ_1 (psi)			
Length of Cure (days)		7	28	7	28
Lateral Pressure δ_3 (psi)		20	20	0	0
% Screenings	% Cement				
0	0	59.5	74.2	23.6	35.0
0	2	42.0	69.0	22.5	33.0
0	4	130	166	80.1	114
0	8	385	523	314	531
0	12	554	843	496	762
25	0	33.0	39.0	16.0	17.0
25	2	50.0	73.0	29.0	42.0
25	4	237	271	149	238
25	8	544	789	438	709
25	12	723	1067	623	968
50	0	55.0	48.0	20.0	17.0
50	2	130	169	70.0	108
50	4	346	477	291	418
50	8	666	866	621	789
50	12	598	888	501	762
75	0	61.0	66.0	12.9	15.0
75	2	222	321	141	230
75	4	382	718	209	653
75	8	496	811	360	675
75	12	722	1068	619	912

Table 6. Summary of Compressive Strength Tests, Soil VII Combined with Stone Screenings and Portland Cement.

		Deviator Stress δ_1 (psi)			
Length of Cure (days)		7	28	7	28
Lateral Pressure δ_3 (psi)		20	20	0	0
% Screenings	% Cement				
0	0	63.7	74.2	33.6	53.8
0	2	190	209	169	200
0	4	421	555	393	550
0	8	731	909	737	866
0	12	944	1075	932	1023
25	0	70.0	67.7	20.7	23.7
25	2	242	312	186	264
25	4	430	653	362	599
25	8	652	945	527	872
25	12	958	1316	819	1124
50	0	81.1	80.0	14.7	15.5
50	2	255	329	153	266
50	4	386	547	288	476
50	8	697	980	573	843
50	12	1009	1179	838	1084
75	0	73.3	74.7	4.6	3.7
75	2	236	290	103	166
75	4	378	377	236	252
75	8	806	824	630	648
75	12	1305	1682	1158	1558

Table 7. Summary of Compressive Strength Tests, Soil VIII Combined with Stone Screenings and Portland Cement.

		Deviator Stress δ_1 (psi)			
Length of Cure (days)		7	28	7	28
Lateral Pressure, δ_3 (psi)		20	20	0	0
% Screenings	% Cement				
0	0	56.2	58.0	47.0	38.0
0	2	92.0	83.0	71.0	56.0
0	4	147.5	137.0	95.0	100.0
0	8	280.0	291.0	242.0	242.0
0	12	341.0	444.0	281.0	395.5
25	0	60.7	45.0	40.0	37.6
25	2	95.2	88.0	73.0	62.0
25	4	166.0	202.0	148.0	169.0
25	8	349.2	394.0	278.6	346.0
25	12	434.0	568.0	430.0	539.7
50	0	39.1	45.2	21.8	31.2
50	2	190.0	266.0	160.0	225.0
50	4	417.0	581.0	375.0	518.0
50	8	527.0	847.0	466.0	776.0
50	12	649.0	945.0	555.0	923.0
75	0	77.6	80.0	29.6	37.0
75	2	324.0	458.0	250.0	382.0
75	4	506.0	744.0	432.0	664.0
75	8	695.0	1032.0	632.0	882.0
75	12	972.0	1392.0	848.0	1242.0

Table 8 . Summary of Compressive Strength Tests, Soil IX Combined with Stone Screenings and Portland Cement.

		Deviator Stress δ_1 (psi)			
Length of Cure (days)		7	28	7	28
Lateral Pressure, δ_3, (psi)		20	20	0	0
% Screenings	% Cement				
0	0	56.0	106.5	32.0	71.7
0	2	83.5	92.5	57.8	62.0
0	4	197.3	216.5	138.0	194.0
0	8	336.8	382.0	288.8	338.5
0	12	423.3	571.0	356.5	502.0
25	0	57.8	130.1	41.8	81.0
25	1.5	123.1	280.0	98.5	98.2
25	3	295.3	416.6	256.1	354.1
25	6	513.0	718.3	466.1	651.8
25	9	601.6	1065.2	630.5	1060.5
50	0	78.6	40.9	42.4	38.3
50	1	95.5	95.5	80.9	93.2
50	2	271.5	391.3	252.0	373.7
50	4	379.0	691.0	401.0	637.0
50	6	456.0	755.0	462.0	792.0
75	0	30.9	80.4	27.8	38.8
75	0.5	72.6	95.5	35.2	86.5
75	1.0	221.0	280.0	140.0	213.0
75	2.0	310.0	442.0	235.0	369.0
75	3.0	357.0	588.0	288.0	525.0

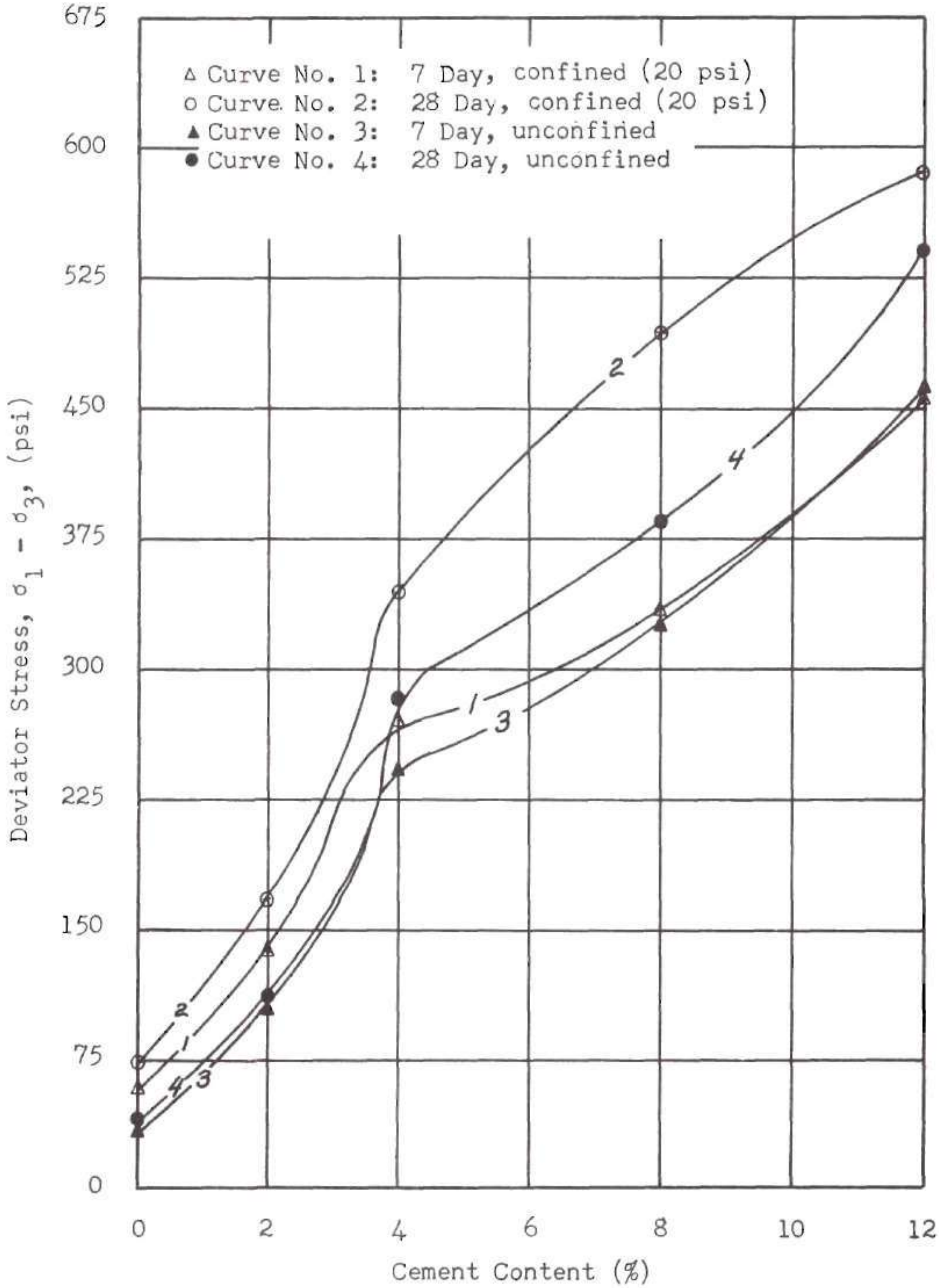

Figure 15. Deviator Stress Vs. Cement Content, Soil IV (No Screenings)

