THE UNIVERSITY OF ARKANSAS

CIVIL ENGINEERING DEPARTMENT

1871

Development of Design Criteria for Fill Slopes in Eastern Arkansas

NOT FOR PUBLICATION

Highway Research Project
No. 28

Development of
Design Criteria for
Fill Slopes in
Eastern Arkansas

Interim Technical Report No. 1

THE ARKANSAS STATE HIGHWAY DEPARTMENT

PLANNING AND
RESEARCH DIVISION

In Cooperation With

THE U.S. DEPARTMENT
OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION,
BUREAU OF PUBLIC ROADS

REVIEW COPY

February, 1972

DEVELOPMENT OF DESIGN CRITERIA FOR FILL SLOPES IN EASTERN ARKANSAS

BY

E. WALTER LEFEVRE

Principal Investigator

and

FREDERIC C. TUCKER

Graduate Research Assistant

Civil Engineering Department
University of Arkansas
Fayetteville, Arkansas

INTERIM TECHNICAL REPORT NO. 1

of

HIGHWAY RESEARCH PROJECT NO. 28
"Development of Design Criteria for
Fill Slopes in Eastern Arkansas"

for

THE ARKANSAS STATE HIGHWAY DEPARTMENT
PLANNING AND RESEARCH DIVISION

in cooperation with
The U. S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

February, 1972

ABSTRACT

This thesis contains a summary of the physiography and geology of Eastern Arkansas. Soil areas of particular interest for the research are described. Climatic conditions in Eastern Arkansas are discussed. Preliminary and detailed investigations of four embankment slope failures are presented. The detailed investigation contains an account of the boring and sampling program and laboratory testing program. Tabulations of test results are presented. From the accumulated data the four embankments are generalized into typical sections which are to be used in stability analyses. Two slope stability computer programs are described. The operation and use of the programs are illustrated through use of an example problem. Further considerations for stability analyses of embankment slopes in Northeast Arkansas are discussed.

KEY WORDS: slope stability, computer analysis, embankments, shear strength, triaxial test, clay, silty clay, method of slices, circular failure arcs, Normal Method, Simplified Bishop equation.

TABLE OF CONTENTS

TABLE OF CONTENTS CONTINUED

LIST OF FIGURES

LIST OF FIGURES CONTINUED

LIST OF TABLES

LIST OF PLATES

CHAPTER I

INTRODUCTION

Many highway fill slopes constructed in Eastern Arkansas are susceptible to pocket slope failures. Generally, the failures are relatively small in extent and rarely obstruct traffic. However, they are expensive to repair and create an additional workload on the maintenance force, and the highway user is inconvenienced during the repair. In addition, many of the failures occur on the Interstate System where appearance of right of way is important.

Concern by the Arkansas Highway Department prompted the authorization of Highway Research Project 28 (HRP 28) on September 16, 1970, in cooperation with the Department of Transportation, Federal Highway Administration. The project is a joint effort of the Arkansas Highway Department and the University of Arkansas.

The primary objective of this research is the development of guidelines for design, construction, and maintenance that will, when incorporated, reduce the probability of slope failures on newly constructed embankments in Eastern Arkansas. Furthermore, it is hoped that the results of this research will aid maintenance foremen in repairing failed embankment slopes or in initiating remedial measures on slopes of incipient failure.

Contained in this paper is a detailed review of the progress of the research. It includes a brief description of the geologic and environmental conditions; a description and investigation of four selected embankment failures and laboratory test results of bag samples and undisturbed samples taken at the failure sites; a description of two slope stability computer programs that will be used for the stability analyses and explanation of their use.

Results of the stability analyses and recommendations of design criteria, construction procedures and maintenance practices will be presented when the research is completed.

Most slope failures in Eastern Arkansas occur on the embankment slopes of levees and highway or railway fills. Few instances of cut slope failures occur for the reason that the terrain of Eastern Arkansas is relatively flat and therefore, by comparison, few deep cuts exist except in the area of Crowleys Ridge.

An inspection trip was made in early spring, 1971, for the purpose of selecting failure sites for detailed investigation. With the help and cooperation of Arkansas Highway Department engineers and personnel a successful tour of the problem areas in Crittenden and Mississippi Counties was completed. Many of the failures inspected occur on fill slopes that have no previous history of instability. Other slopes that have failed and have been repaired in the past have failed again or are in the process of failing. Two aspects common to most of the embankment failures are worth mentioning: (1) the embankments are constructed of a fairly homogeneous clay or silty clay; (2) the slope failures are located at or near the bridge ends.

One of the first steps in this research was to study recent literature dealing with the problem of slope instability. This literature was obtained from the various highway departments, government agencies, and universities. Published and non-published information on case histories of slope failures and corresponding corrective measures are plentiful. However, from the information reviewed, very few instances of documented slope failures resemble the type that occur in Eastern Arkansas, especially with respect to the two common characteristics mentioned above. That is, each different physiographic province in the United States seems to produce slope failures peculiar to that region, the geology of the region being directly or indirectly responsible as a contributing factor in the slope instability in many cases. For instance, in the Pierre Hills of South Dakota the Pierre Shale formation has been a severe problem in the construction of highway cuts and fills. Failures have occurred frequently during construction where the shale is highly weathered. Furthermore, progressive weathering of the sound shale has brought about slope failures several years after construction (9)*. Failures of this nature have been a problem in Eastern Kansas also. The slopes have failed five to ten years after construction (10).

In Kentucky and West Virginia most embankment failures occur in side hill fill sections where a fill acts as a barrier to prevent the free drainage of seepage water from the hill, or where the fill is constructed over unstable shale formations (12, 13).

The Georgia Highway Department has had problems with cut slopes in cherty clay and weathered shale formations. During the wet season water enters the slopes through cracks and fissures, creating conditions of instability. The shale bedding and jointing parallel to the face of a slope have contributed to failure in many cases (11).

---

*Numbers in parentheses refer to corresponding items in the list of References.

Landslide topography presents serious slope stability problems in route location, as evidenced by the Pipe Organ Landslide in Beaverhead County, Montana (14).

In all these instances the geology or physiography of the area plays a direct role in the slope stability problem. In Eastern Arkansas the physiography has an indirect influence. The material economically available for embankment construction is largely limited to the soils of the Mississippi Alluvial Plain. These alluvial soils are not always the most desirable for highway fill construction. Consequently, problems of instability have resulted.

In regions of variable geology slope failures are likely to have unique or individual causes. However, in Eastern Arkansas it appears that the causes precipitating most of the failures are similar, if not identical. Therefore, the results of this research should find wide application in this area of the state.

CHAPTER II

GENERAL PHYSIOGRAPHIC, GEOLOGIC, SOIL AND CLIMATIC CONDITIONS IN EASTERN ARKANSAS

A. Physiography, Geology and Soil (3), (5), (6)

Eastern Arkansas physiographically is a part of the Mississippi embayment of the Gulf Coastal Plain. The Mississippi embayment is bordered by Paleozoic sedimentary rocks on the east, north and west. In Arkansas the western border is the Ozark province (Paleozoic highlands). The embayment itself represents a downwarped trough of the Paleozoic rocks; the trough being filled to its present level with mostly unconsolidated deposits ranging in age from Cretaceous to Recent. The depth of the trough along its axis is greater than 2,500 feet and probably reaches a maximum depth of 3,000 feet.

Cretacous age deposits occupy the bottom of the trough and probably have a thickness of 2,000 feet. The Cretaceous outcrops in small belts along the northwestern limit of the embayment in Arkansas.

Eocene age deposits overlie the Cretaceous to a thickness of 1,000 feet or more. Crowleys Ridge in Northeast and East Central Arkansas represents the major highlands of the embayment region in Arkansas. Eocene deposits make up the core of Crowleys Ridge. The Eocene outcrops in South Central Arkansas and in areas along the western margin of the embayment and along Crowleys Ridge. The Eocene deposits of Crowleys Ridge are partly overlain with sands and gravels of the Lafayette formation which is believed to be Pliocene age. Partly overlying the Lafayette and capping Crowleys Ridge is loess of Pleistocene age. Deposits similar to the Lafayette formation and the loess cap the crests of Paleozoic hills on the western margin of the embayment.

The Mississippi and Ohio Rivers have partly removed the older deposits to depths of 100 to 225 feet below the present surface of the lowlands in Eastern Arkansas. Sediments of Quaternary age have refilled the previously eroded areas to the present surface level.

East from Crowleys Ridge to the Mississippi River the area is almost completely covered with Recent age alluvium. Pleistocene sediments generally underlie the Recent deposits. The area comprises the Mississippi lowlands. The Recent and Pleistocene sediments consist of alluvial silts, loams, clays, sands and gravels.

Between Crowleys Ridge and the Ozark province lie the Advance lowlands. Pleistocene deposits lie directly beneath the surface except in the flood plains of the present streams where the sediments are Recent age. It is believed that the upper Pleistocene sediments are deposits laid down by an ancient Mississippi River which flowed west of Crowleys Ridge and joined the ancient Ohio River which followed the present Mississippi drainage path along the eastern border of Arkansas at the southern tip of Crowleys Ridge. The general sequence of Pleistocene alluvium is a gradation from fine surface silts or loams through compact clays (hardpan) and fine sands to coarse sands and gravels at the base.