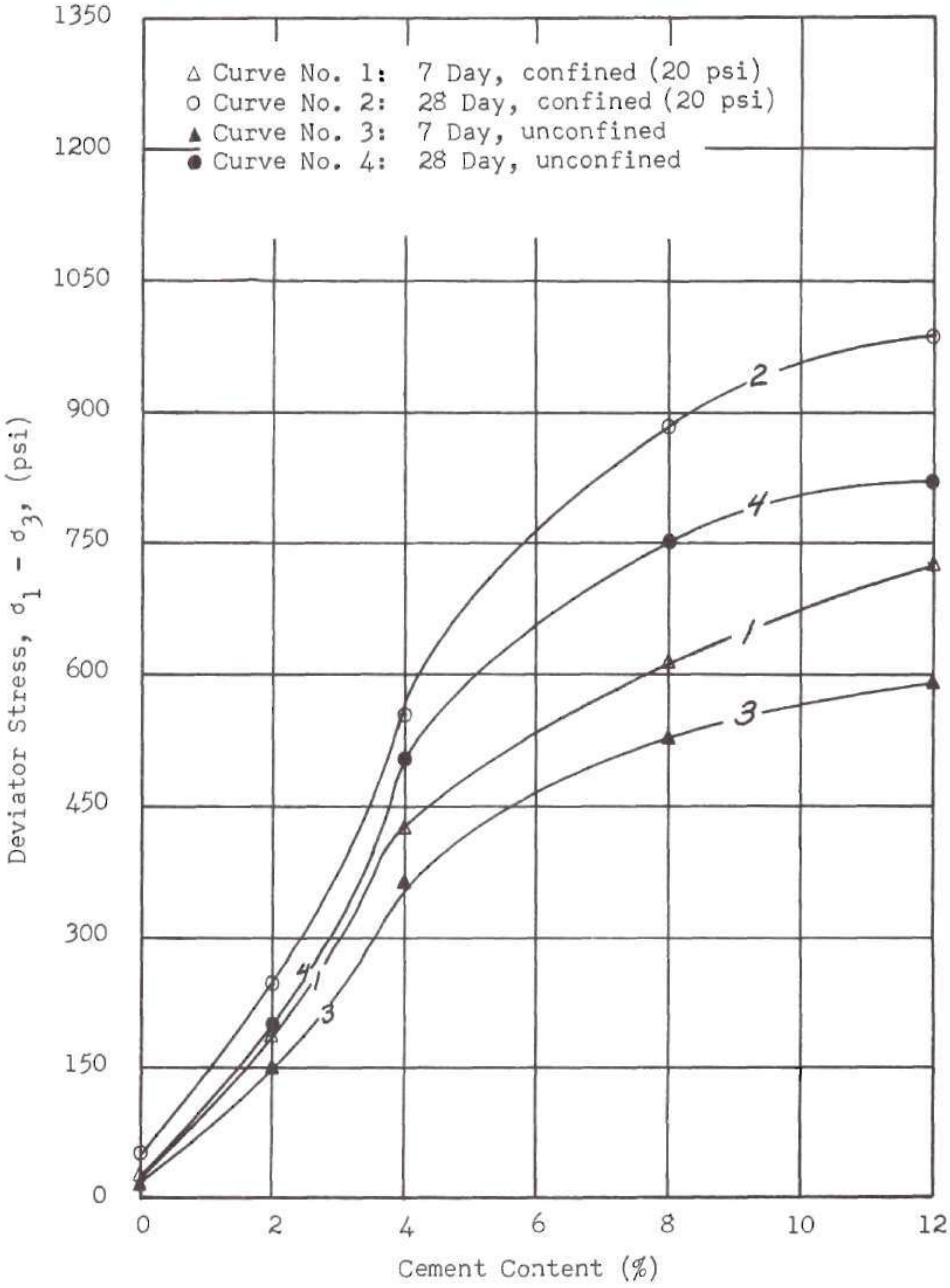

Figure 16. Deviator Stress Vs. Cement Content, Soil IV + 25% Screenings

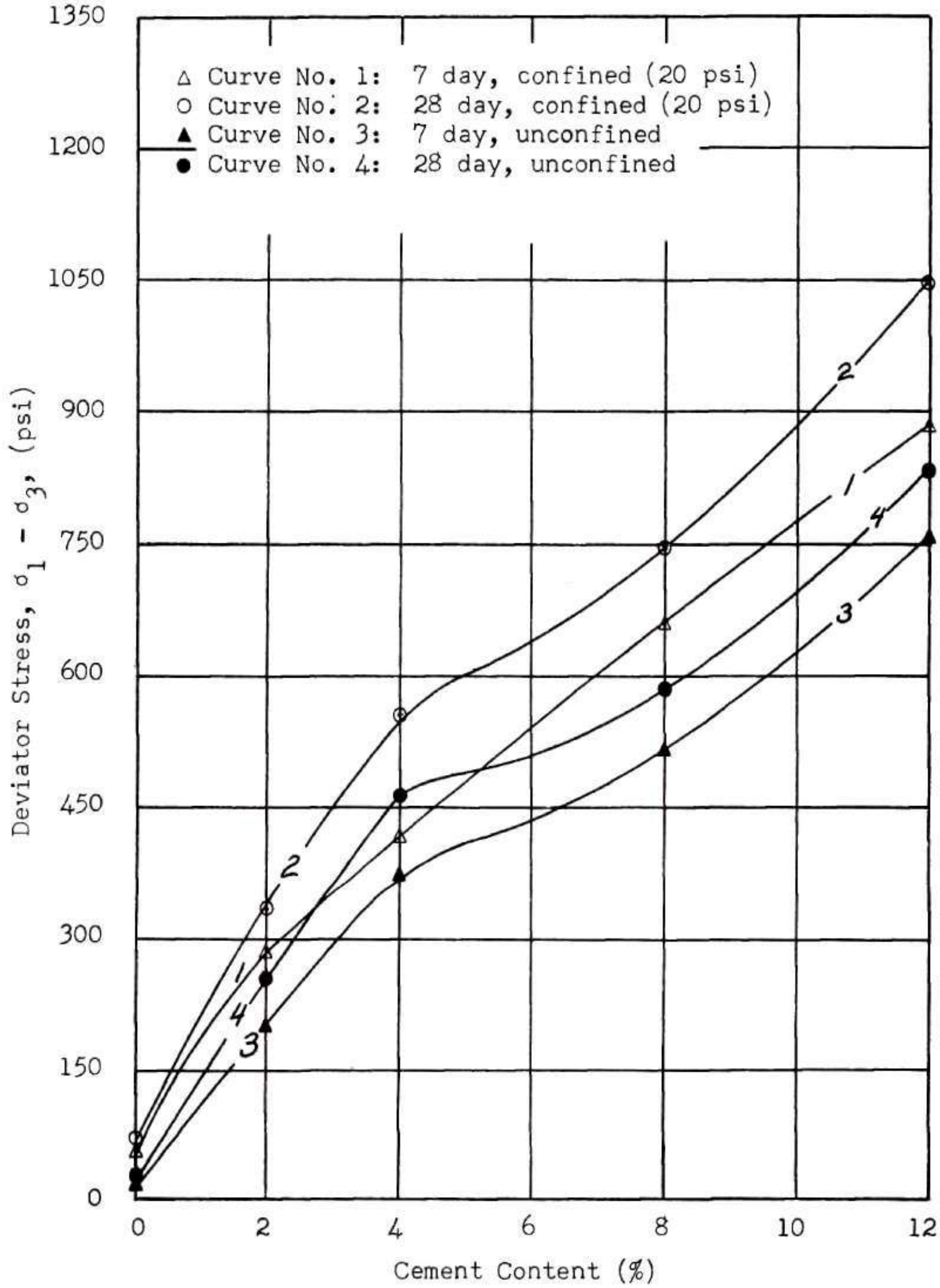

Figure 17. Deviator Stress Vs. Cement Content, Soil IV + 50% Screenings

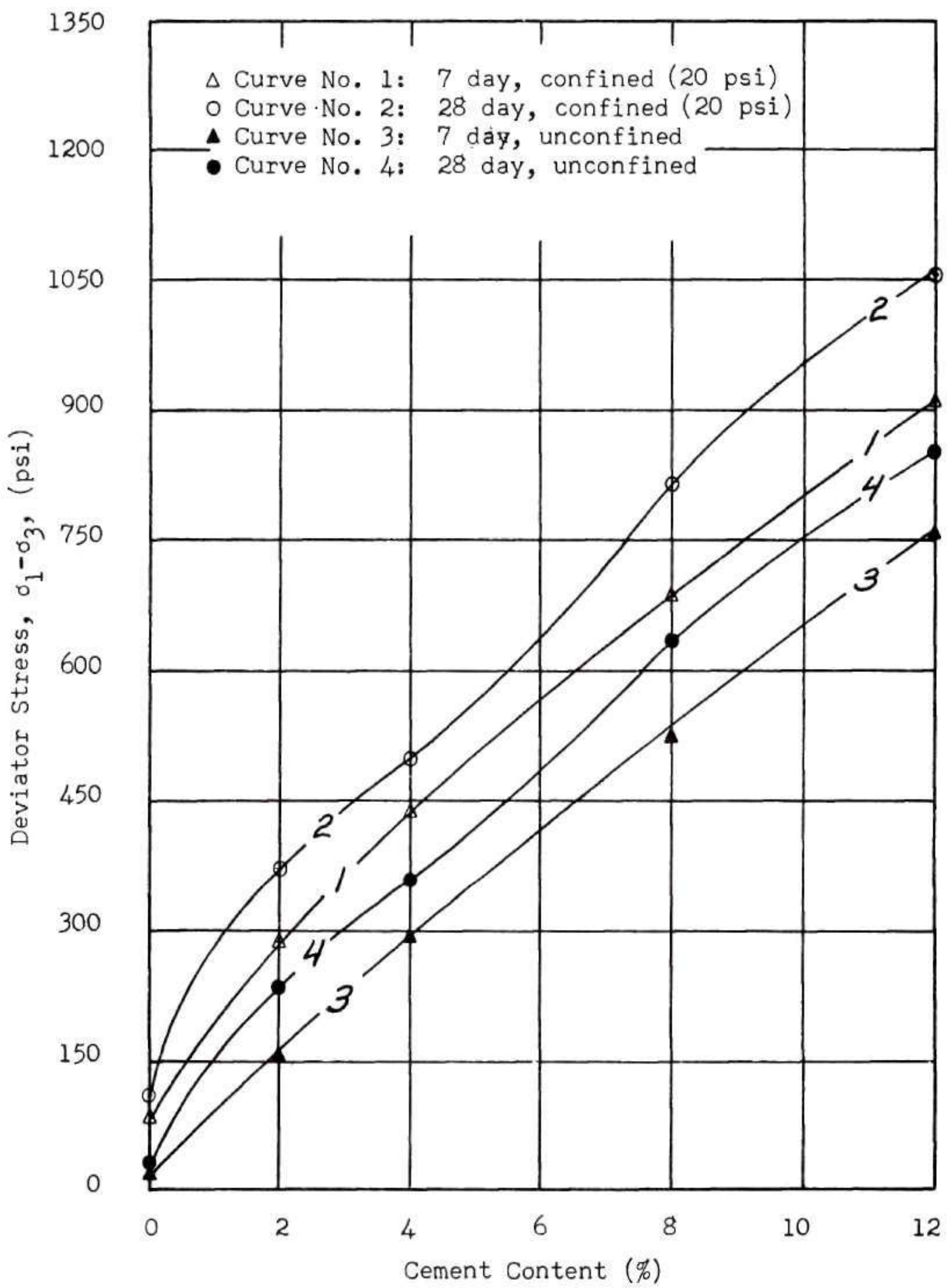

Figure 18. Deviator Stress Vs. Cement Content,
Soil IV + 75% Screenings

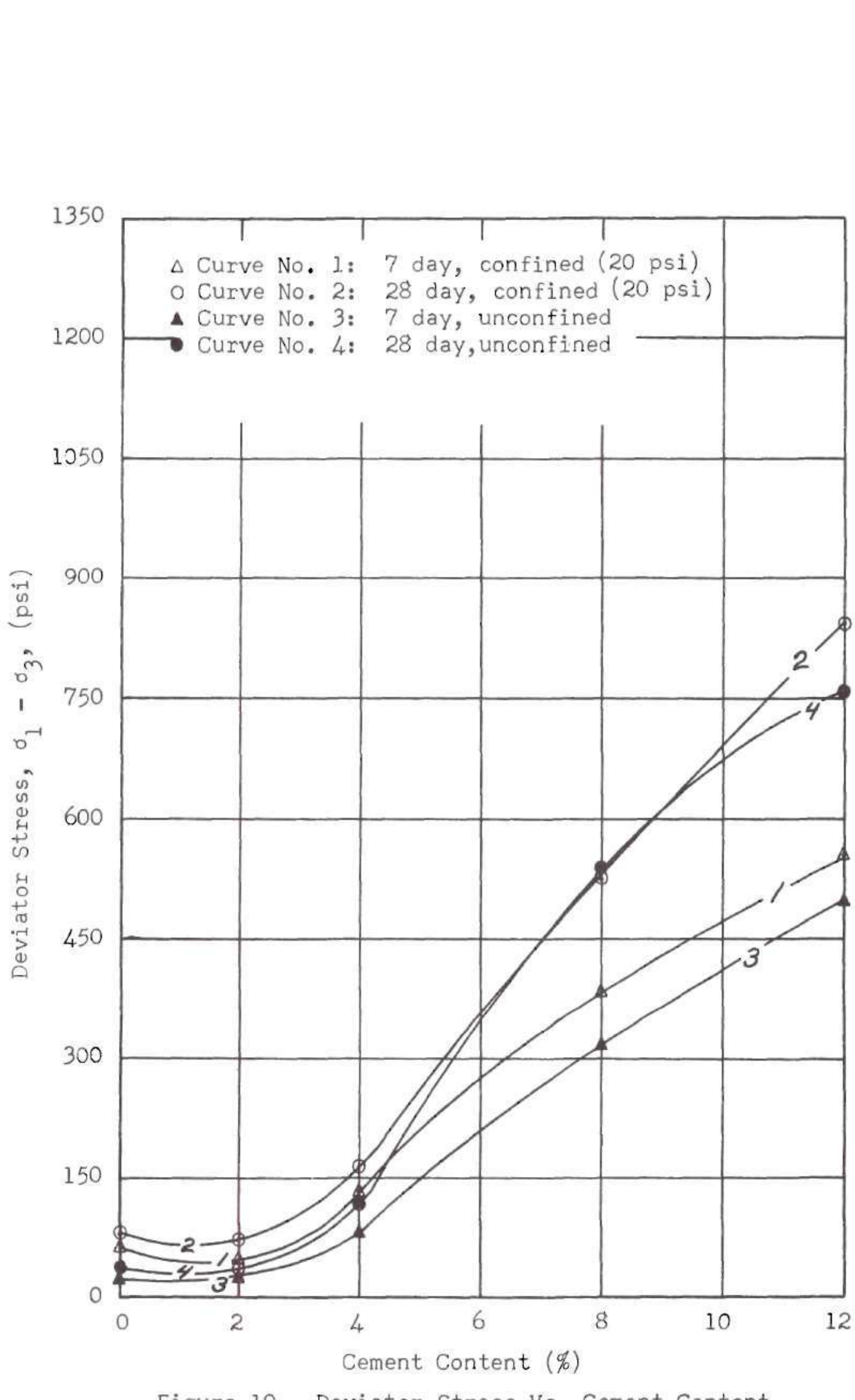

Figure 19. Deviator Stress Vs. Cement Content, Soil V-A (No Screenings)

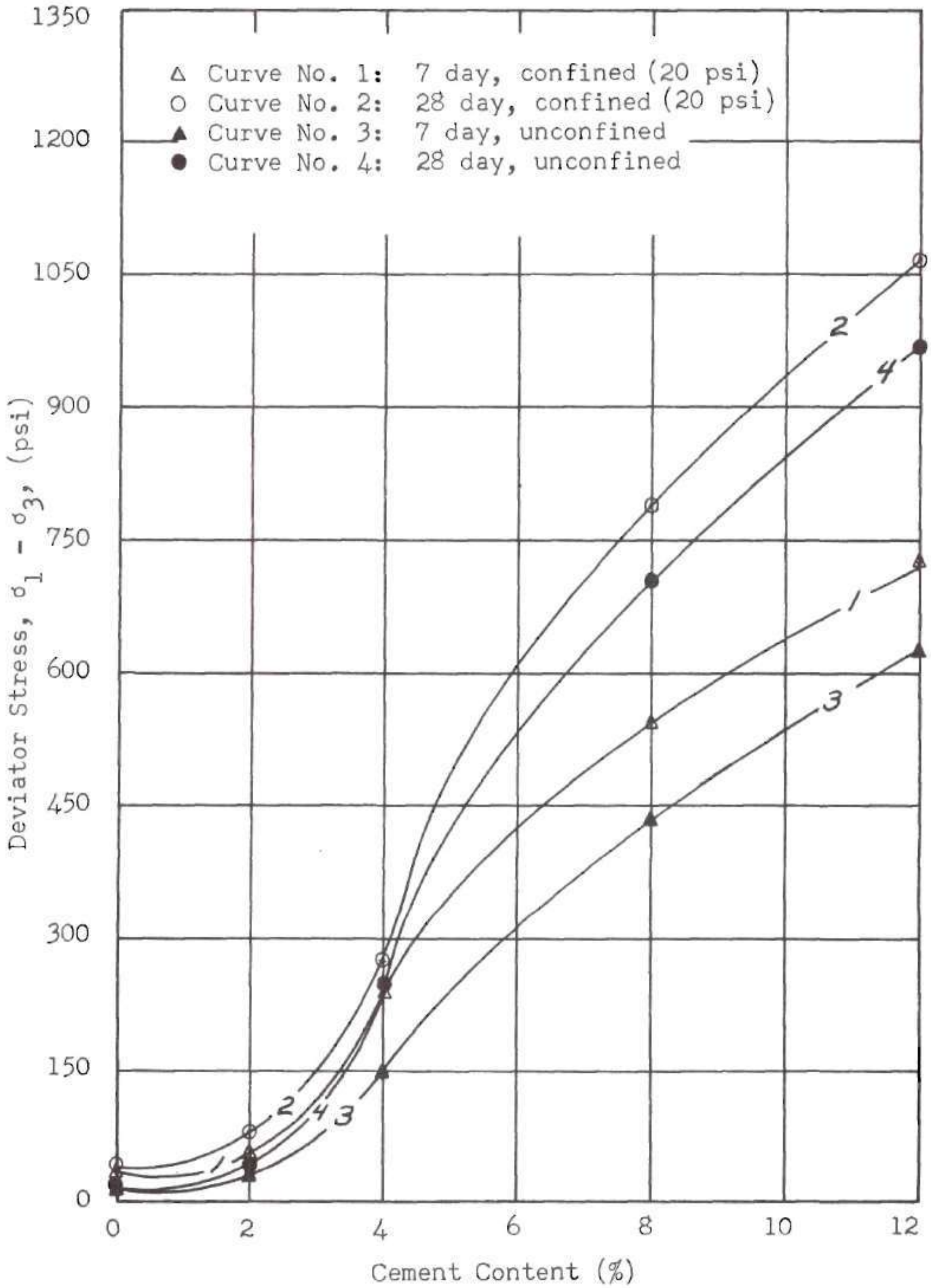

Figure 20. Deviator Stress Vs. Cement Content,
Soil V-A + 25% Screenings

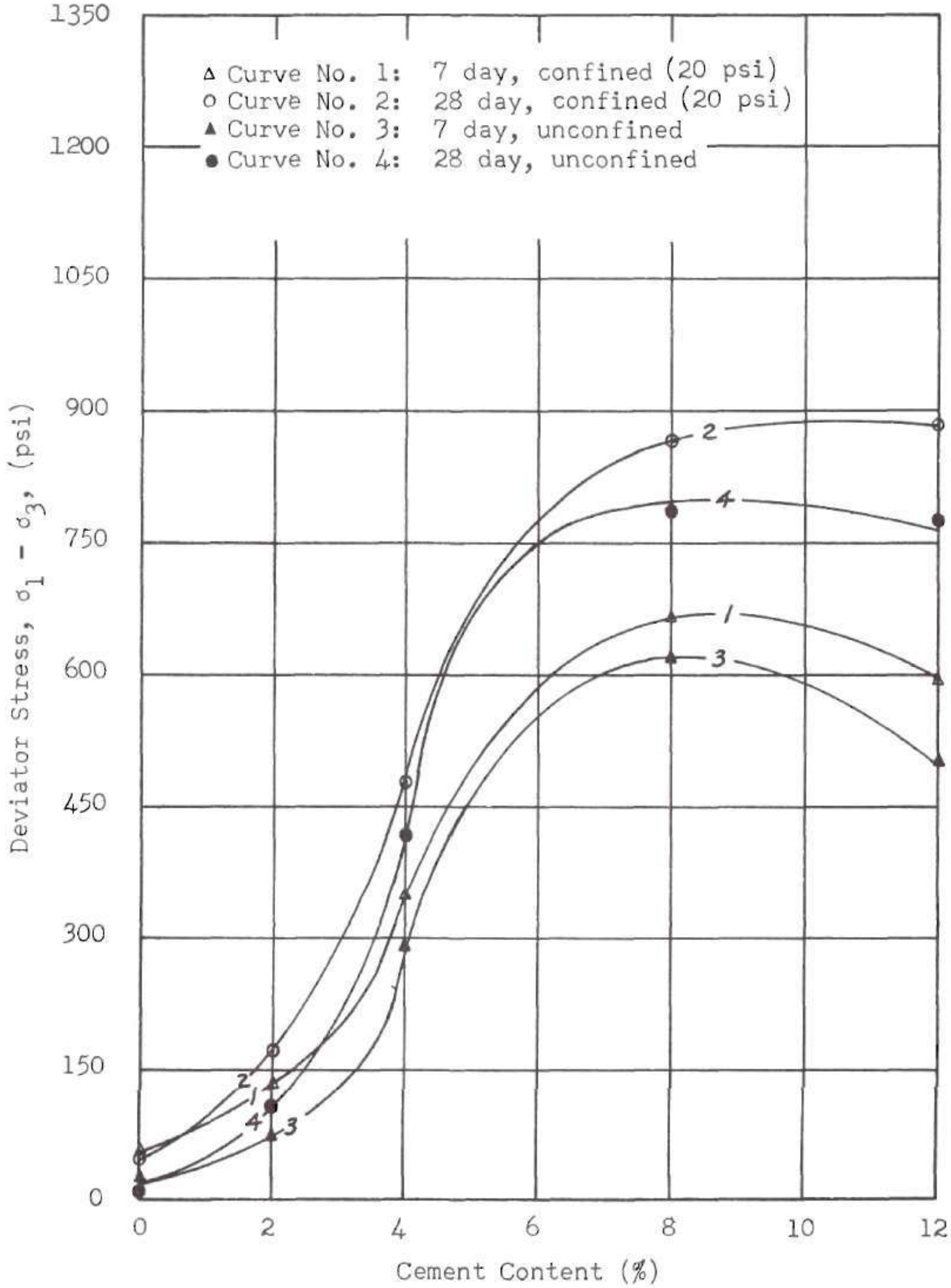

Figure 21. Deviator Stress Vs. Cement Content, Soil V-A + 50% Screenings

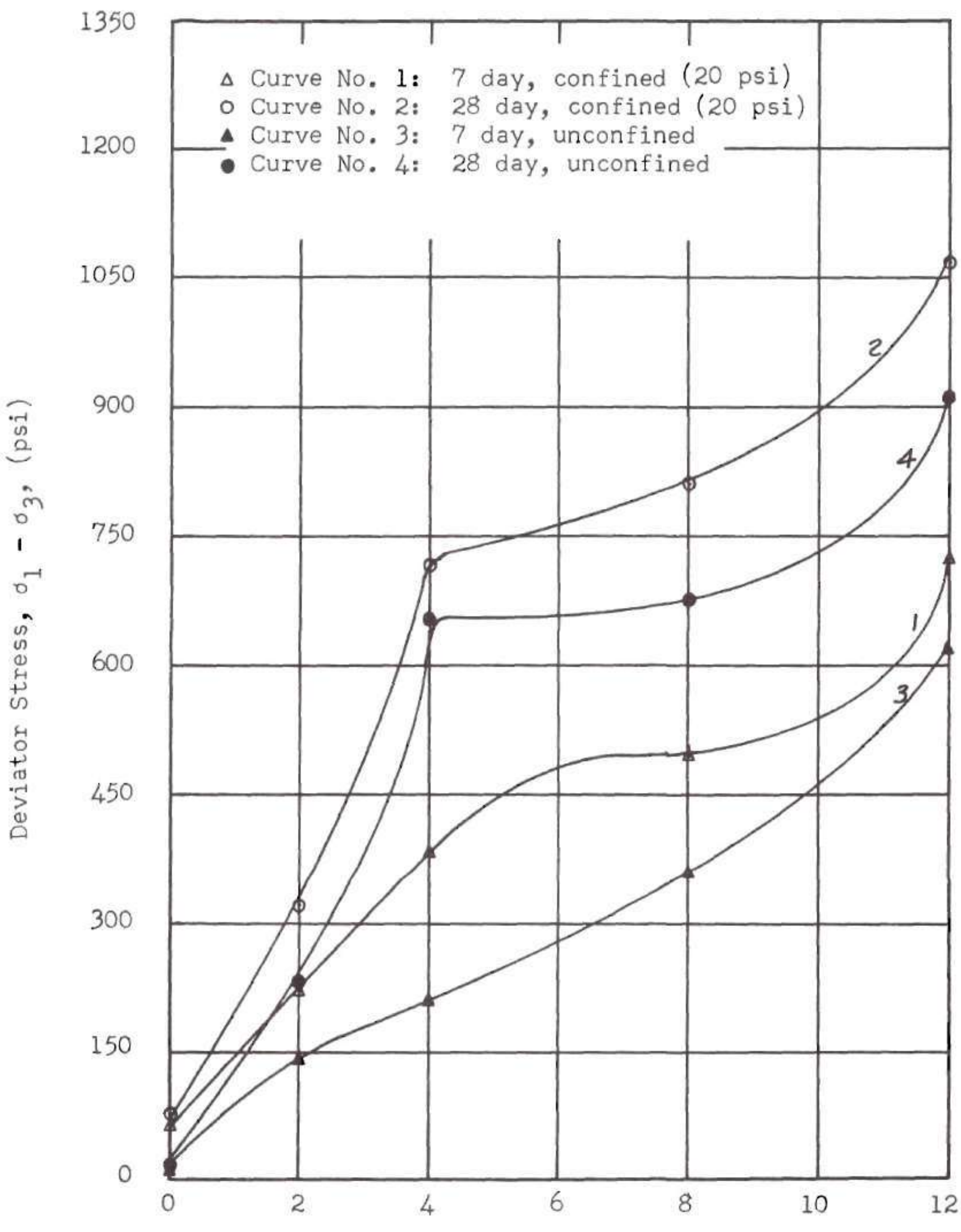

Figure 22. Deviator Stress Vs. Cement Content, Soil V-A + 75% Screenings

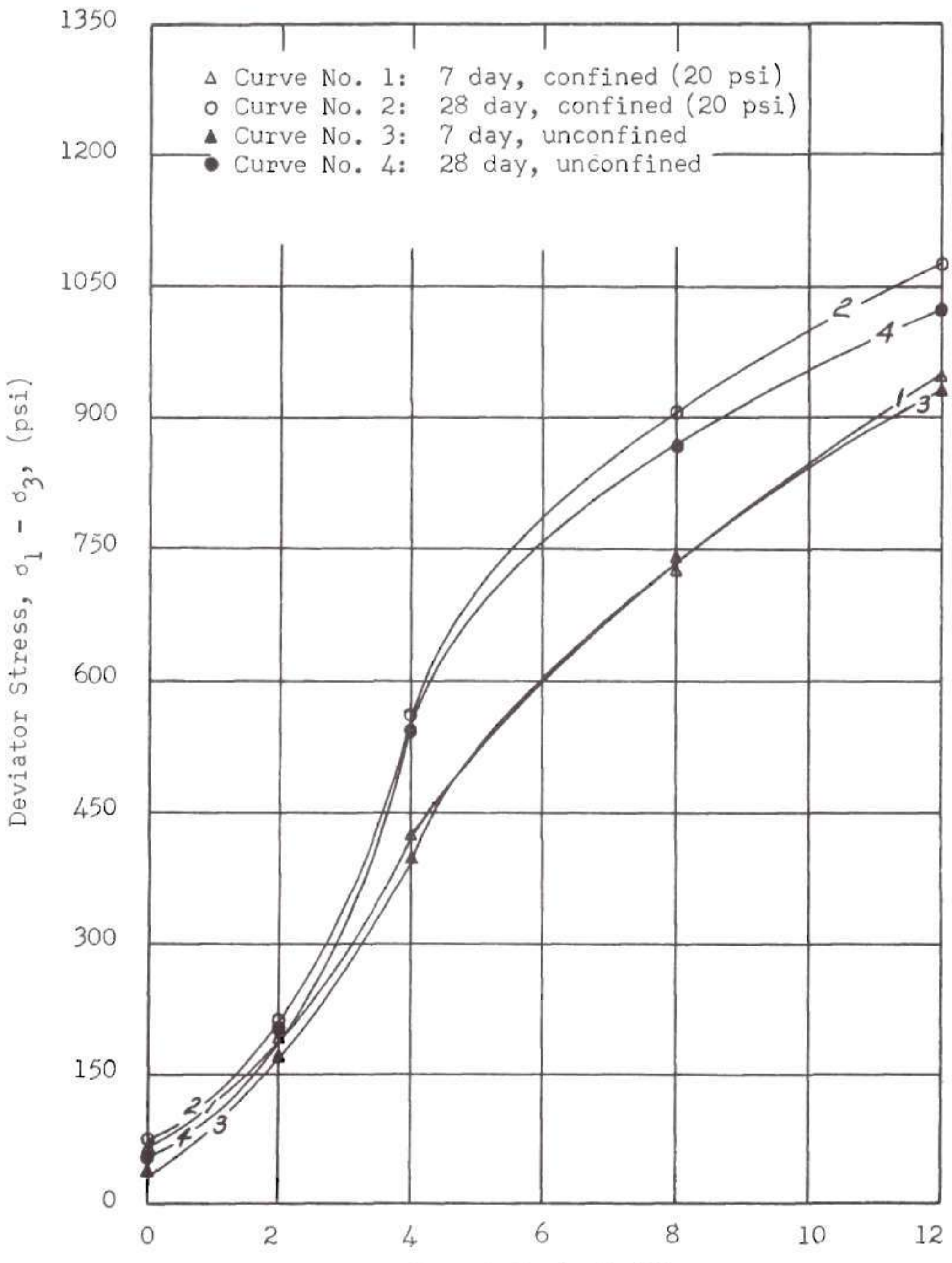

Figure 23. Deviator Stress Vs. Cement Content, Soil VII (No Screenings)