The specific areas of investigation for HRP 28 are Mississippi, Crittenden, and Prairie Counties. Embankment slope failures in each of these counties are being studied.

Mississippi and Crittenden Counties both lie within the physiographic region of the Mississippi lowlands. The terrain is nearly level to gently rolling alluvial plain. Elevations range from 200 to 260 feet above sea level. Ponds, swamps, abandoned stream channels, bayous and thick forests were common in the area near the turn of the century. Today most of the forests have been cleared and the land is extensively cultivated. Drainage and flood control measures have since been effected.

The thickness of sedimentary material ranges from 100 to 180 feet. The surface materials are Recent alluvial sands and clays deposited from the waters of the Mississippi River. A typical boring may reveal a gray clay, loam, gumbo, buckshot*, or silty clay underlain with silts, fine sands and gravels which are underlain with coarse sands and gravels.

The embankments selected for investigation are constructed in soil areas characteristic of the Sharkey Series of the Bottomlands and Terraces Soil Associations in Arkansas. Sharkey soil areas are nearly level, poorly drained and consist of dark gray clays which are often called gumbo. The clays often display a blocky structure and have high shrink-swell potential.

Prairie County lies on the Advance lowlands. The topography in general is a gently undulating and rolling plain. Elevations range from 200 to 240 feet above sea level. The interstream areas are immediately underlain with Pleistocene deposits of silty loams and clays. Large and small tracts of prairie separated by wooded lowlands occupy much of the interstream lands.

Recent alluvium occupies the stream flood plains. Swamps, bayous, etc., characterize the bottom lands.

---

*Buckshot is a ferruginous clay containing numerous limonite concretions ranging in size from a pinhead to a marble in diameter.

The Quaternary (Pleistocene and Recent) alluvial deposits immediately underlie the surface to depths of 125 to 180 feet. A typical boring may reveal a stratification of loam and red clay underlain with blue clay and fine sand which are underlain with sand and gravel.

The prevalent soil type near Hazen, where an embankment slope failure occurs, belongs to the Crowley Series of the Loessial Terraces Soil Associations. Crowley soils occupy nearly level, broad prairie lands. The surface soil is a dark grayish brown silt loam. The subsoil is light brownish gray clay mottled with red and brownish yellow. Crowley soils are less clayey and lighter colored than the Sharkey soils. Drainage of the soil is poor. The more clayey soils have high shrink-swell potential.

B. Climate (4), (5), (7)

Generally, the climate of Eastern Arkansas is mild. The mean annual temperature ranges from 60° F in Northeast Arkansas to 64°F in Southeast Arkansas. Mean annual precipitation varies from 48 to 52 inches, Northeast to Southeast, respectively.

Winters are short and cool except for brief cold periods when temperatures drop below 0° F. The mean minimum temperature in January ranges from 28° F to 36° F (NE to SE). The average annual snowfall is less than five inches total annual accumulation. Snow accumulations melt quickly and generally last no more than a couple of days. Snow accounts for about one percent of the total annual precipitation. The wet season in Eastern Arkansas occurs in winter, January being the month for greatest amount of rainfall (5 to 6 inches).

The spring and fall seasons are long and mild. Fall is the dry season. Monthly precipitation varies from 2 to 3 inches. Droughts occasionally occur in local areas. The last moderately severe drought was in 1963. The most severe dry period on record lasted 18 months in 1953-54.

Summers are hot and humid. The mean maximum temperature in July ranges from 92° F to 94° F (NE to SE).

CHAPTER III

PRELIMINARY INVESTIGATION OF SELECTED EMBANKMENT FAILURES

In April of 1971 many failed embankment slopes in Eastern Arkansas were inspected, and four failure sites were chosen for investigation. Figure III-1 shows the location of the sites. Site No. 1 is located at the Club Road and Interstate 55 grade separation in West Memphis; Site No. 2 at the Highway 70 and Interstate 55 grade separation in West Memphis; Site No. 3 at the Highway 181 and Interstate 55 overpass, two miles south of Keiser; and Site No. 4 at the Highway 11 and Interstate 40 grade separation, 3 miles north of Hazen.

The fill approach ramps to the Club Road grade separation were constructed in 1958 under State Job No. 11605 and F.A.P. No. I-55-1(12)4. Foundation soils consisted of moist medium firm brown clay to a depth of 8 feet. The clay was underlain with 10 feet of moist medium loose brown fine sand. The embankments were constructed according to the Standard Specifications adopted by the Arkansas State Highway Commission in 1940. Special provisions were made for embankment material, source of embankment material, embankment surcharge and special compaction of earthwork. The plans called for side slopes of 4:1, front slopes of 2:1, and crown widths of 36 feet. Natural ground elevation was approximately 216 feet above sea level. The maximum height of fill reached an elevation of 234 feet. The select material immediately underlying the pavement was classified as A-2-4(0).

The Highway 70 and I-55 grade separation is the oldest fill being investigated. It was constructed in 1951 as part of State Job No.

FIGURE III-1

Failure Site Locations

11397 and F.A.P. No. U.I.-55-1(5)4. The 1940 Standard Specifications with special provisions for earthwork and borrow pits were followed. The embankments were to be constructed with 3:1 side slopes, 2:1 front slopes, and crown widths of 38 feet. The embankments were raised from a natural ground elevation of 216 feet to a maximum elevation of 233 feet. Foundation soil in the vicinity had the following properties*:

Gray Brown Clay . . . . depth = 0-7 feet
nat. w. c. = 45%
LL = 75%
PI = 45%
c = 800 psf
ϕ = 1 deg

Gray Brown Clay . . . . depth = 7-10 feet
nat. w. c. = 40%
LL = 65%
PI = 40%
c = 600 psf
ϕ = 12 deg

Gray Brown Clay to Clayey Silt. . . . depth = 10-15 feet
LL = 60%
PI = 35%
c = 400 psf
ϕ = 13 deg

The Highway 181 and I-55 Overpass (Hilton Interchange) was constructed in 1960 under State Job No. 10607 and F.A.P. No. I-55-1(40)43. Plan side slopes were to be 4:1, and the crown widths were to be 44 feet. Natural ground elevation was approximately 229 feet. Maximum

---

*Properties obtained from the files of the Arkansas Highway Department.

fill elevation was approximately 258 feet. Upgraded embankment material, classified A-2-4(0), was constructed beneath the pavement and shoulders.

The Highway 11 grade separation near Hazen was constructed in 1964--State Job No. 6717 and F.A.P. No. I-40-4(9). The 1959 Standard Specifications with special provisions were used. Borings revealed that the foundation soil was moist soft brown clay silt (with some fine sand) to a depth of 15 feet. Underlying the clay silt to a depth of 31 feet were moist soft reddish brown silt and clay with occasional lenses of fine sand and silt. Soils in the vicinity had the following properties[*]:

Borrow Pit No. 2 . . . . Soil color: Brown
Classification: A-7-6(35)
% passing no. 200 Sieve = 99%
LL = 77%
PI = 48%

Borrow Pit No. 15. . . . . Soil color: Brown-gray
Classification: A-7-6 (39)
% passing no. 200 Sieve = 100%
LL = 94%
PI = 66%

Sta. 1634 on ℄ I-40. . . . . Depth = 0-8 feet
Soil Color: Brown-gray
Classification: A-7-6(19)
% passing no. 200 Sieve = 98%
LL = 48%
PI = 28%

The plans called for 3:1 side slopes, 2:1 front slopes and crown widths of 36 feet.

---

[*] Taken from Highway Department files.

CHAPTER IV

DETAILED INVESTIGATION OF SELECTED EMBANKMENT FAILURES

An important phase of HRP 28 was to gather pertinent data from the four existing failed embankment slopes in Eastern Arkansas. The plan involved executing a boring and sampling program and performing a laboratory testing program.

Index properties and soil classification were determined from bag samples which were obtained during the inspection trip.

The boring and sampling operation was carried out in June, 1971, with the assistance of Arkansas Highway Department personnel. One standard auger boring was made through the embankment at each failure site. Plate 1 shows the drilling and sampling operation at Site No. 1. Where possible continuous undisturbed samples were obtained with 24 inch long, 2 inch O. D. Shelby tubes. The tubes were cut to the length of soil sample retained; the ends capped and sealed with paraffin; and the tubes stored in damp sawdust. The length of soil retained in the tubes ranged from 3 to 12 inches.

Original construction drawings of the embankments and cross section notes of the failure areas were obtained. Using the cross section data and the STAMPEDE* computer program available at the University of Arkansas, contour maps of the failures were drawn on a CALCOMP 563 pen plotter.

Two triaxial tests were considered for use in determining the strength parameters of the soil samples. . . the unconsolidated undrained test (UU test) and the consolidated undrained test (CU test). The CU test would

---

*STAMPEDE is an acronym for Surface Techniques, Annotation and Mapping Programs for Exploration, Development and Engineering.

PLATE 1

Drilling and Sampling Operation

subject the soil specimens to conditions closer to the actual field conditions, i.e., by consolidating a specimen to its in-situ conditions before applying the deviator stress. However, the embankments carry no heavy static loads other than the weight of the fills themselves. The embankments are relatively low. . . three are less than 20 feet high; one is approximately 30 feet high. Therefore, rebound of the soil samples, due to sampling, was considered to be small, and the UU test should give results comparable to those of the CU test. Consequently, the UU test was chosen because it requires less time to perform.

Pore pressure measurements were not made because a total stress analysis will be performed in the slope stability calculations. The state of pore pressures in the field was unknown. For this reason it was decided not to use an effective stress analysis. In addition, many of the soil samples appeared to be only partially saturated, especially at Site No. 2. For an unsaturated soil pore pressure measurements would be difficult to take and would probably be unreliable.

The triaxial test procedure was as follows:

A Shelby tube sample was extruded, and, depending on the length of the sample, from 1 to 3 test specimens were cut from the sample. It was desired to have test specimens of 3 3/4 to 4 inches in length. However, some were as short as 3 inches. After a specimen was carefully trimmed and measured for length, diameter and weight, nonporous plates and top and bottom caps were placed on the ends of the specimen, and a rubber membrane was stretched around the specimen. The test specimen was placed inside a triaxial cell and exposed to an air confining pressure (σ_3). The range of confining pressure was dependent upon the depth from which the samples were obtained. Soon after the confining pressure was maintained around the specimen, the deviator stress ($\sigma_1 - \sigma_3$) was applied at a 1 to 1.5 percent per minute strain rate. The testing operation is shown in Plate 2. No air or water was allowed to escape the voids. The strain was carried out to well past the peak stress. In most cases the approximate failure angle (α) was recorded. After the test was completed a moisture specimen was obtained.

A computer program was written to facilitate calculations of stress and strain. The program takes the raw test data. . . length, initial area, confining pressure, displacement dial readings, proving ring dial readings, number of test points, sample number, specimen number, location, date of test. . . and calculates the stress-strain values and plots stress vs. strain diagrams on the CALCOMP pen plotter. The program listing is contained in Appendix A. Appendix B presents the resulting stress-strain curves for the test specimens.

The Mohr rupture envelopes which were used to determine the strength parameters, c and ϕ, are obtained in Appendix C.

Failure site descriptions and laboratory test results are presented in the following subsections.

A. Site No. 1

The location is the Club Road and I-55 overpass in West Memphis. Club Road is elevated over the I-55 freeway. The maximum height of the fill approach ramps to the bridge is approximately 18 feet. Two slope failures occur in the north fill near the bridge end, one on the east flank and one on the west flank of the fill. Plate 3 shows the

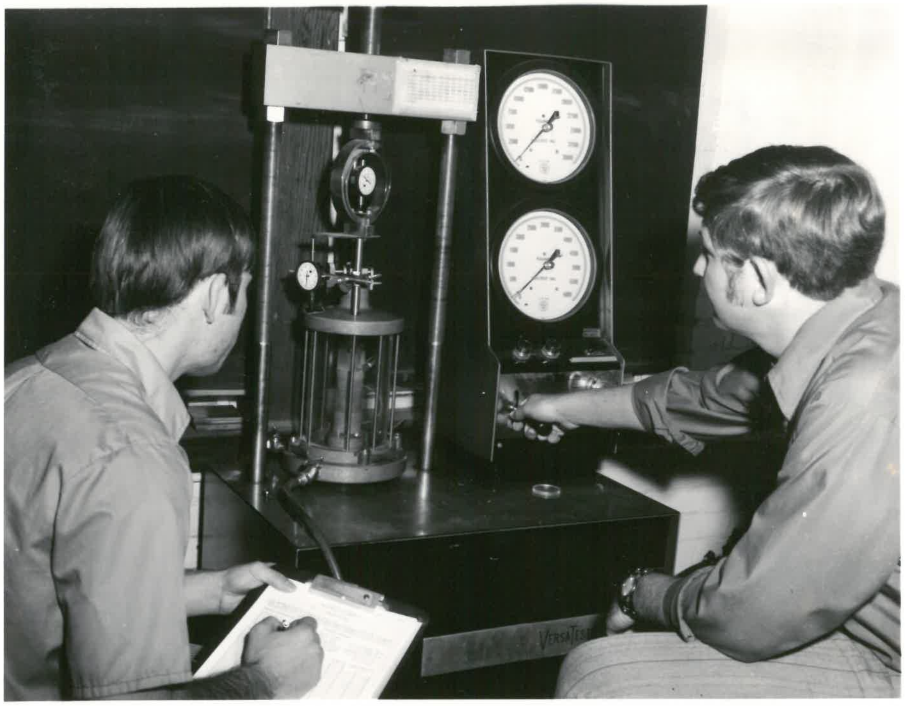


PLATE 2

Triaxial Testing

PLATE 3

Slope Failure - Site No. 1

PLATE 4

failure on the west side. A closer view of the failure surface is shown in Plate 4.

The failures are relatively small. The length of embankment involved in the movements is approximately 80 feet. The contour map in Figure IV-1 shows the extent of the failures. A typical centerline section of the east flank failure is shown in Figure IV-2.

The embankment is constructed of a brown-gray clay, locally termed gumbo. The dry strength of the clay is very high, i.e., it does not crumble easily under finger pressure. When wet, the clay readily adheres to shoes, tires, etc. Classification tests reveal the soil to be a CH material by the Unified System or an A-7-6 material by the AASHO system.

Boring A was drilled through the pavement in the northbound lane approximately 10 feet from the bridge end. Table IV-1 contains the log of boring.

Laboratory test results of the embankment soils are presented in Table IV-2.

B. Site No. 2

At this site the Highway 70 exit ramp leads from the I-55 NW bound lanes and overpasses the SE connection to Highway 70 in a westerly direction. The failure occurs on the north flank of the approach fill at the east end of the bridge. Plates 5 and 6 are pictures of the failure. The slope appears to have slipped along several failure surfaces, the upper ends of the failure surfaces being almost vertical.

The size of fill, location and extent of slope disturbance are similar to the failures at Site No. 1. Figure IV-3 is a contour map of the failure. A typical cross section is shown in Figure IV-4.