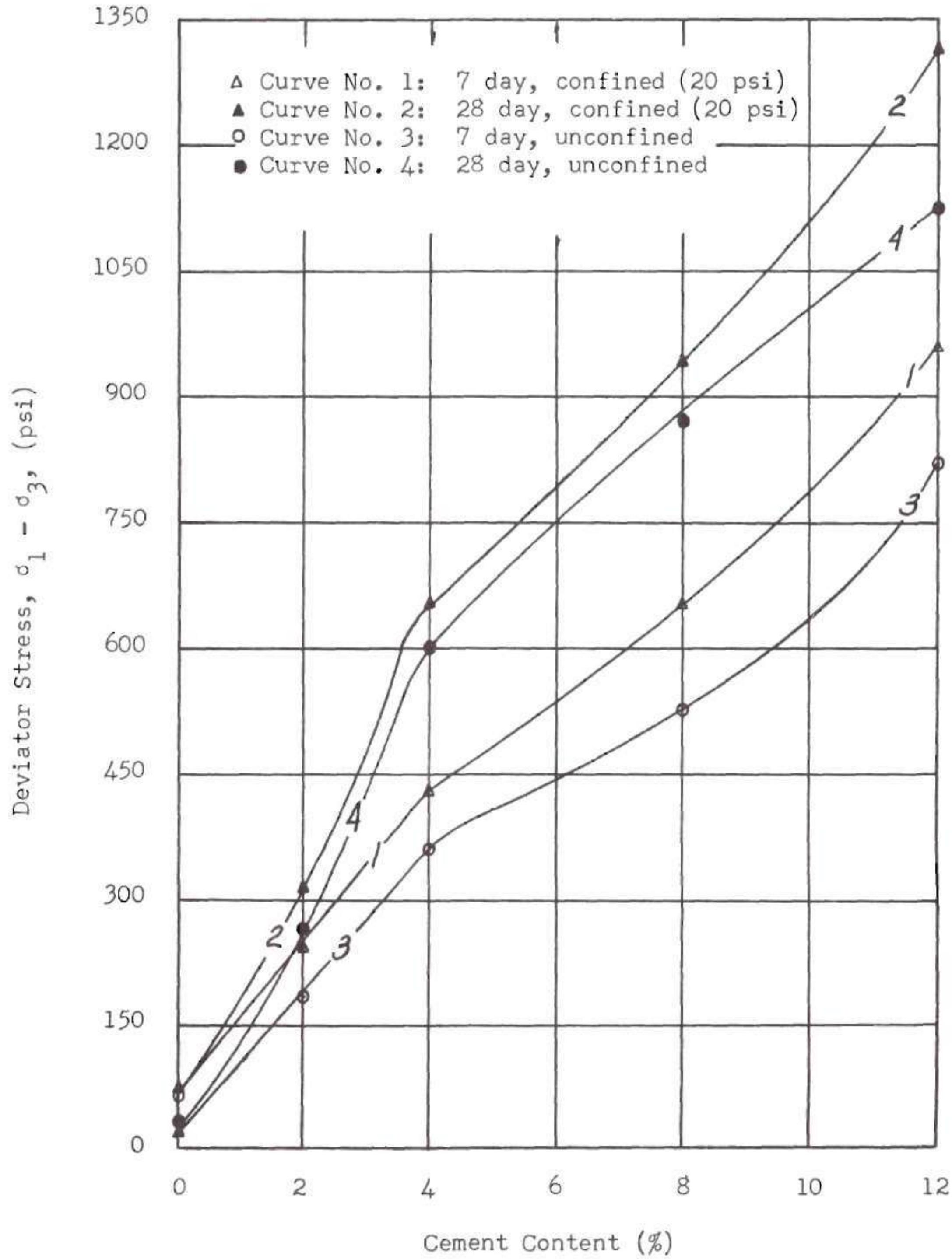

Figure 24. Deviator Stress Vs. Cement Content, Soil VII + 25% Screenings

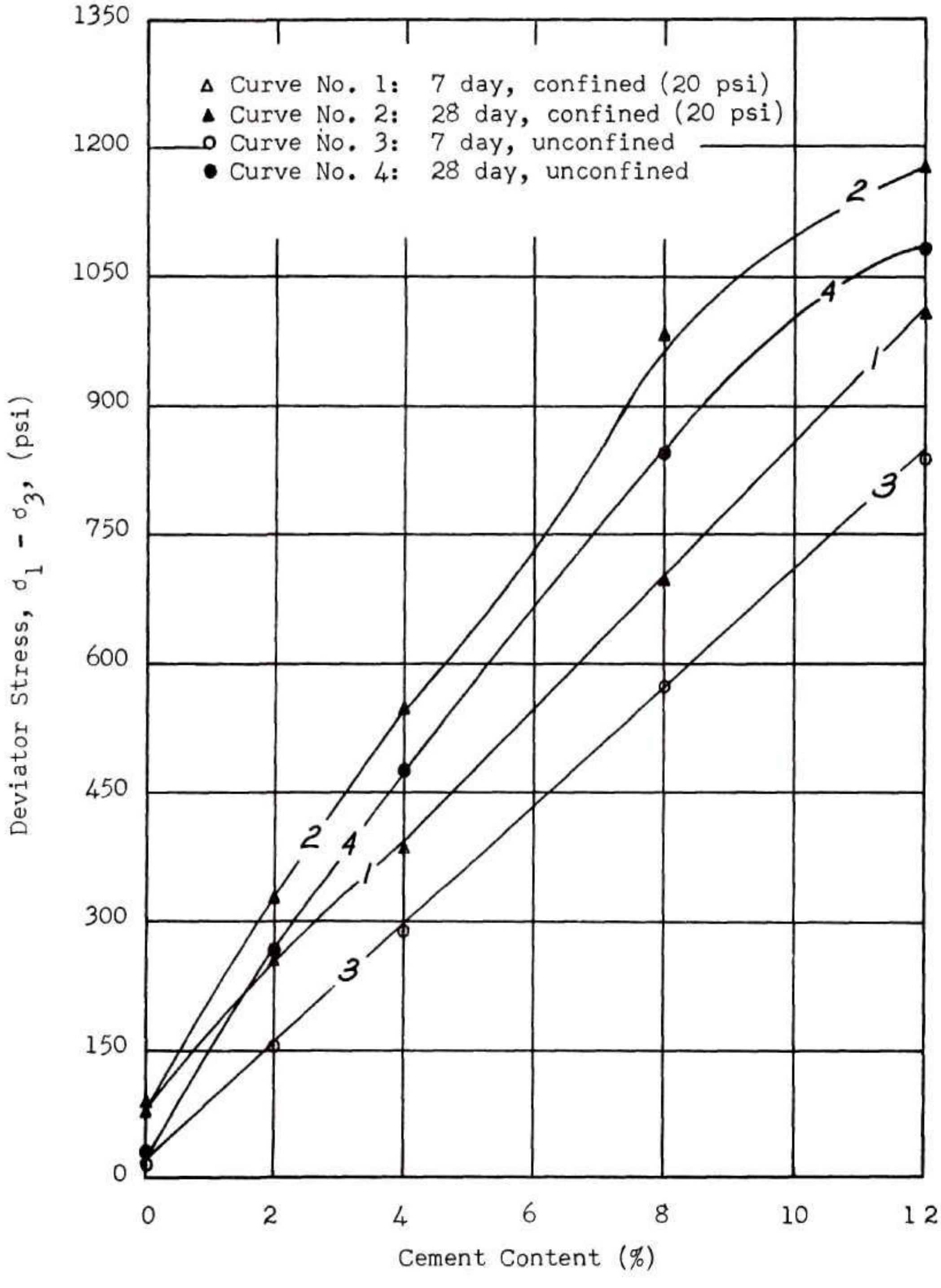

Figure 25. Deviator Stress Vs. Cement Content, Soil VII + 50% Screenings

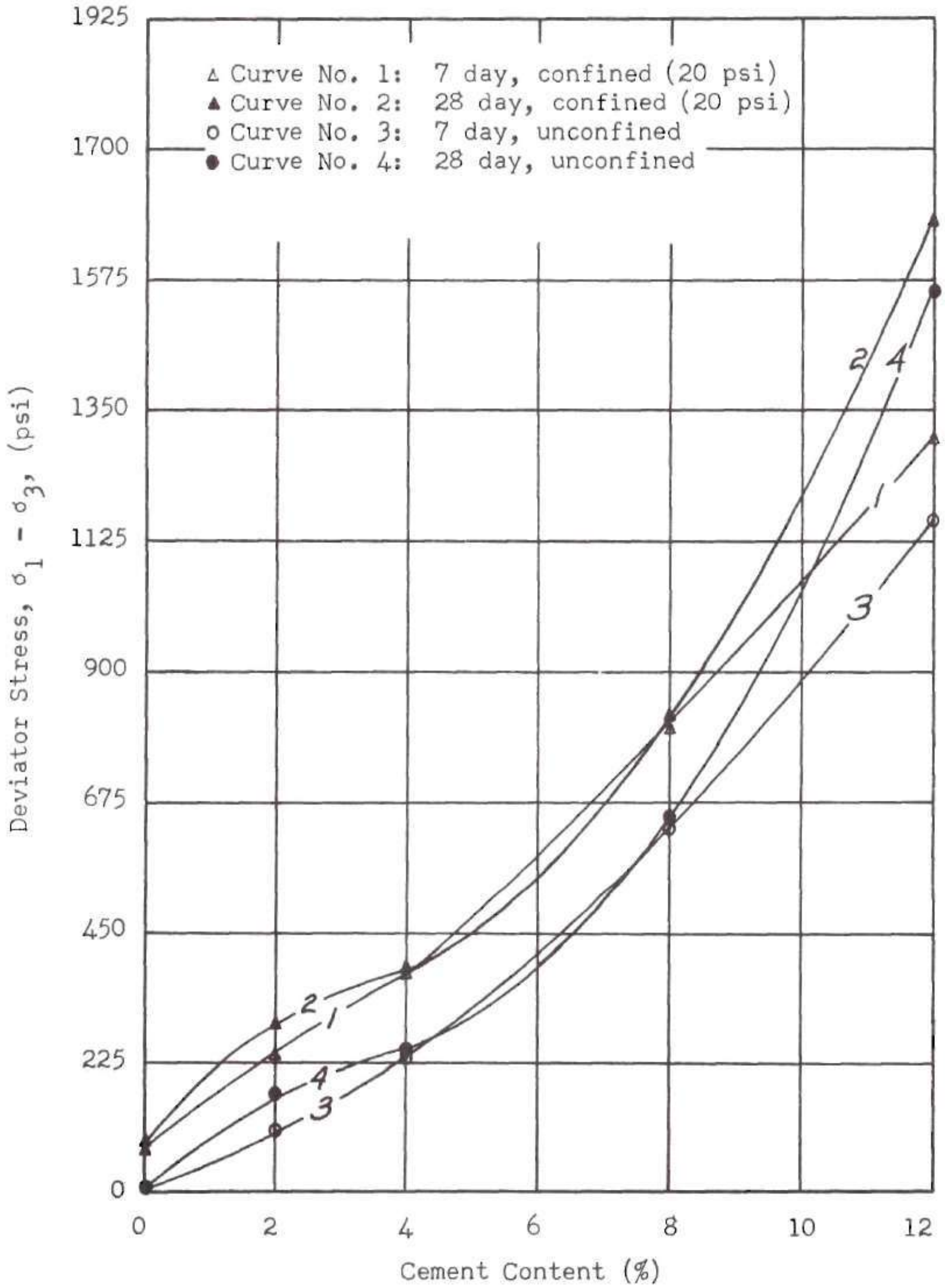

Figure 26. Deviator Stress Vs. Cement Content, Soil VII + 75% Screenings

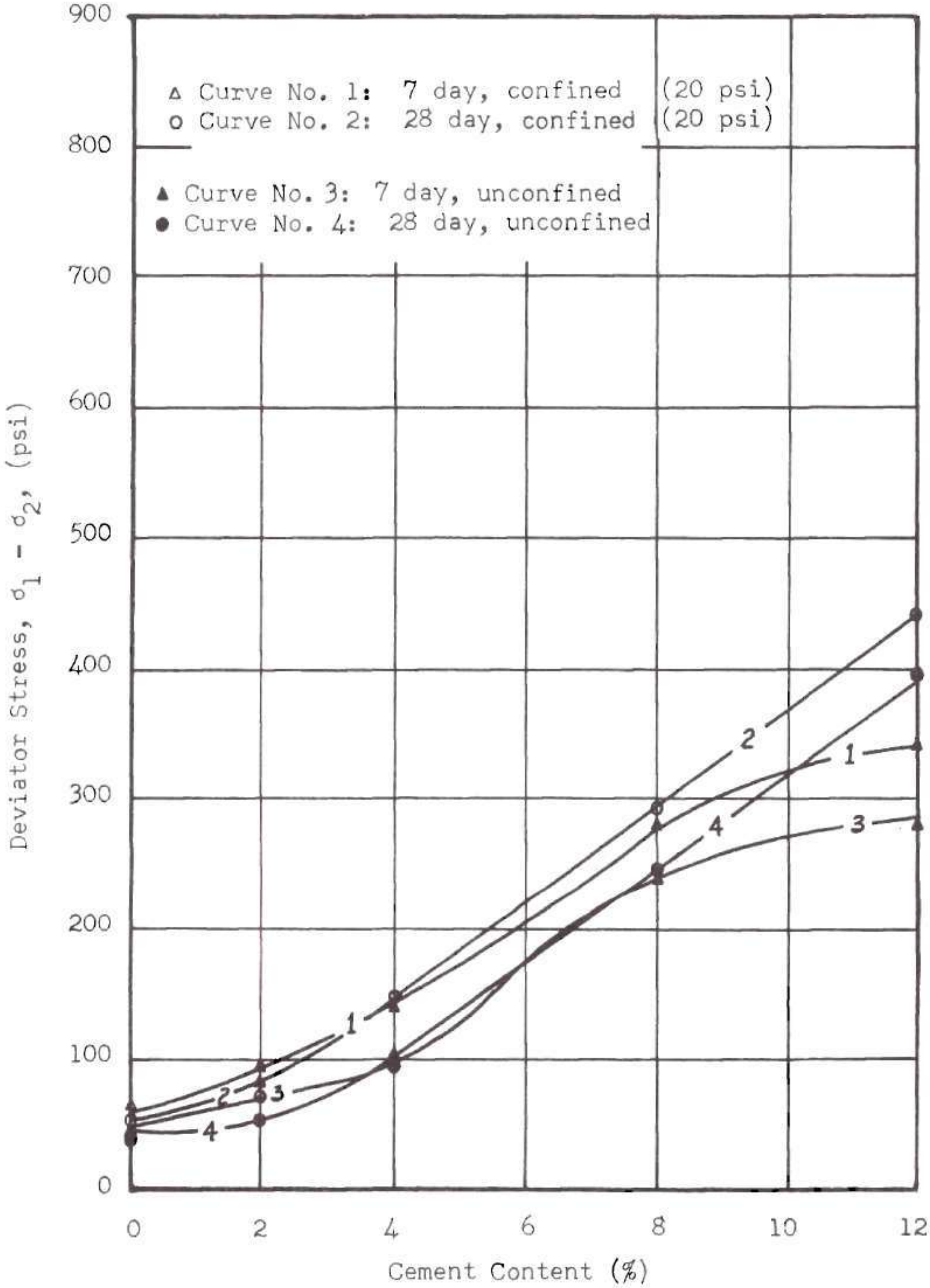

Figure 27. Deviator Stress Vs. Cement Content
Soil VIII (No Screenings)