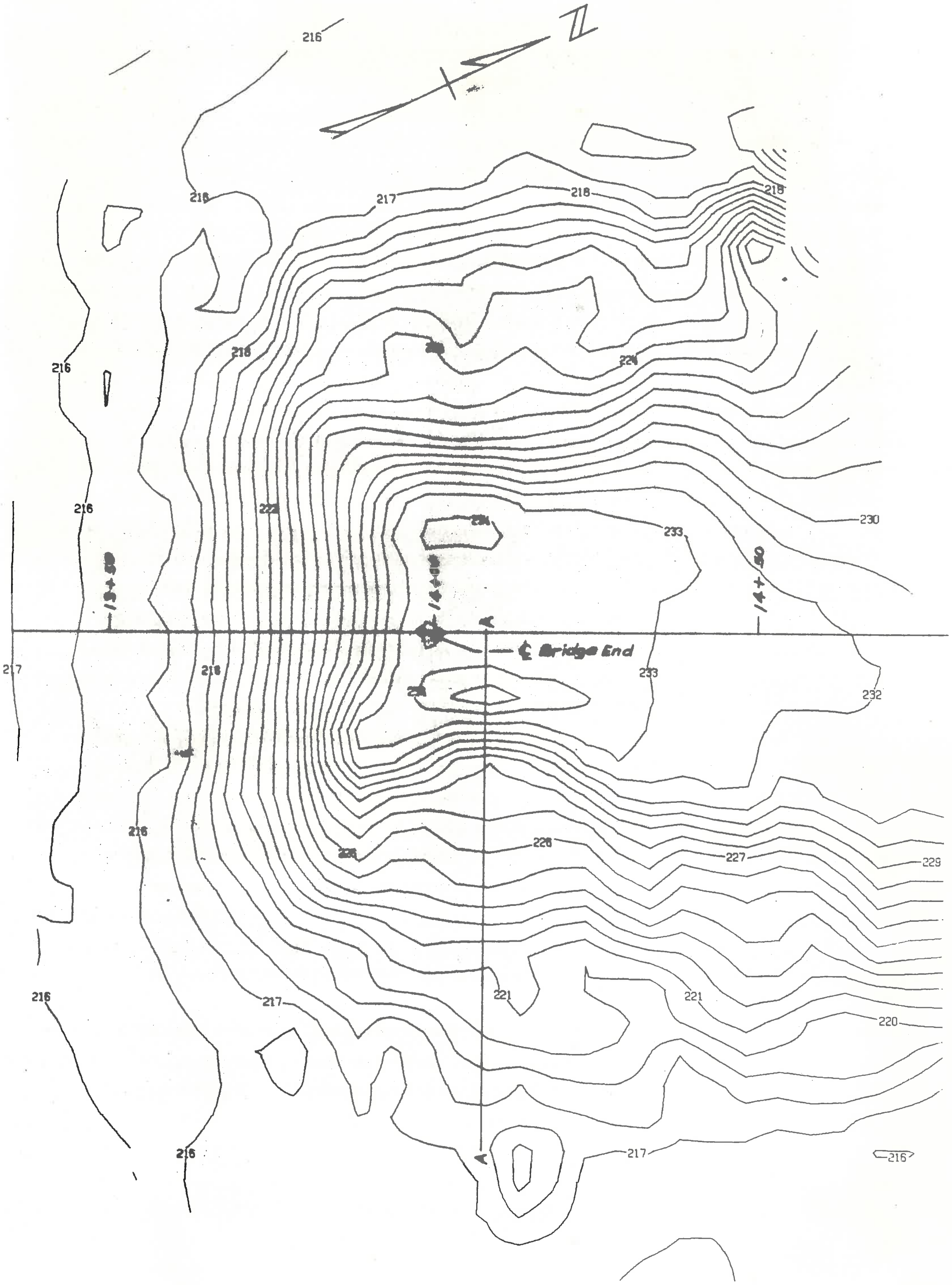


FIGURE IV-1
Contour Map - Site No. 1

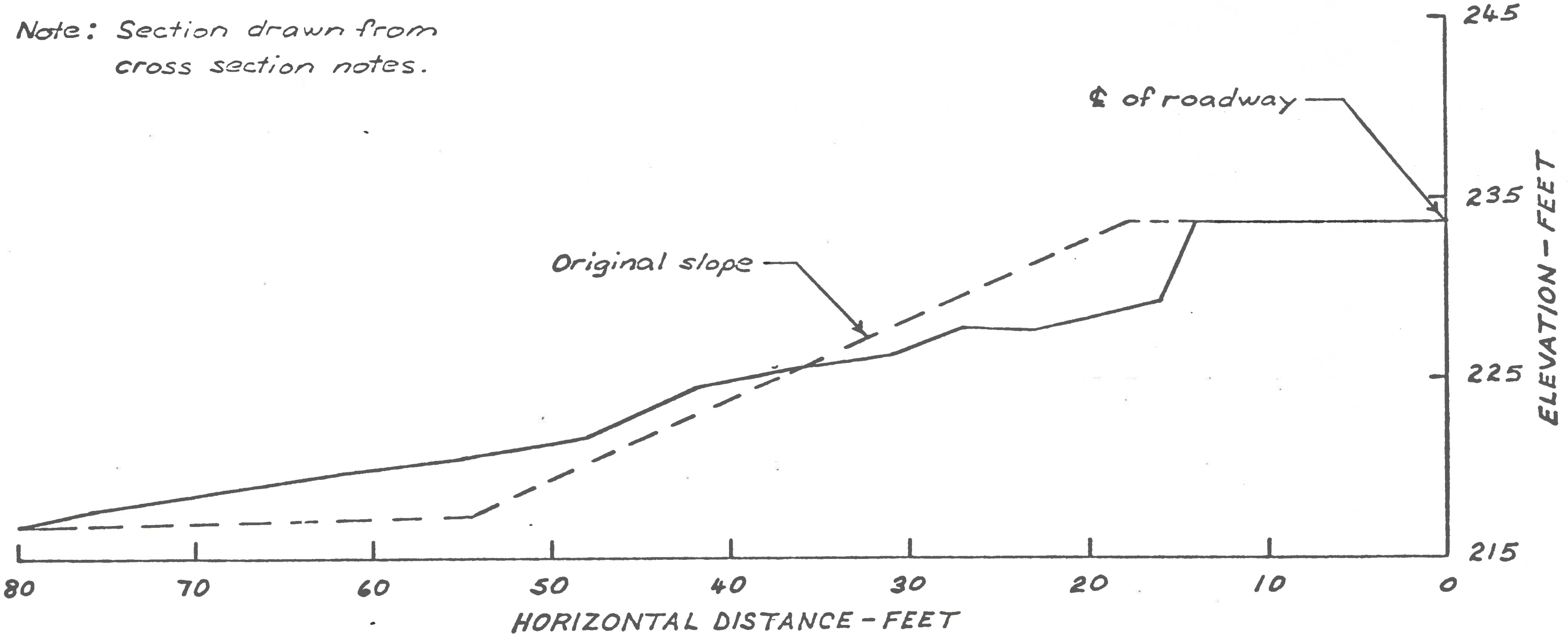


FIGURE IV-2

Section AA - Site No. 1

TABLE IV-1

Failure Site No. 1 Log of Boring

Hole A

Club Road and I-55 Overpass

Depth (ft.)	Sample No.	Remarks
0-1½	Drilled	Pavement and Selected Material
1½-3	A-1	Embankment Material
6-7½	A-2	Embankment Material
8-9½	A-3	Embankment Material
10-11½	A-4	Embankment Material
12-13½	A-5	Embankment Material (very wet)
14-15½	A-6	Embankment Material and Natural Ground
16-17½	A-7	Natural Ground

NOTE: Pavement Thickness = 7 inches

Depth (ft.)	Sample No.	Specimen No.	M.C. (%)	Wet Unit Wt. (pcf)	Dry Unit Wt. (pcf)	Degree of Sat. (%)	σ_3 (psf)	σ_1 (psf)	C (psf)	ϕ (deg)
1½-3	A-1	1 2	41 41	114 111	81 79	99 95	288 1008	2141 3236	700	11.5
6-7½	A-2	1 2 3	42 36 36	113 112 113	79 82 83	98 91 93	720 1440 2160	2597 2783 4365	750	6.5
8-9½	A-3	1 2	44 46	111 112	77 77	98 100	1008 1728	3464 4468	850	10
10-11½	A-4	1 2	44 43	114 115	80 81	100 100	1152 2160	3926 5426	870	12.5
12-13½	A-5	1 2	45 33	112 116	78 87	100 93	1440 720	4278 3676	1430	0
14-15½	A-6	1 2	38 32	120 119	87 90	100 97	1584 720	5996 4644	1400 2100	13 0
16-17½	A-7	1 2	32 33	115 119	87 90	91 98	1872 1152	5983 5762	2175	0

TABLE IV-2

Failure Site No. 1 Laboratory Test Results

Gs = 2.77
LL = 71
PI = 39
AASHO Class.: A-7-6
Unified Class.: CH

PLATE 5

Slope Failure - Site No. 2

PLATE 6

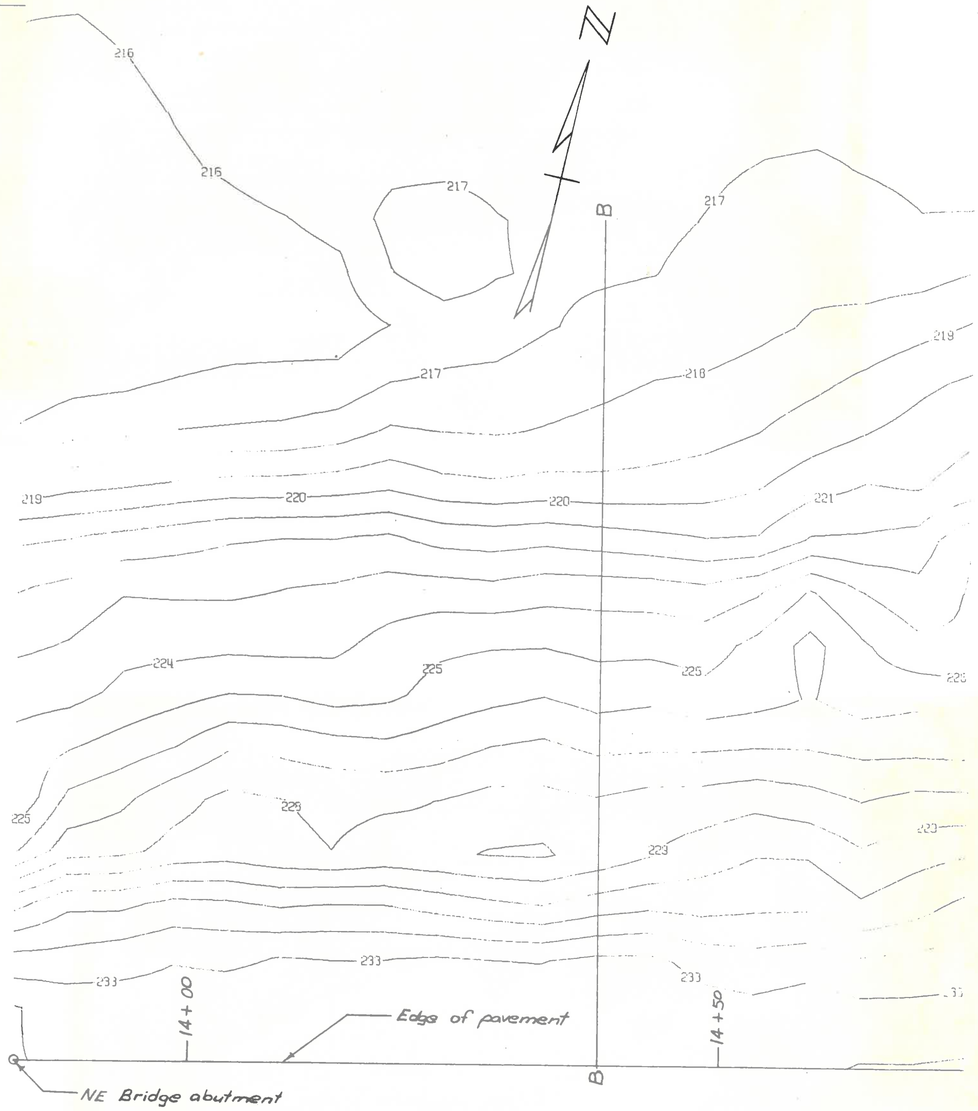


FIGURE IV-3
Contour Map - Site No. 2

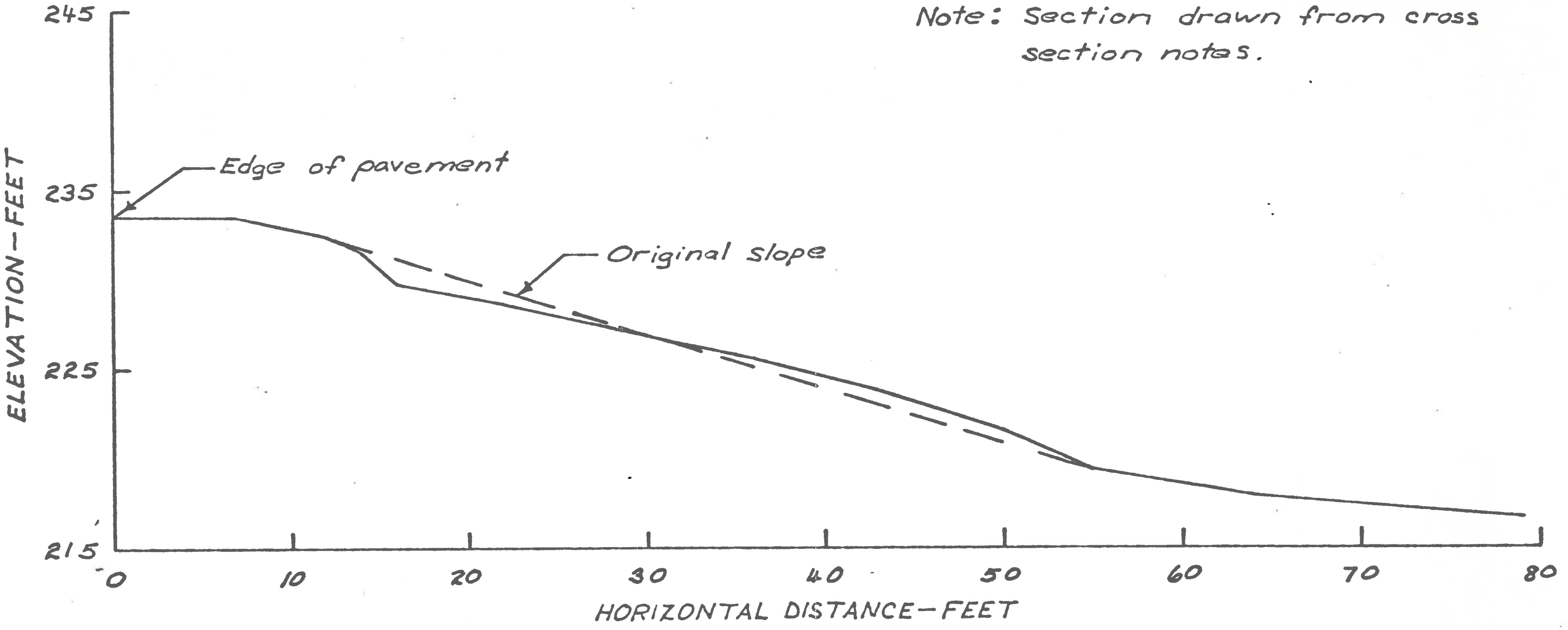


FIGURE IV-4

Section BB - Site No. 2

The embankment soil is classified as a CH material. Its water content is somewhat lower than the soil at Site No. 1.

Undisturbed samples were obtained from Boring B. See Table IV-3. The boring was drilled on the north shoulder of the roadway, 57 feet from the NE bridge abutment. The estimated water table is at a depth of 16 1/2 feet. Below the water table very little soil would remain in the Shelby tubes.

Many of the triaxial test specimens contained fine sand and/or roots and organic matter. Table IV-4 is a tabulation of the laboratory test results.

C. Site No. 3

The Highway 181 and I-55 grade separation is the location of the largest failure being investigated. I-55 passes over Highway 181. Extensive slope disturbances occur in the NW flank of the fill at the SW end of the bridge in the SW bound lanes. Plates 7 and 8 are two views of the failure surface. The pictures were taken in April, 1971, during the inspection trip. By the time a boring was made in June, 1971, slumping at the top of the slope had advanced the failure surface closer to the highway shoulder. Inspection at the time of drilling revealed further tension crack development at the top of the slope. Figure IV-5 is a typical section of the failure after the later movement.

The maximum height of the fill is approximately 30 feet. The large failure occurs near the bridge end. A smaller disturbance occurs 180 feet SW from the edge of the large failure. The length of embankment involved in the slope distress is approximately 230 feet at the large

TABLE IV-3

Failure Site No. 2 Log of Boring

Hole B

Highway 70 and I-55 Overpass

Depth (ft.)	Sample No.	Remarks
0-2	Drilled	Selected Material
2-3½	B-1	Embankment Material
4-5½	B-2	Embankment Material
6-7½	B-3	Embankment Material
8-9½	B-4	Embankment Material
10-11½	B-5	Embankment Material
12-13½	B-6	Embankment Material
14-15½	B-7	Embankment Material
16-17½	B-8	Embankment Material
18-19½	B-9	Embankment Material

NOTE: (a) Estimated Water Table at 16½'

(b) Hole Location: 57' from NE bridge abutment. 3' North of pavement edge.

Depth (ft.)	Sample No.	Specimen No.	M.C. (%)	Wet Unit Wt. (pcf)	Dry Unit Wt. (pcf)	Degree of Sat. (%)	σ_3 (psf)	σ_1 (psf)	C (psf)	ϕ (deg)
2-3½	B-1	1 2 3	42 37 38	111 111 112	78 81 81	96 91 95	432 1440 2160	1649 3715 4775	600	12
4-5½	B-2	1	36	106	77	83	576	3896	1660*	--
6-7½	B-3	1	35	105	78	80	720	3587	1433*	--
8-9½	B-4	1	35	113	84	92	1008	3484	1238*	--
10-11½	B-5	1	28	116	91	87	1152	2482	665*	--
12-13½	B-6	1	35	110	81	88	1584	3389	1333**	--
12-13½	B-6	2	33	112	84	88	2880	6406		--
14-15½	B-7	1 2	38 42	113 112	82 79	96 99	1584 2880	4051 4859	1150**	--
16-17½	B-8	1	36	104	76	80	1872	5431	1780*	--
18-19½	B-9	(too short)	35	---	--	--	--	--	--	--

TABLE IV-4

Failure Site No. 2 Laboratory Test Results

Gs = 2.73
LL = 79
PI = 43
AASHO Class.: A-7-6
Unified Class.: CH

* Peak shear strength.
** Average shear strength.

PLATE 7

Slope Failure - Site No. 3

PLATE 8

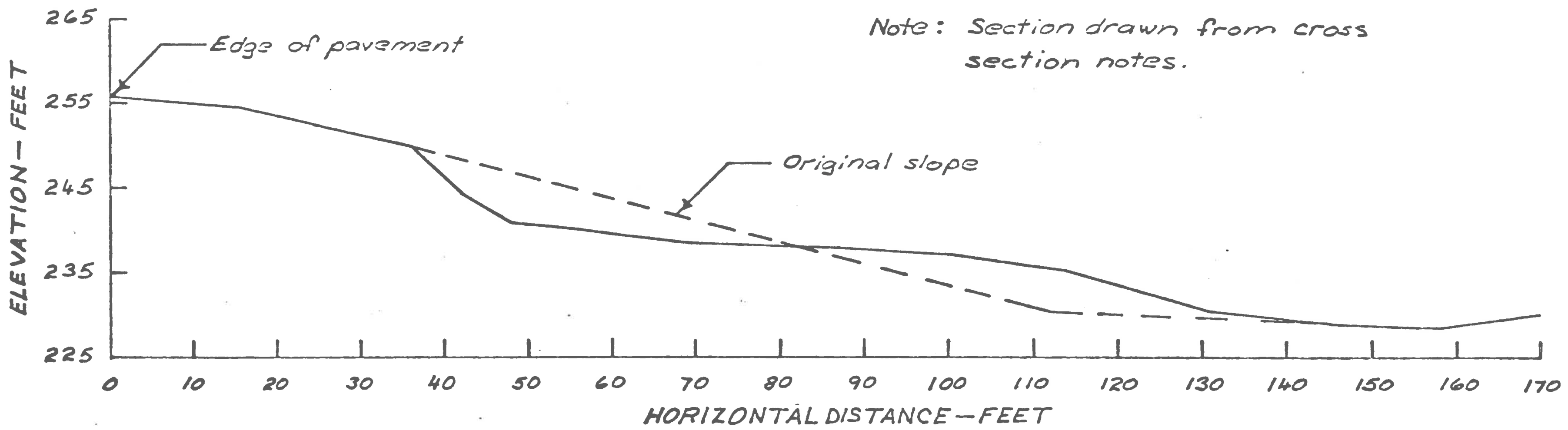


FIGURE IV-5

Section CC - Site No. 3

slide and approximately 160 feet at the small slide. See contour maps in Figures IV-6 and IV-7. The disturbances can be clearly outlined. . . steep failure surface at the top of the slope and bulge at the bottom.

Boring C was drilled on the shoulder of the road near mid length of the large failure. The log of boring is shown in Table IV-5. During the first attempt to drill the hole, water under a pressure head gushed from the hole.

The soil samples taken from the boring were very wet and were at or near 100 percent saturation. See Table IV-6 for tabulation of laboratory test results.