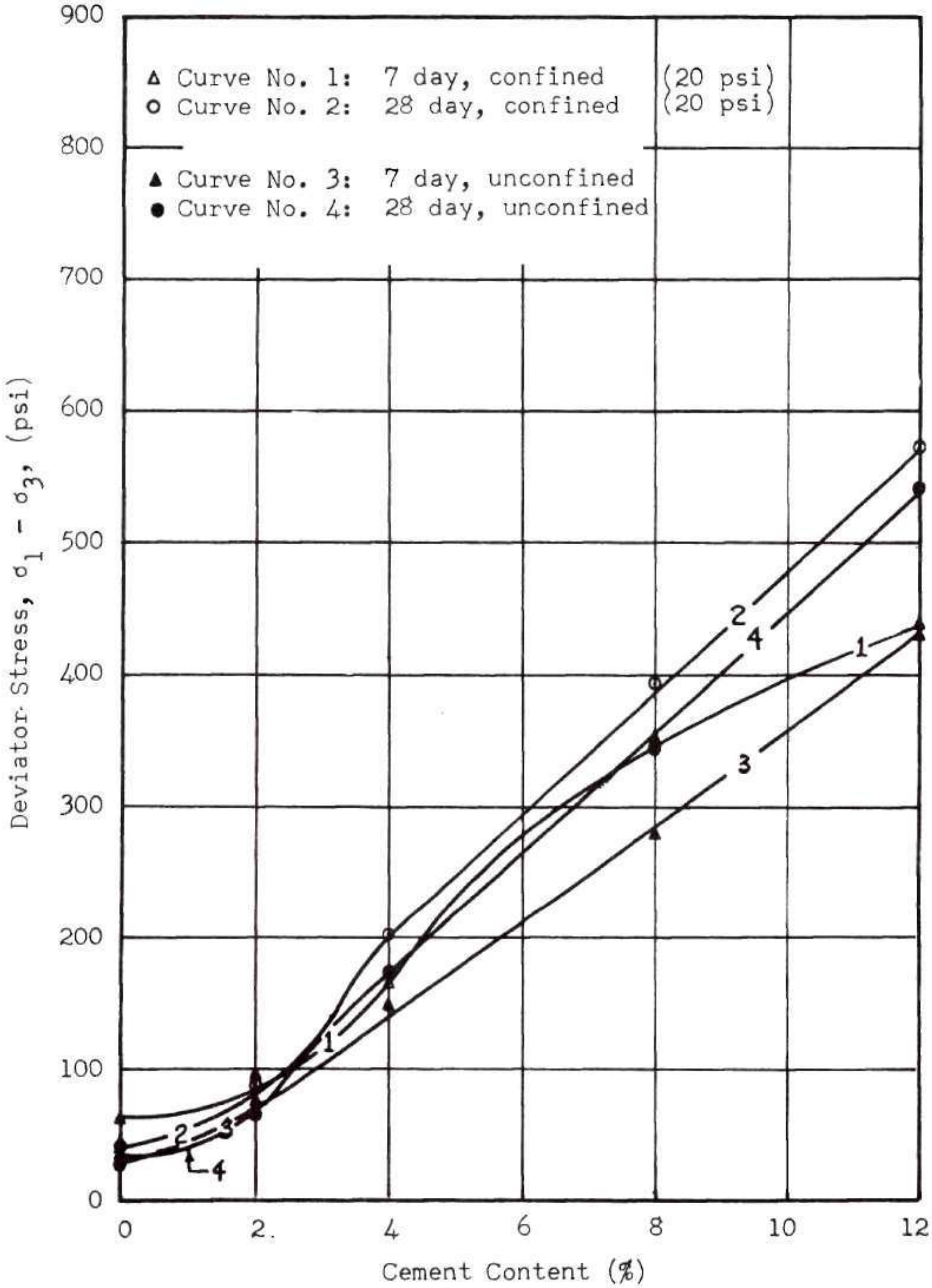

Figure 28. Deviator Stress Vs. Cement Content, Soil VIII + 25% Screenings

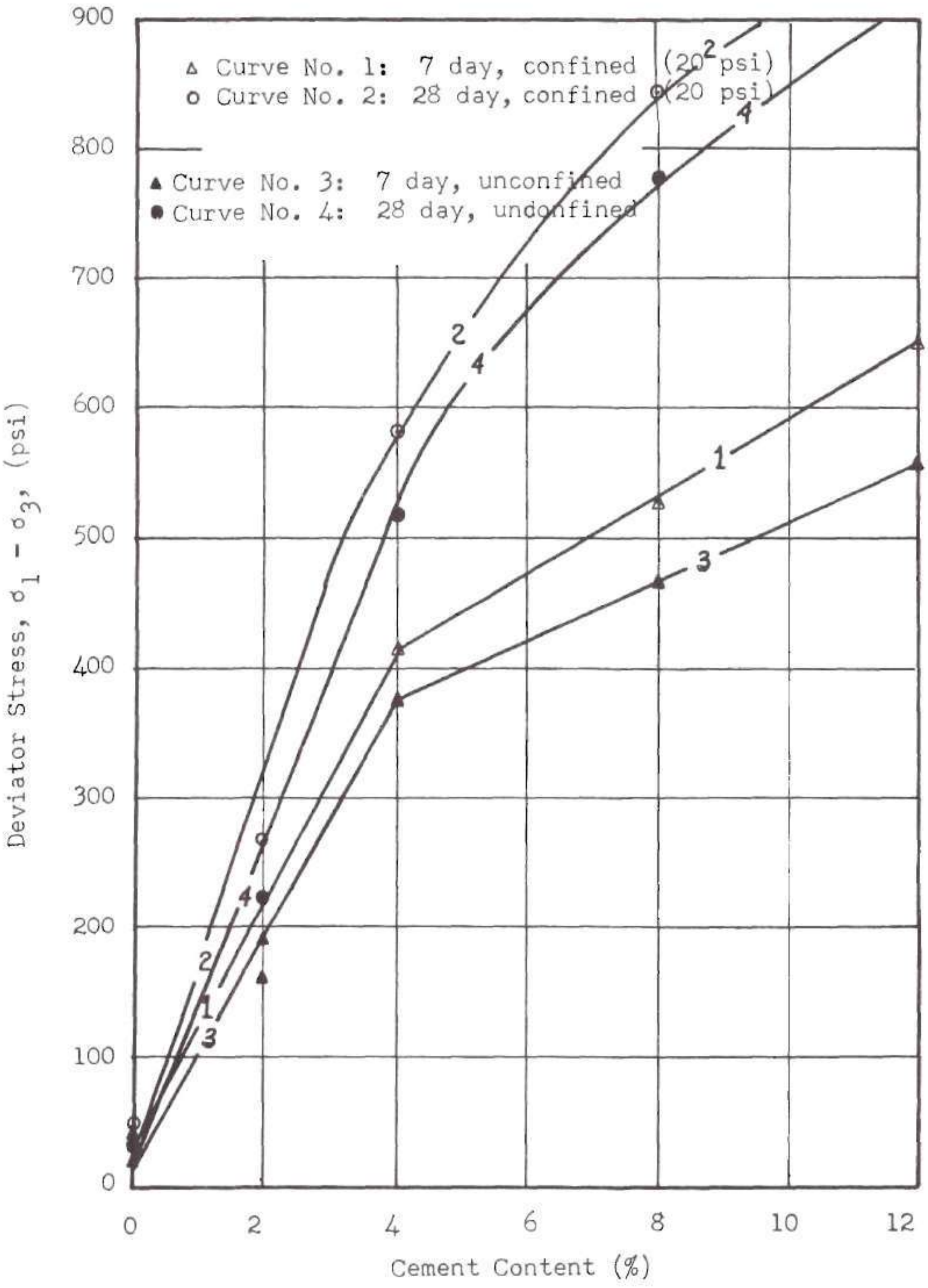

Figure 29. Deviator Stress Vs. Cement Content, Soil VIII + 50% Screenings

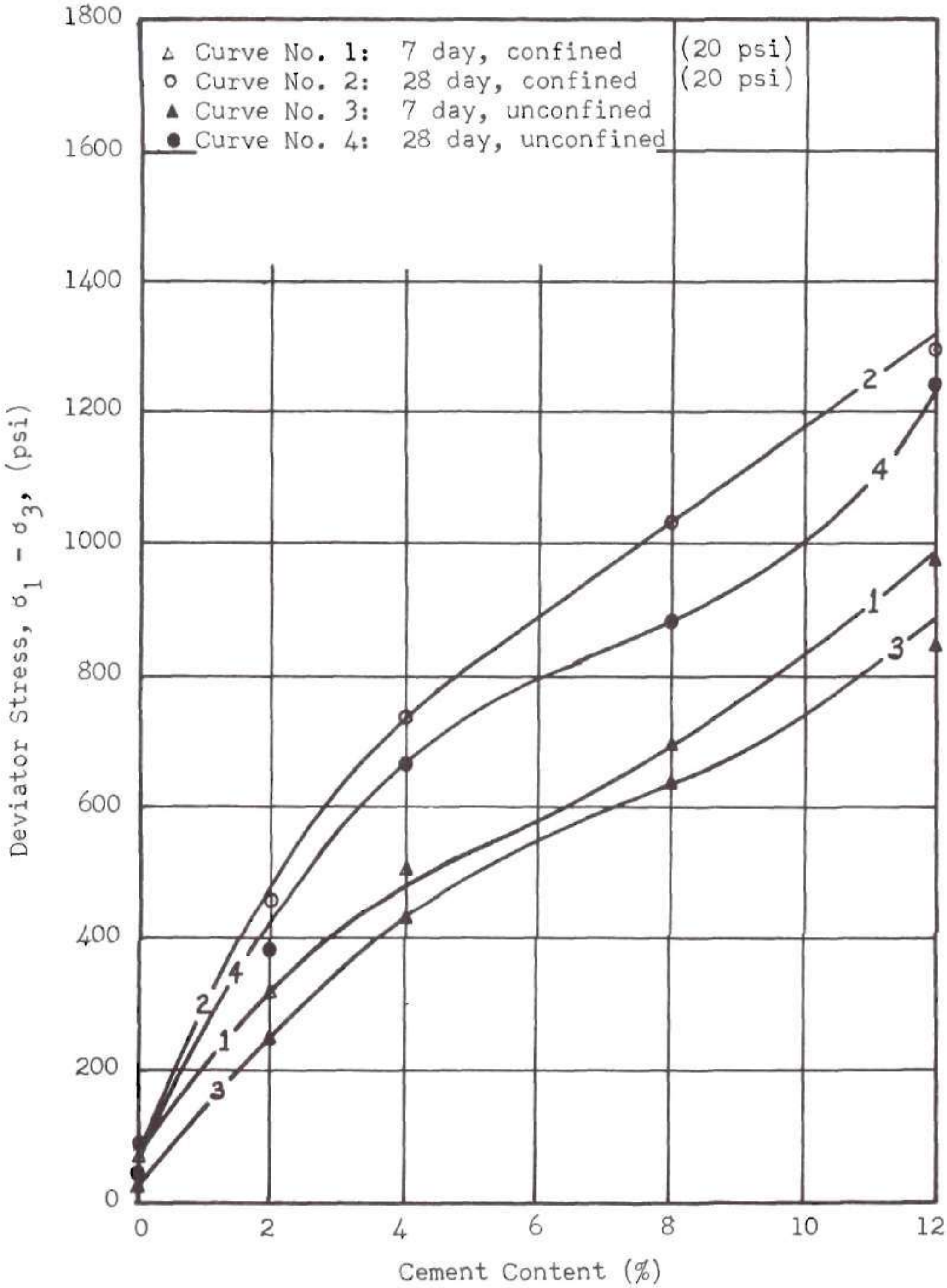

Figure 30. Deviator Stress Vs. Cement Content, Soil VIII + 75% Screenings

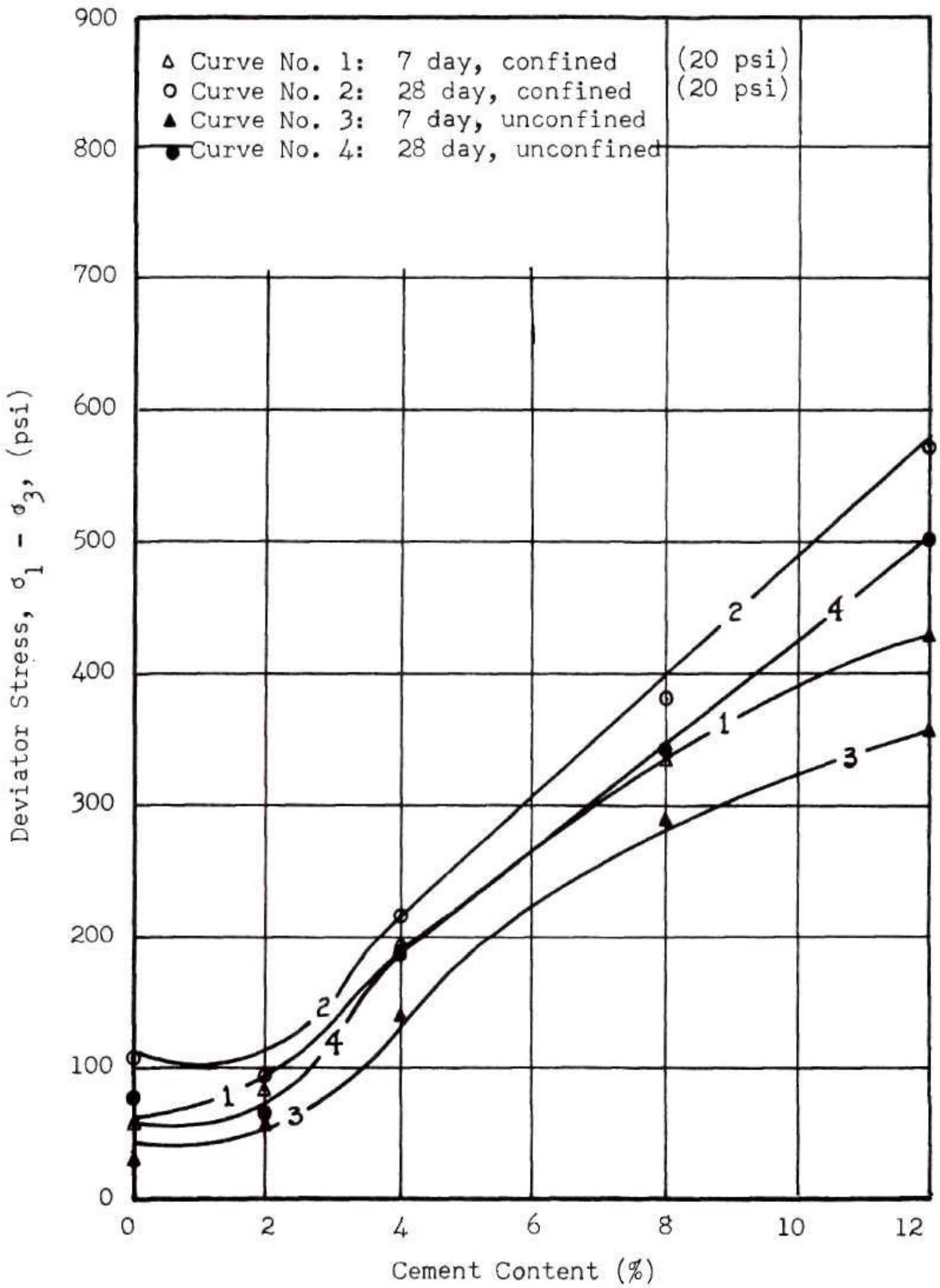

Figure 31. Deviator Stress Vs. Cement Content, Soil IX (No Screenings)