The soil is a CH material. It has characteristics very similar to the soils at Sites 1 and 2. A couple of the Shelby tube samples contained sand seams running the length of the samples.

D. Site No. 4

Highway 11 overpasses the I-40 freeway in a N-S direction. Slope disturbance occurs on the NW "point" of the south fill near the concrete riprap under the bridge. See Plates 9 and 10. The toe of the failure had slipped over the guard rail and onto the shoulder of the road (removed by the time the photograph was taken). The depth of failure is shallow. . . to just below the grass roots. Figure IV-8 is a typical cross section, and Figure IV-9 is a contour map of the disturbance. The maximum height of the slope is approximately 20 feet.

Boring D was drilled 9 1/2 feet from the south end of the bridge, 3 1/2 feet west of the pavement edge. See Log of Boring, Table IV-7.

The embankment soil is a red clay, classified as a CL material. It is not as plastic as the soils at the other sites. Many samples contained

FIGURE IV-6

Contour Map No. 1 - Site No. 3

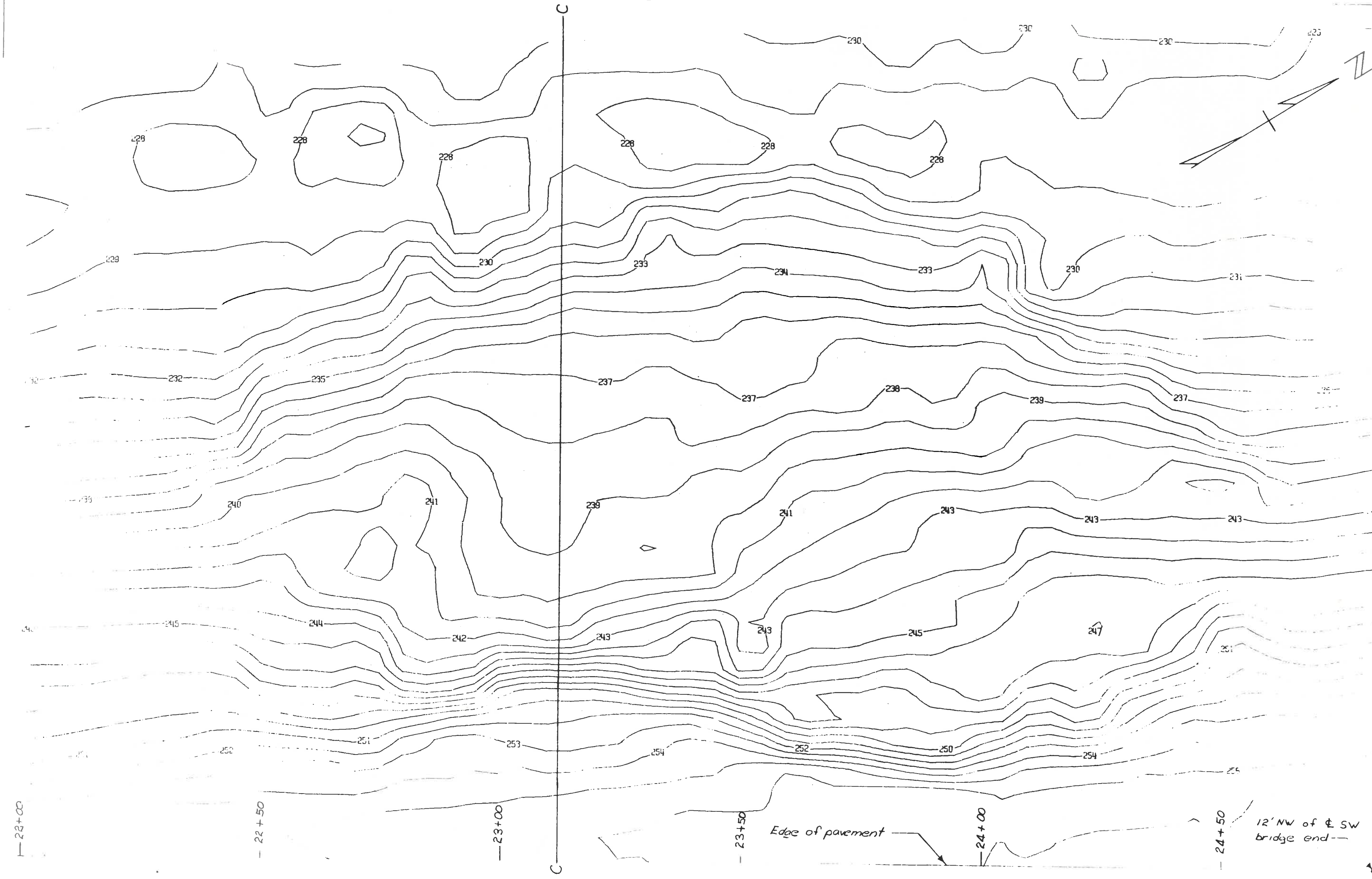


FIGURE IV-7

Contour Map No. 2 - Site No. 3

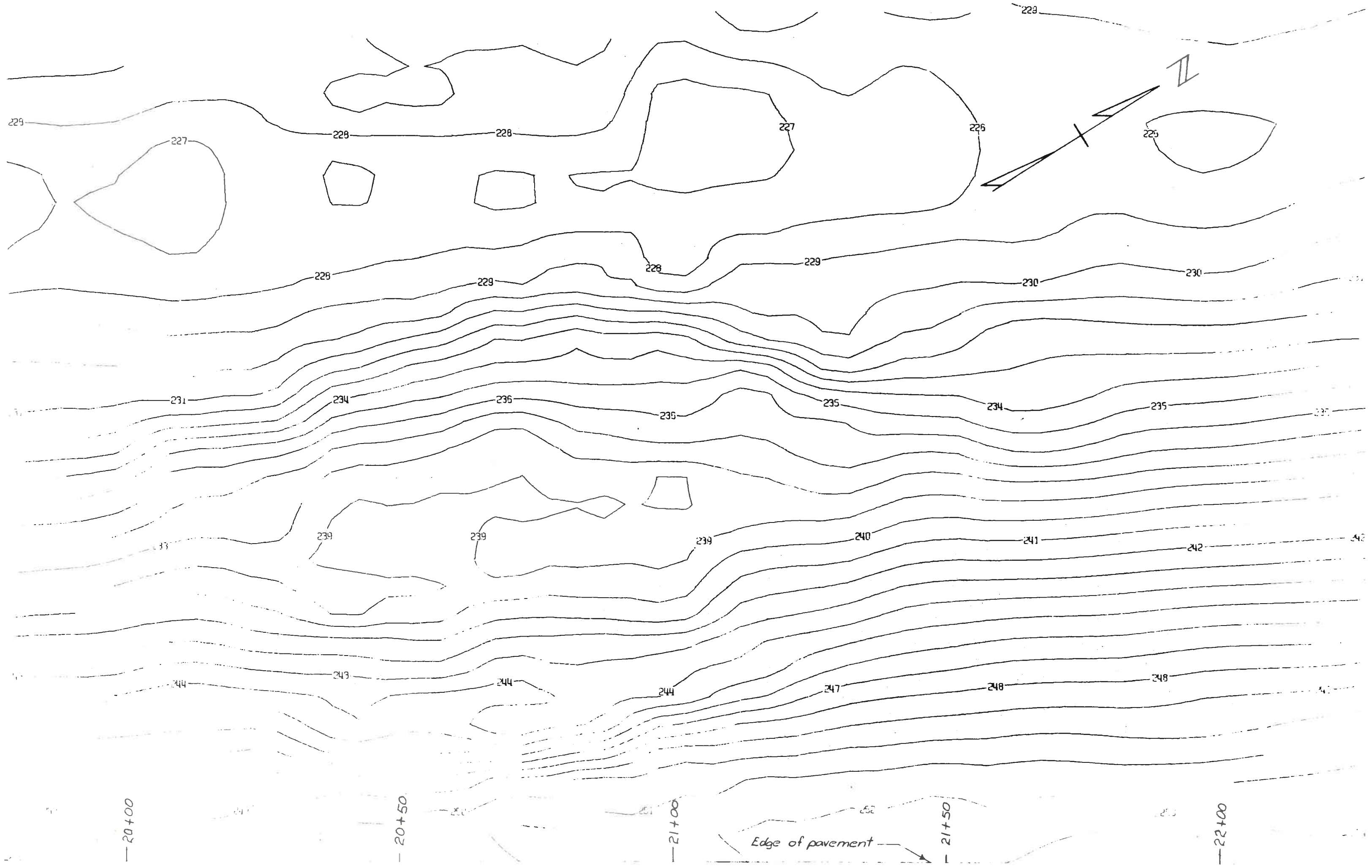


TABLE IV-5

Failure Site No. 3 Log of Boring

Hole C

Highway 181 and I-55 Overpass

Depth (ft.)	Sample No.	Remarks
0-4	C-1 (Sack)	Wet Sand
5-6½	C-2	Very Wet Embankment Material
7-8½	C-3	Very Wet Embankment Material
9-10½	C-4	Very Wet Embankment Material
11-12½	C-5	Very Wet Embankment Material
13-14½	C-6	Very Wet Embankment Material
15-16½	C-7	Very Wet Embankment Material
17-18½	C-8	Very Wet Embankment Material
19-20½	C-9 (Lost Sample)	Very Wet Embankment Material
21-22½	C-10	Wet Embankment Material
23-24½	C-11	Wet Embankment Material
29-30½	C-12	Wet Embankment Material
34-35½	C-13	Wet Embankment Material

Depth (ft.)	Sample No.	Specimen No.	M.C. (%)	Wet Unit Wt. (pcf)	Dry Unit Wt. (pcf)	Degree of Sat. (%)	σ_3 (psf)	σ_1 (psf)	C (psf)	ϕ (deg)
0-4	C-1	(Sack)	--	--	--	--	--	--	--	--
5-6½	C-2	1 2 3	48 38 41	111 115 113	75 83 80	100 96 97	720 1440 2160	1922 3813 5159	450	16.5
7-8½	C-3	1	43	114	79	100	864	3771	1454	0
9-10½	C-4	1 2	43 42	118 117	83 82	100 100	1152 432	5246 3222	1720*	--
11-12½	C-5	1 2	43 45	121 116	84 80	100 100	576 1296	3343 4015	1400	0
13-14½	C-6	1 2 3	41 42 42	112 115 114	79 82 80	96 100 99	864 1584 2304	3594 4588 5911	850	14
15-16½	C-7	1 2	36 38	119 113	87 82	100 94	864 1584	4537 5489	1450	9
17-18½	C-8	1 2	44 39	115 116	80 83	100 99	1296 2016	4040 5130	850	11.5
19-20½	C-9	(lost)	--	---	--	---	--	--	--	--
21-22½	C-10	1 2	39 37	117 117	84 85	100 98	1728 2448	6218 6624	2100	0
23-24½	C-11	1 2 3	34 36 35	114 116 116	85 85 86	89 96 94	1872 2592 3312	5921 6640 7292	2000	0
29-30½	C-12	1 2	40 38	112 114	81 82	94 95	2592 3312	5475 6531	700	10.5

TABLE IV-6

Failure Site No. 3 Laboratory Test Results

Gs = 2.83
LL = 87
PI = 55
AASHO Class.: A-7-5
Unified Class.: CH

* Average shear strength.

PLATE 9

Slope Failure - Site No. 4

PLATE 10

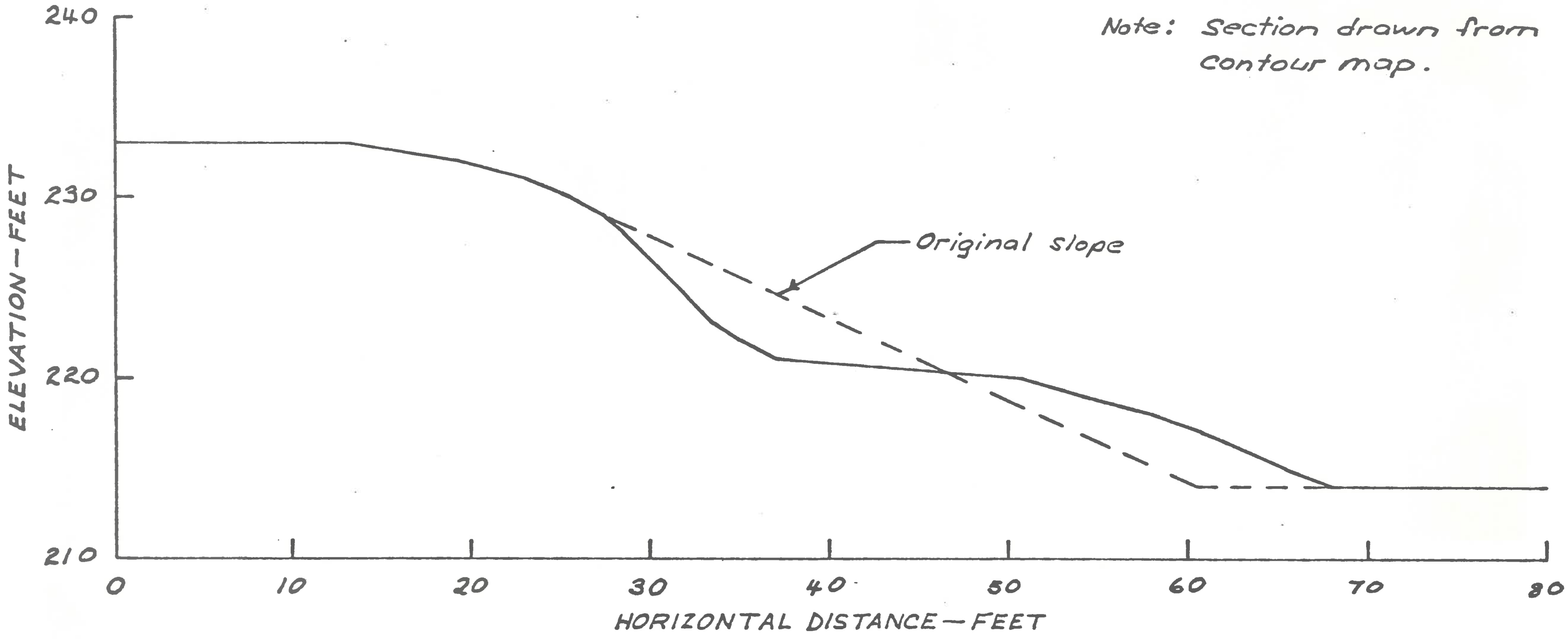


FIGURE IV-8

Section DD - Site No. 4

FIGURE IV-9
Contour Map - Site No. 4

TABLE IV-7

Failure Site No. 4 Log of Boring

Hole D

Highway 11 and I-40 Overpass

Depth (ft.)	Sample No.	Remarks
0-2	Drilled	Selected Material
2-3½	D-1	Embankment Material
4-5½	D-2	Embankment Material
6-7½	D-3	Embankment Material
8-9½	D-4	Embankment Material
10-11½	D-5	Embankment Material
12-13½	D-6	Embankment Material
14-15½	D-7	Embankment Material
16-17½	D-8	Embankment Material
18-19½	D-9	Embankment Material
19½-29½	D-10 (Drilled)	Sack Sample taken at 29½' from bit
New hole was located 6 inches to west of Hole D.		
1½-3	D-11	Embankment Material

NOTE: Hole Location: 9½' from SE bridge abutment.
3½' West of pavement edge.

fine sand or silt. The samples ranged from soft at the top of the boring to stiff near the bottom. Slickensides were prevalent in the stiffer clays. Laboratory test results are presented in Table IV-8.

E. Conclusion to Laboratory Testing

Inspection of the tables of laboratory test results in the preceding subsections reveals somewhat variable results from sample to sample. This can be expected with rolled fill construction because the soil constructed in each lift may have been excavated from several different locations, and each lift may have been compacted to nonuniform densities. Degrees of saturation in particular are inconsistent or unreliable. The problem can be attributed to the specific gravity values used in the calculations. For each site one specific gravity was determined from a bag sample obtained from the exposed failure surface. It is obvious that one specific gravity value is not representative of all the soil in a fill. However, it is useful in determining the range of values for degree of soil saturation in the fills.

Theoretically a fully saturated, purely cohesive, normally consolidated soil has a ϕ angle equal to 0° when tested under unconsolidated undrained conditions. However, many of the test specimens have angles of internal friction greater than 0°, usually on the order of 10-15 degrees. The reason is that many of the test specimens are not 100 percent saturated. Compression of air in the voids of partially saturated soils results in intergranular contact of soil solids and thus increases the ϕ angle from 0°. The magnitude of the ϕ angle is greater than what may be expected for a partially saturated pure clay. The test specimens are not pure clay. Almost all the specimens contain traces of

Depth (ft.)	Sample No.	Specimen No.	M.C. (%)	Wet Unit Wt. (pcf)	Dry Unit Wt. (pcf)	Degree of Sat. (%)	σ_3 (psf)	σ_1 (psf)	C (psf)	ϕ (deg)
2-3½	D-1	(lost)	28	---	--	--	----	----	----	--
4-5½	D-2	1 2	24 30	121 122	98 94	88 100	576 1296	1309 2130	300	4.5
6-7½	D-3	1 2	30 38	123 119	95 87	100 100	720 1440	2466 3070	825	0
8-9½	D-4	1 2	30 27	122 123	93 97	100 99	1008 1728	3538 4415	1025	6
10-11½	D-5	1 2	36 36	118 120	87 88	100 100	1152 432	4331 3891	1650	0
12-13½	D-6	1 2	30 36	125 123	96 91	100 100	1440 720	4750 4757	1800	0
14-15½	D-7	1 2	26 27	122 126	97 99	95 100	720 1584	4216 4936	1750	0
16-17½	D-8	1 2 3	30 33 29	122 122 124	94 92 96	100 100 100	2160 1440 720	6282 6169 5458	2390	0
18-19½	D-9	1 2	33 30	121 125	91 96	100 100	1440 2160	5427 7836	2416*	--
19-29½	D-10	(Sack)	--	---	--	--	--	--	--	--
1½-3	D-11	1	29	121	94	98	720	1559	420**	--