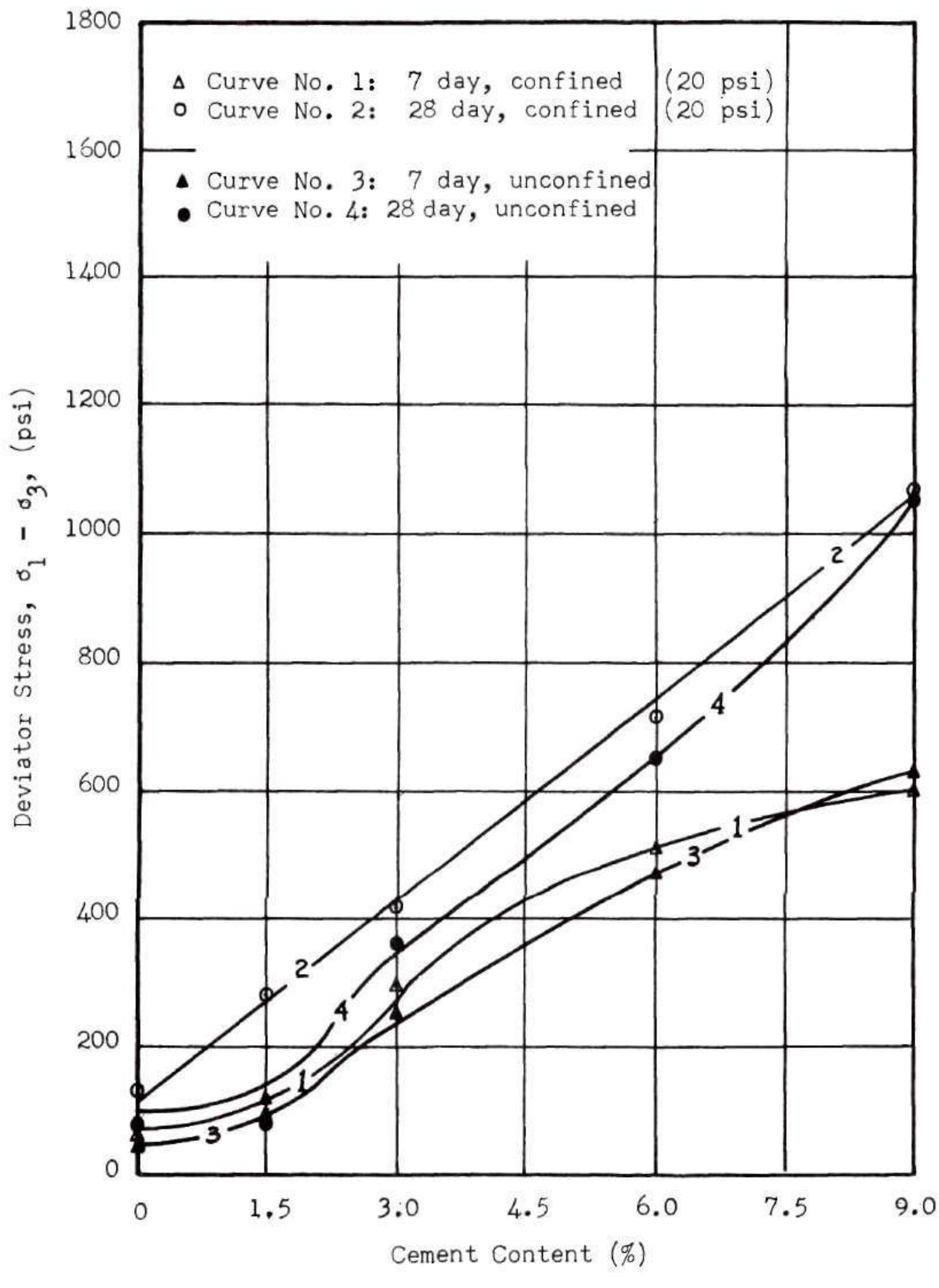

Figure 32. Deviator Stress Vs. Cement Content,
Soil IX + 25% Screenings

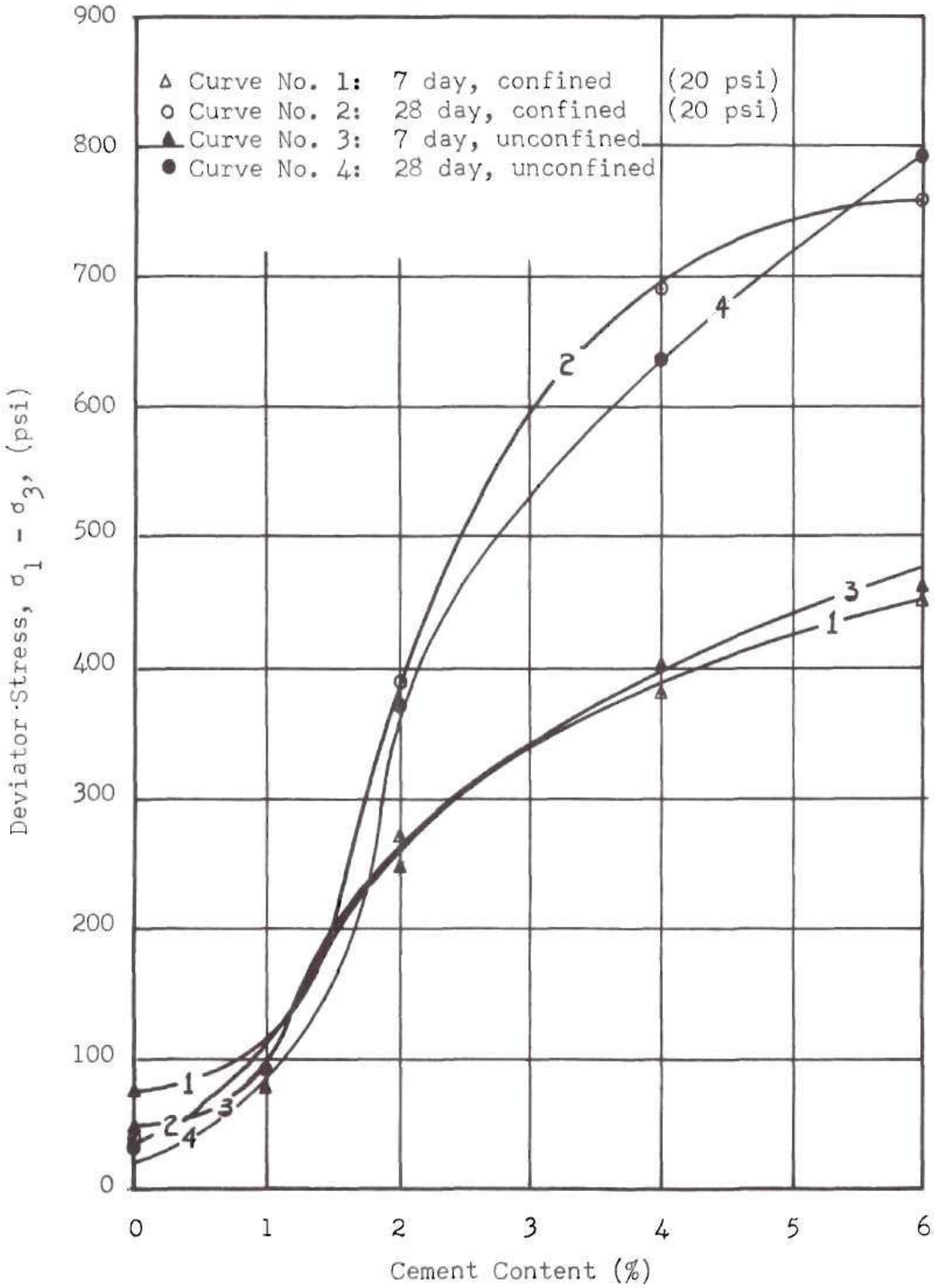

Figure 33. Deviator Stress Vs. Cement Content, Soil IX + 50% Screenings

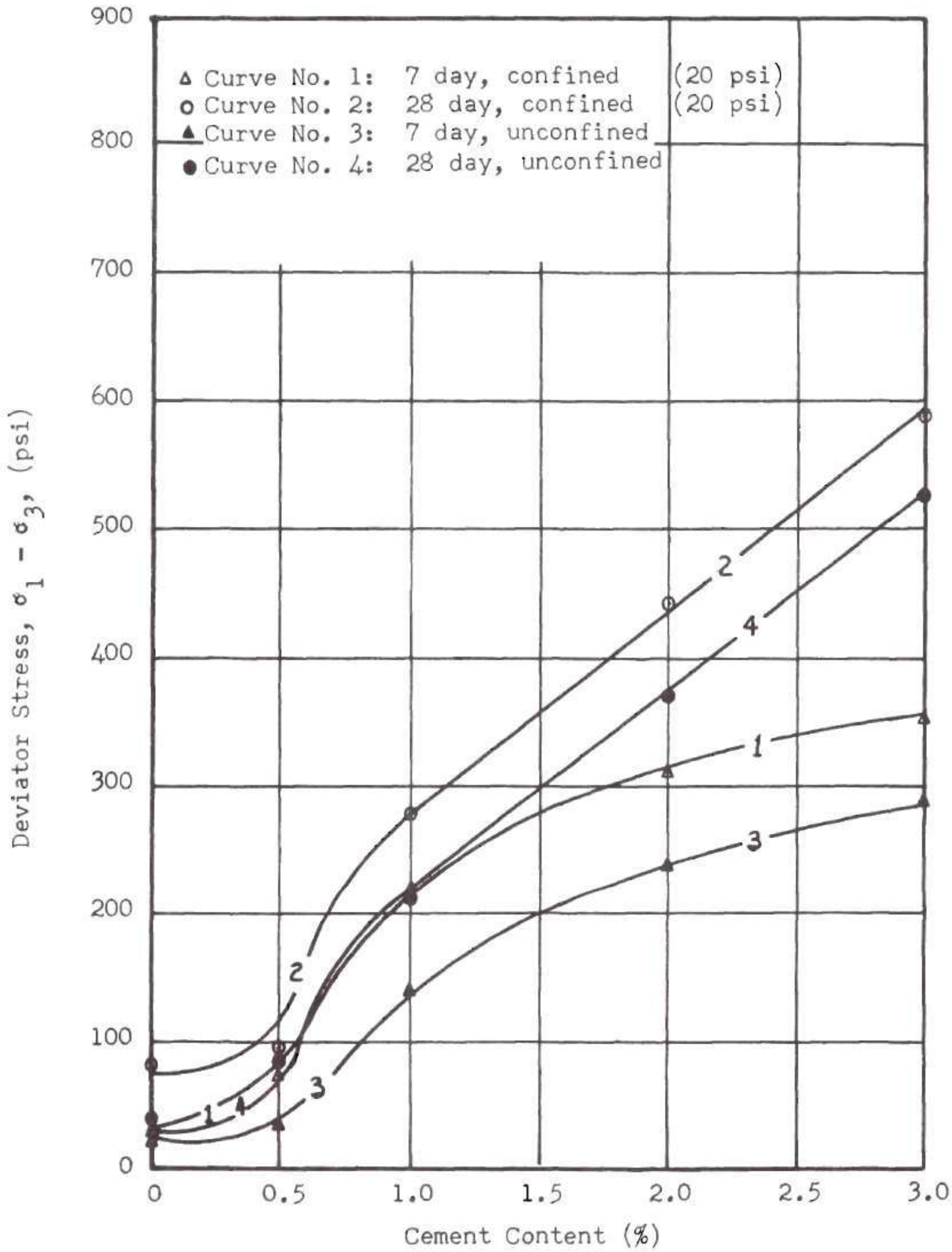

Figure 34. Deviator Stress Vs. Cement Content, Soil IX + 75% Screenings

Effect of Stone Screenings on Compressive Strength.--The influence of screenings content on the compressive strength of the different soils can be determined from Tables 4 through 8. For all soil-cement combinations, the strength increased with increasing screenings content. However, the addition of screenings to soils not containing cement generally did not improve the strength; in fact, decreases in strength often occurred. This is most likely due to the effect of the stone screenings on the two distinct components of compressive strength--the angle of internal friction and the cohesion. Table 9 is a summary of values of deviator stress, angle of internal friction and cohesion; the latter two values were determined from the Mohr diagrams. The natural compressive strength of these soils is composed of both cohesive strength and internal friction. On the other hand, the stone screenings depend entirely on internal friction for strength.

For Soil IV the addition of greater and greater amounts of screenings causes a steady reduction in cohesion, as expected. The effect on the angle of internal is more difficult to explain, however. It appears that the addition of 25% screenings is not enough to improve the natural grain interlock of the soil; this would explain the loss of internal friction and consequent reduction in deviator stress, when greater amounts of screenings are added the grain interlock of the screenings is predominant and the soil acts more as a binder.

The same type of reasoning can be used to explain the effects of stone screenings on the compressive strengths of the other soils.

When cement and screenings are added to the natural soil the effect of screenings on compressive strength becomes much more complicated. In order to properly evaluate this, the relative cohesions of the natural soil

Table 9. Effect of Stone Screenings on Strengths of Soils not containing Portland Cement.

	Stone Screenings Content (%)	Deviator Stress $\delta_1 - \delta_3$ (psi)	Cohesion (psi)	Angle of Internal Friction (Degrees)
Soil IV 7-Day Cure	0	58	11	23
	25	30	8	12
	50	50	5	28
	75	73	2	38
Soil V-A 7-Day Cure	0	60	7	28
	25	33	6	17
	50	55	6	28
	75	61	3	35
Soil VII 7-Day Cure	0	64	10	26
	25	70	6	34
	50	81	4	39
	75	73	2	39
Soil VIII 7-Day Cure	0	56	19	12
	25	61	15	16
	50	39	8	18
	75	78	8	33
Soil IX 7-Day Cure	0	56	11	22
	25	58	16	17
	50	79	13	28
	75	31	12	4

binder and the cement must be well established. This was beyond the scope of this research work.

It should be emphasized again that the above statements apply only to the conditions of curing and lateral pressure under which the testing was conducted.

Effect of Stone Screenings in Reducing Cement Content.--In order to determine the actual value of stone screenings as a substitute for Portland cement in a stabilized base or subgrade course, it is necessary to establish a design compressive strength. Since a minimum confined (20 psi) compressive strength of 300 pounds per square inch after seven days of curing is specified by the Georgia Highway Department for soil-cement base courses, this value was adopted for comparison purposes in this study.

The estimated percentages of cement necessary to produce a deviator stress of 300 psi are shown in Table 10. These values were obtained from Figures 15 through 34. The relative effects of adding screenings to different soils having various percentages of cement are evident in this table. Soil IV benefited from the addition of up to 50% screenings for all four conditions of curing and confining pressure employed. For a 7-day, confined strength of 300 psi, the cement content was reduced from 6.4% to 3.1% by the addition of 25% screenings.

For Soil V-A, the cement contents necessary to provide the design strength were lowered appreciably by the addition of 25% and 50% screenings. For a 7-day, confined strength of 300 psi the cement content was lowered from 6.4% to 3.7% by adding 50% screenings.

The addition of screenings to Soil VII did not cause reductions in cement content under all conditions of curing and lateral pressure; in

Table 10. Estimated* Percentages of Cement Needed For a Compressive Strength of 300 lb./sq.in.

Soil No.	Screenings Content (%)	Cement Content (%) Confined (20 psi) 7-day**	28-day	Unconfined 7-day	28-day
IV	0	6.4	3.5	7.0	4.4
	25	3.1	2.4	3.5	2.9
	50	2.2	1.6	3.1	2.4
	75	2.2	1.2	4.1	2.9
V-A	0	6.4	5.3	7.6	5.5
	25	4.5	4.1	5.8	4.2
	50	3.7	3.0	4.1	3.5
	75	3.0	1.7	6.5	2.4
VII	0	3.1	2.9	3.3	2.7
	25	2.5	1.9	3.2	2.3
	50	2.6	1.7	4.0	2.3
	75	2.7	2.0	4.7	4.9
VIII	0	8.9	8.1	12+	9.5
	25	6.5	6.1	8.4	6.8
	50	2.9	1.8	3.2	2.3
	75	1.7	0.9	2.4	1.2
IX	0	6.9	5.8	8.8	6.8
	25	4.2	2.3	5.0	3.5
	50	4.9	3.5	4.9	3.7
	75	6.9	4.5	12+	6.0

*Estimated from curves of Figures 15-34.

**Used for design by Georgia Highway Department.

those instances in which reductions did take place the cement content was not lowered by more than 30%. For the higher percentages of screenings content used the cement content was unaltered or even increased.

The most drastic reductions in cement contents occurred in Soil VIII where the cement percentage steadily diminished with increasing screenings content. Considering the 7-day confined values, the cement content declined from 8.9% for the soil-cement mix (without screenings) to only 2.9% with the addition of 50% screenings; for 75% screenings, only 1.7% cement was needed to provide the design strength. It should also be noted that for the 28-day, unconfined strength of 300 psi the required cement content was reduced from 9.5% to only 1.2%. The reason for the steady decrease in cement content with increasing screenings content evidently is connected with the great amount of minus No. 200 sieve material in this soil (see Table 1). Apparently, this soil has more natural cohesion than the other soils; however, it is deficient in grain interlock. Therefore, the mechanical stabilization process of adding screenings provides the necessary grain interlock without causing a detrimental loss in the cohesion component of the compressive strength.

The values given in Table 5 for Soil IX produce a pattern somewhat like that of Soil VII; i.e., the only instances in which the cement contents were lowered appreciably were when the screenings content was 25%. However, it can be seen by comparing the data for these two soils that the reduction for Soil IX were considerably greater than those occurring in Soil VII. In fact, except for Soil IV, the addition of 25% screenings was more beneficial to Soil IX in reducing cement content than it was to any other soil.

Establishment of Typical Design Curves.--Although Table 10 gives the percentages of cement needed to produce deviator stresses of 300 psi for screenings contents of 0, 25, 50, and 75% it does not reveal the most economical cement percentages at intermediate percentages of screenings. From the standpoint of economy, these values could be extremely important. The intermediate values can be determined by plotting the per cent stone screenings to per cent cement ratios against the corresponding deviator stress values obtained from the strength tests and then connecting these points. This was done in establishing the typical design curves shown in Figures 35 through 39. The points were plotted from Tables 5 through 8. For example, the deviator stress (7 days, confined) for Soil IV combined with 25% screenings and 4% cement is 429 psi; this value was plotted above the abscissa value of 25/4, or 6.25. Likewise, the deviator stress of 418 psi for 75% screenings and 4% cement was plotted above the abscissa value of 75/4, or 18.8.

It can be seen from Figures 35 through 39 that an infinite number of ratios of screenings content to cement content exist which theoretically give a compressive strength of 300 psi for any given curing period and confining pressure. However, with a little experience, one can quickly determine the best combinations for design - assuming, of course, that the costs of cement, screenings and mixing are known. The most economical combination of Soil V-A, screenings, and cement having a deviator stress of 300 psi may be found by first drawing a horizontal line at 300 psi. Then by picking several values of "R" along this line, the best combination can be determined. For instance, at an "R" value of 10, the screenings content (s) is approximately 35%; therefore, the cement content (c) is 3.5%.

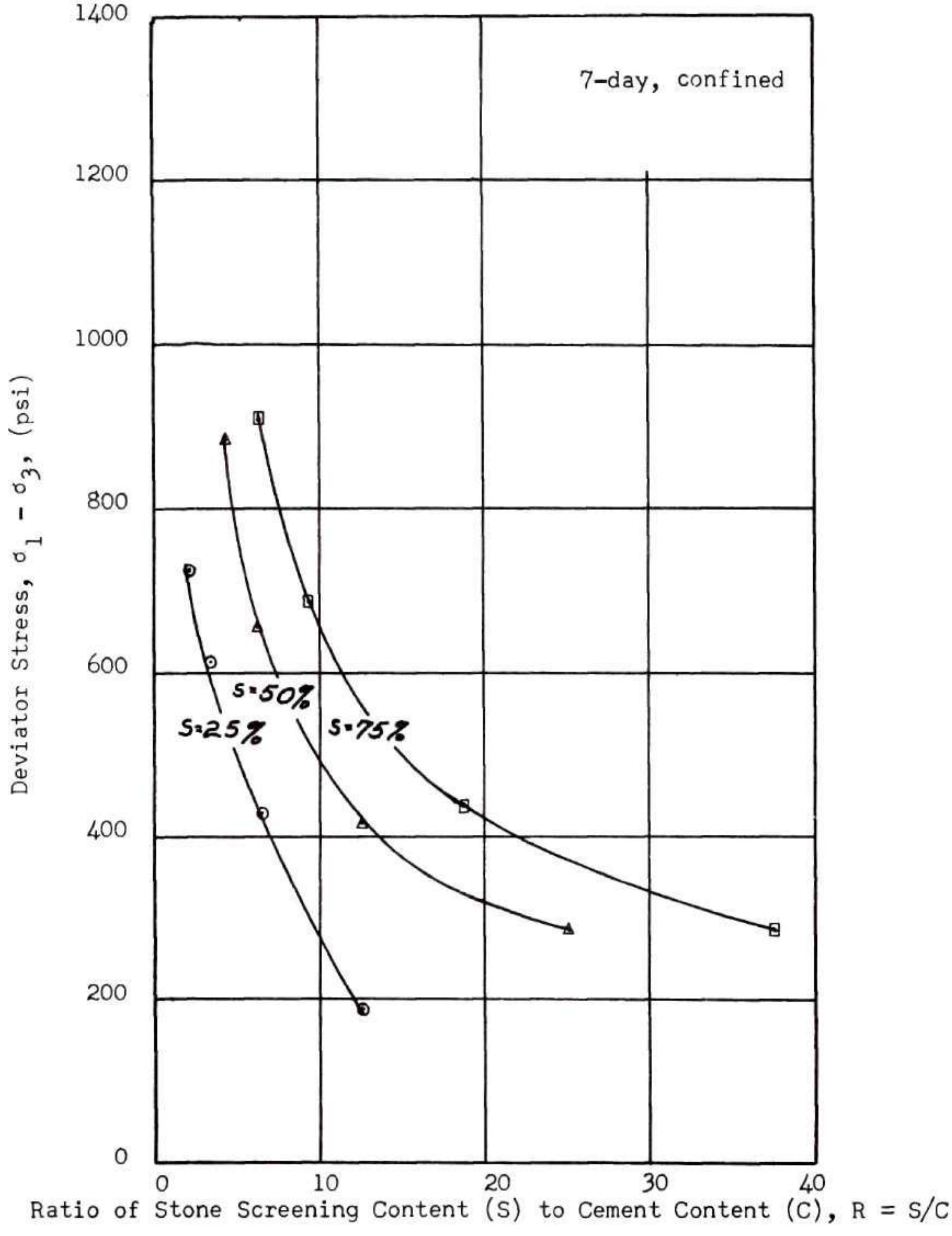

Figure 35. Design Curve, Soil IV Combined with Stone Screenings and Portland Cement

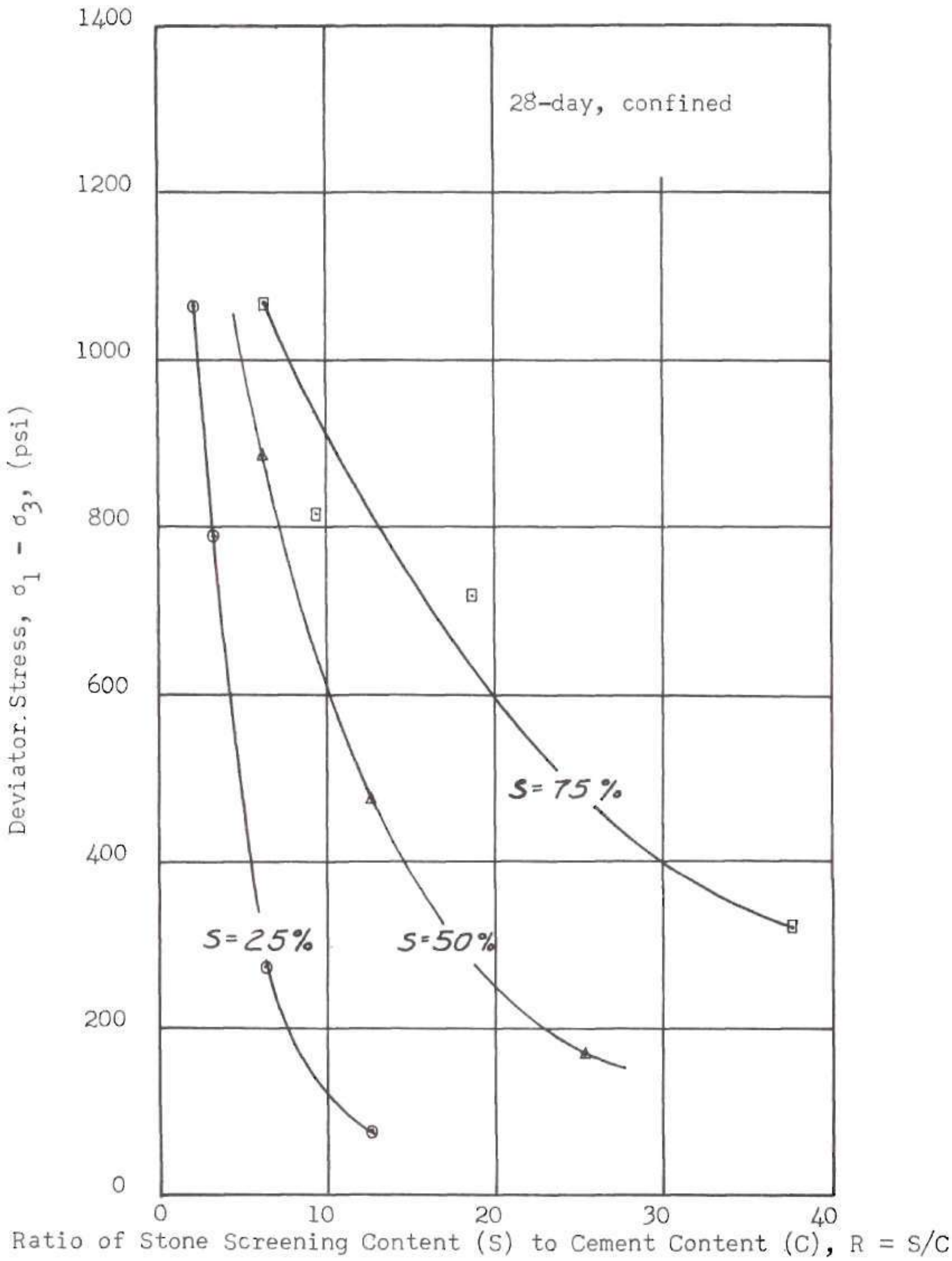

Figure 36. Design Curve, Soil V-A Combined with Stone Screenings and Portland Cement.

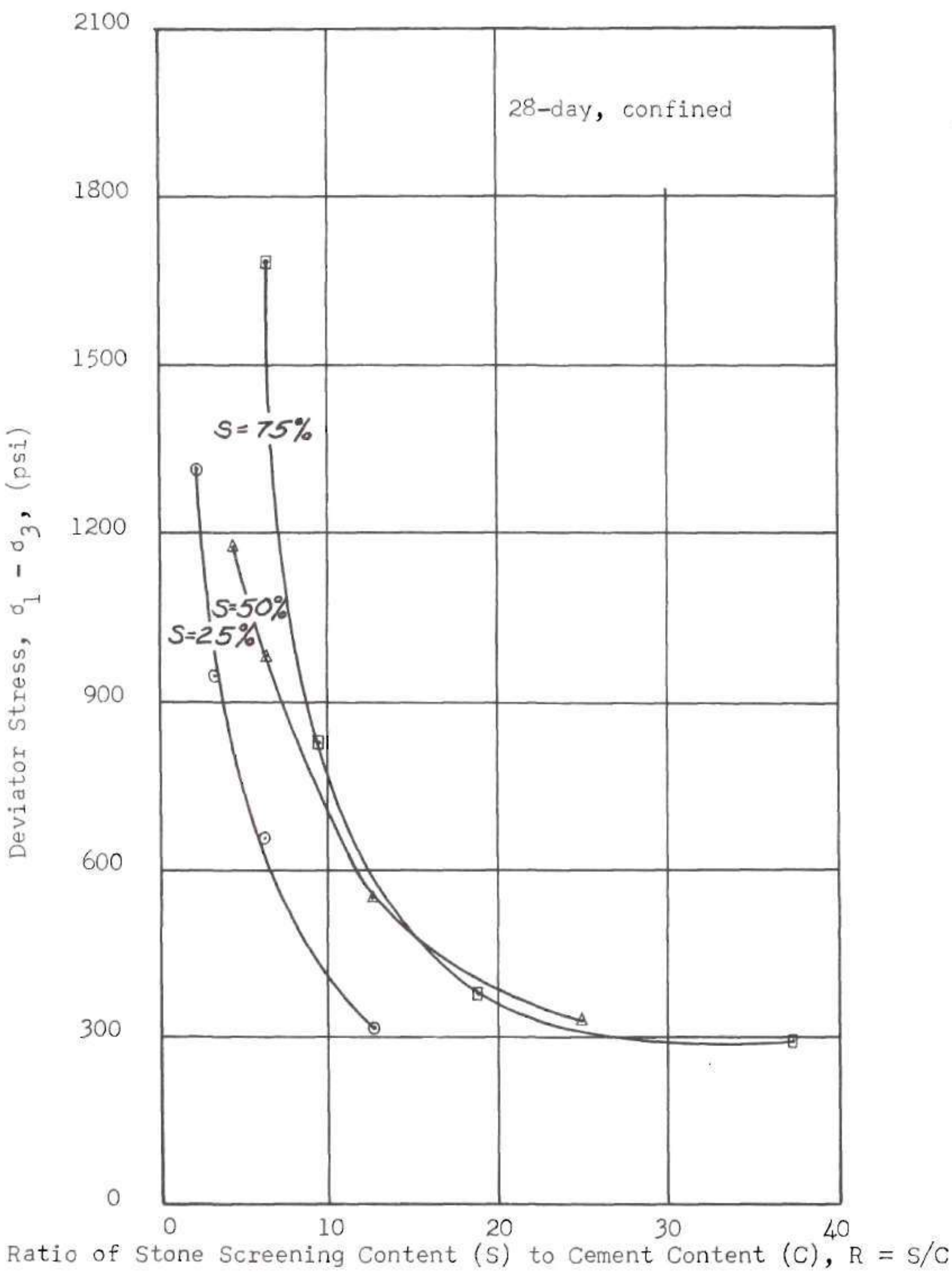

Figure 37. Design Curve, Soil VII Combined with Stone Screenings and Portland Cement

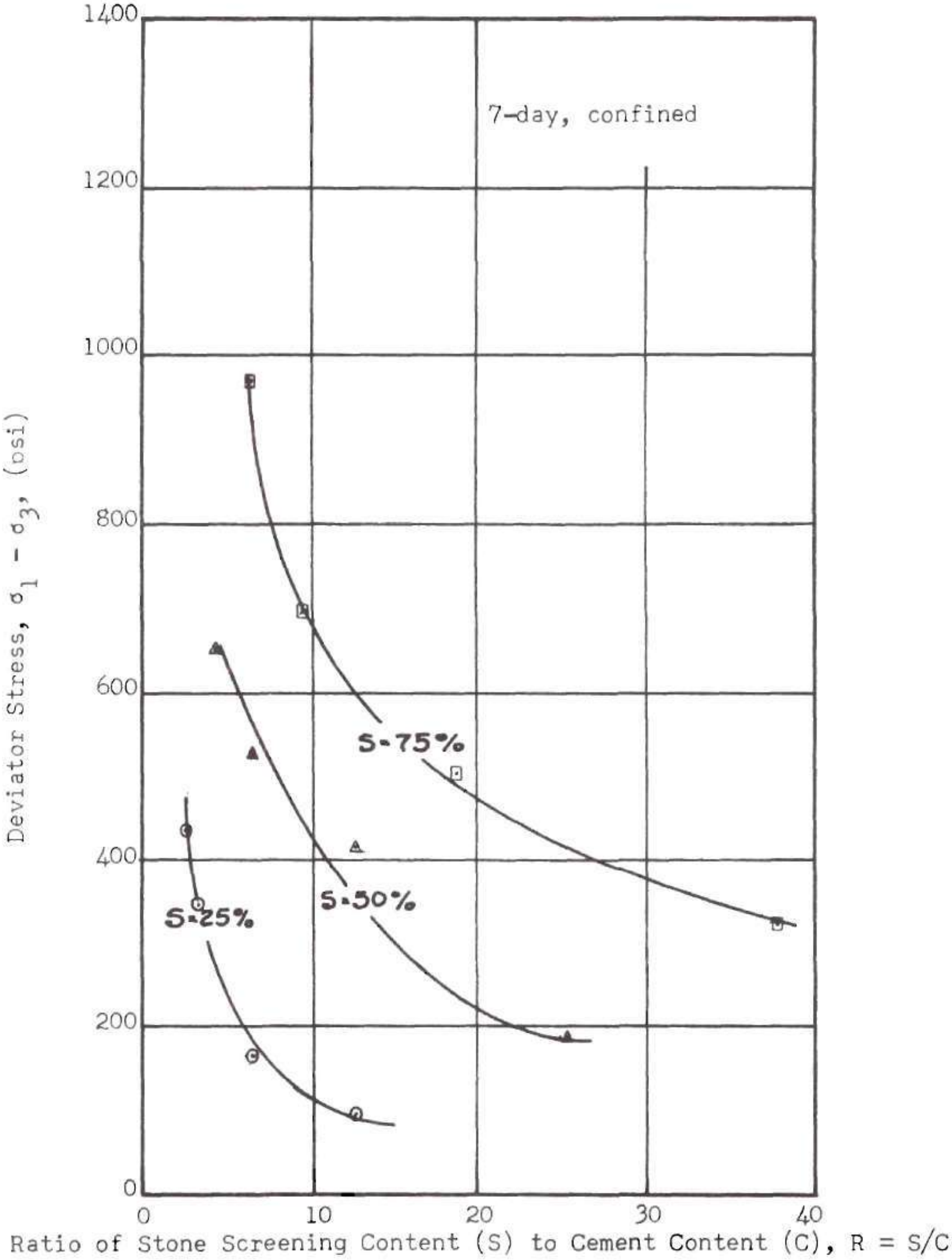

Figure 38. Design Curve, Soil VIII Combined with Stone Screenings and Portland Cement

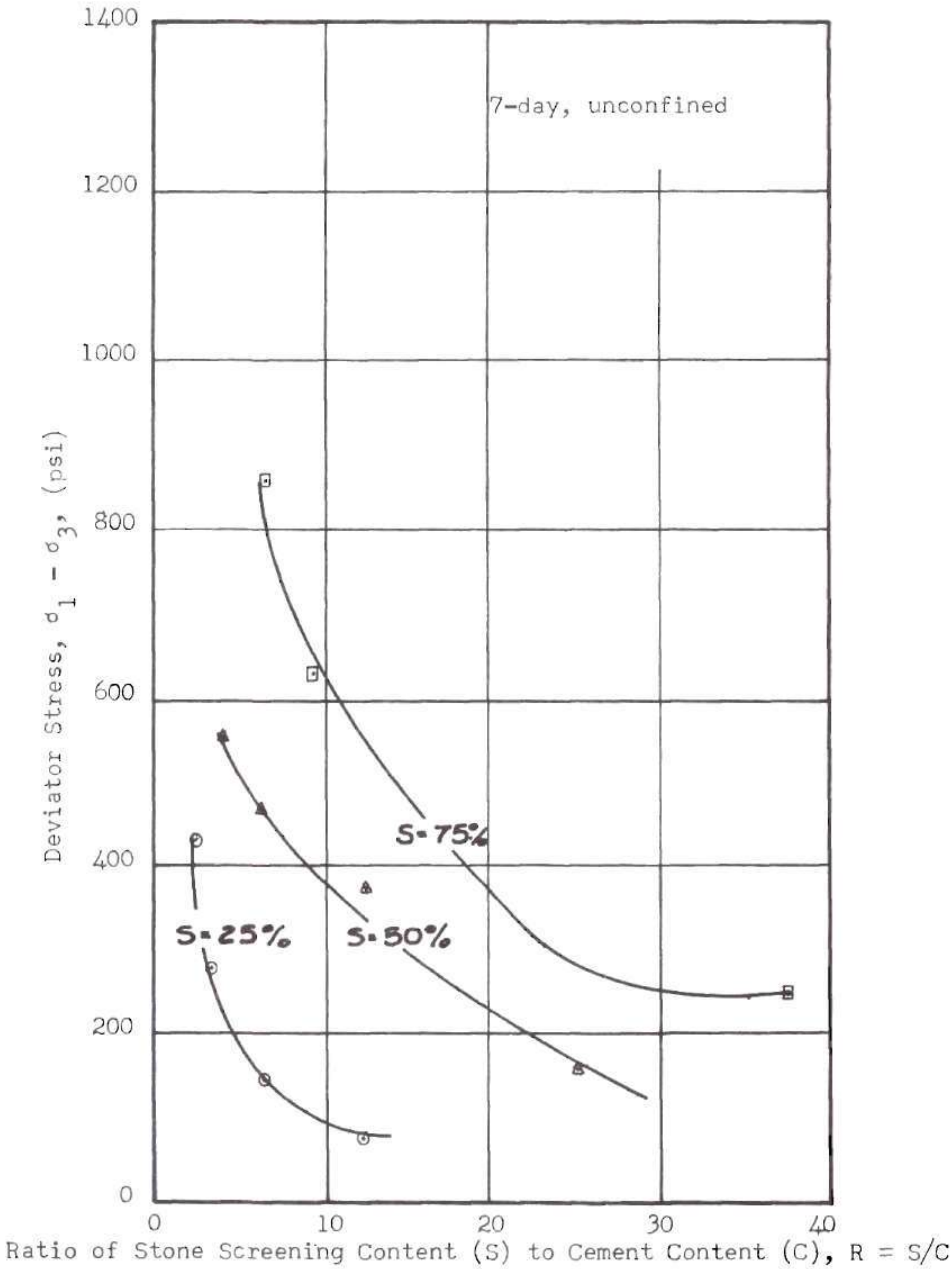

Figure 39. Design Curve, Soil VIII Combined with Stone Screenings and Portland Cement.

CHAPTER V

SUMMARY OF RESULTS, CONCLUSIONS AND RECOMMENDATIONS

Summary of Results.--The results of this study indicate that, for the soils tested and the conditions under which the testing was done:

1) almost all of the gain in dry density caused by the addition of Portland cement and stone screenings to a soil was due to the stone screenings,

2) the compressive strength of a soil containing cement and stone screenings did not increase with increased density,

3) for any fixed amount of screenings, increasing the cement content produced an increase in the compressive strength, and

4) the compressive strength of Soil VIII, (considered to be the poorest of the soils tested, according to the AASHO Soil Classification System) was improved considerably more than any other soil by the addition of stone screenings.

Conclusions.--Several significant conclusions can be drawn from the discussion of the results given in Chapter IV. These are as follows:

1) In all soils tested, the addition of stone screenings was found to reduce the amount of cement required to develop the design compressive strength. However, adding only stone screenings to the soil did not cause the compressive strength to be increased.

2) All soils combined with stone screenings, except Soil V-A, showed a greater strength increase in the 0-4% cement content range than in any other four per cent range.

3) It is very possible that stone screenings could be used economically as a partial substitute for Portland cement in stabilizing highway bases and subgrades; the feasibility of substituting screenings for cement would have to be determined for each individual case in point.

Recommendations.--On the basis of the work described in this report, it is recommended that:

1) a study be made of the effects of wetting-drying cycles on the strength of compacted mixtures of soil-cement and of soil, screenings, and cement (design curves similar to those described in this report could then be established),

2) the effects of shrinkage cracking in soil-cement and soil-screenings-cement base courses be studied so that the feasibility of using stone screenings can become more evident, and

3) a cost study be made by utilizing the design curves given in this report and presenting several examples of typical projects throughout the state of Georgia.

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