TABLE IV-8

Failure Site No. 4 Laboratory Test Results

Gs = 2.73
LL = 48
PI = 28
AASHO Class.: A-7-6
Unified Class.: CL

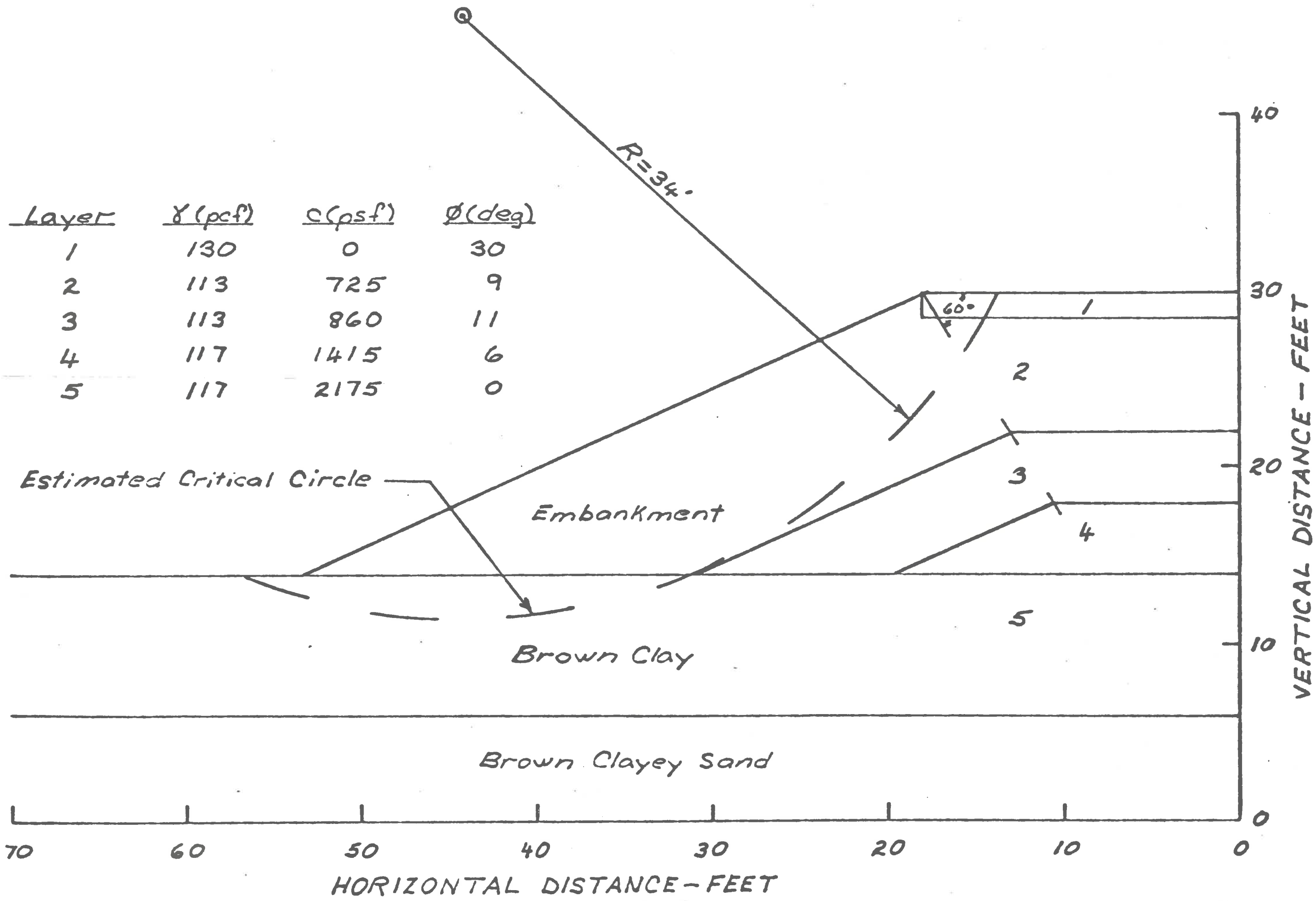
* Average shear strength.
** Peak shear strength.

silt or fine sand, some being very silty or sandy. Silty and sandy clays may be expected to have ϕ angles ranging from 10 to 15 degrees.

The shear strength of samples taken from each boring shows a definite trend. The strength increases with depth. This can be expected since the basement soils are consolidated under a greater overburden pressure. Furthermore, the near surface soils are exposed to the softening effects of weather.

Figures IV-10, IV-11, IV-12 and IV-13 are generalized cross sections of the four failure sites. Soil property information is generalized and assigned to layers. The problem of determining soil boundaries arose. Soil samples were obtained from a boring made on top of each fill. The soils within a boring can be divided into horizontal layers of representative strength parameters. However, extrapolating the layers horizontally to the surface of the slope would not be representative of the soils beneath the slopes, since those soils are not consolidated to as large an overburden pressure as the soils at an equivalent elevation beneath the top of the fill. Furthermore, the soils directly beneath the slope probably have not been compacted to as great a density during construction. And as previously mentioned the soils underlying the slope are more closely exposed to the effects of weather.

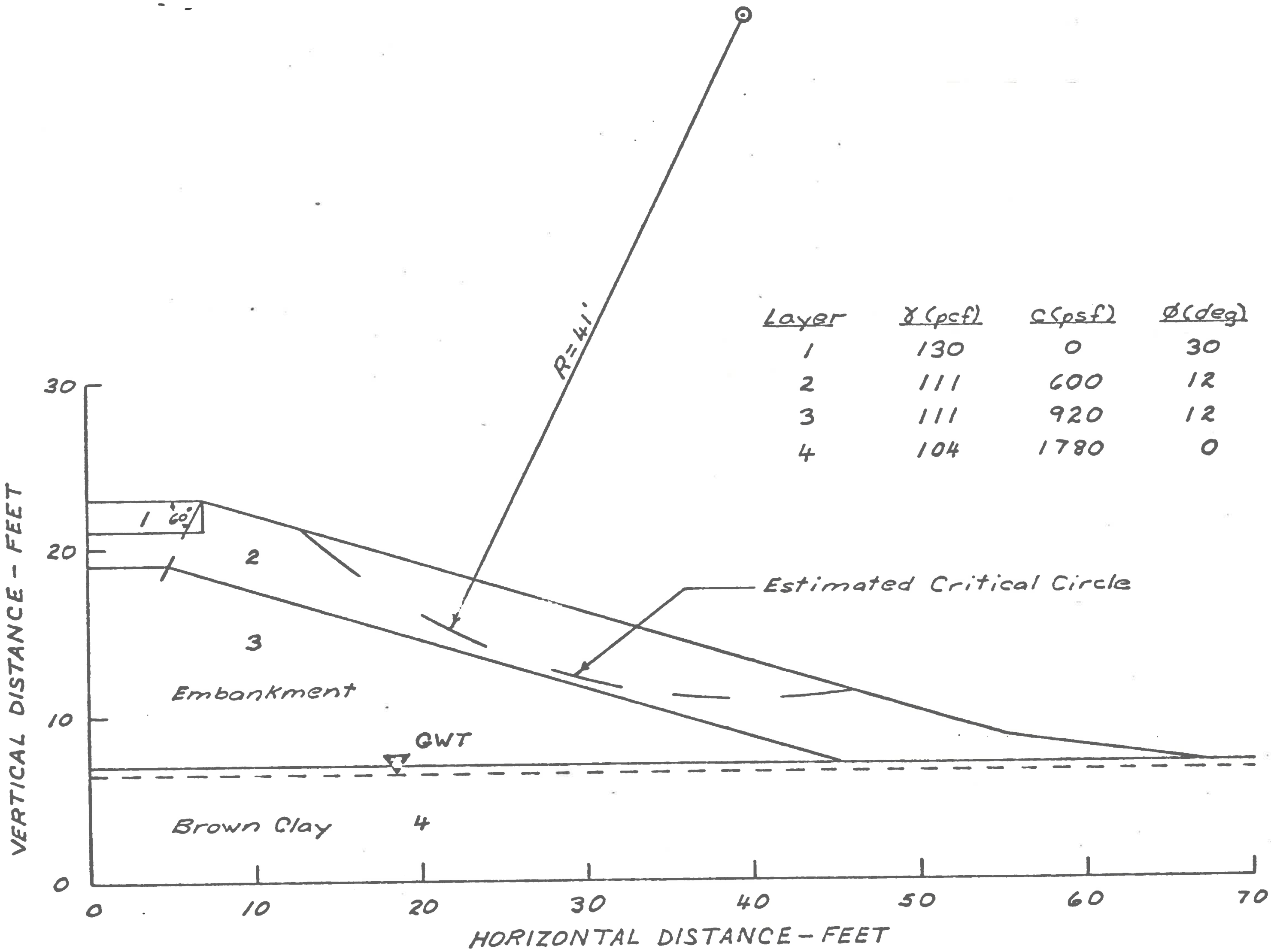
Since no tangible evidence of shear strength is available for the soils that did lie directly beneath the slopes before failure, it is judged that for a more accurate interpretation of the embankment sections the soil boundaries should be positioned as shown in the figures. The soil boundaries within a fill are horizontal to a line which is 60 degrees from the horizontal from the point where the slope begins.



Layer	γ (pcf)	c (psf)	ø (deg)
1	130	0	30
2	113	725	9
3	113	860	11
4	117	1415	6
5	117	2175	0

FIGURE IV-10

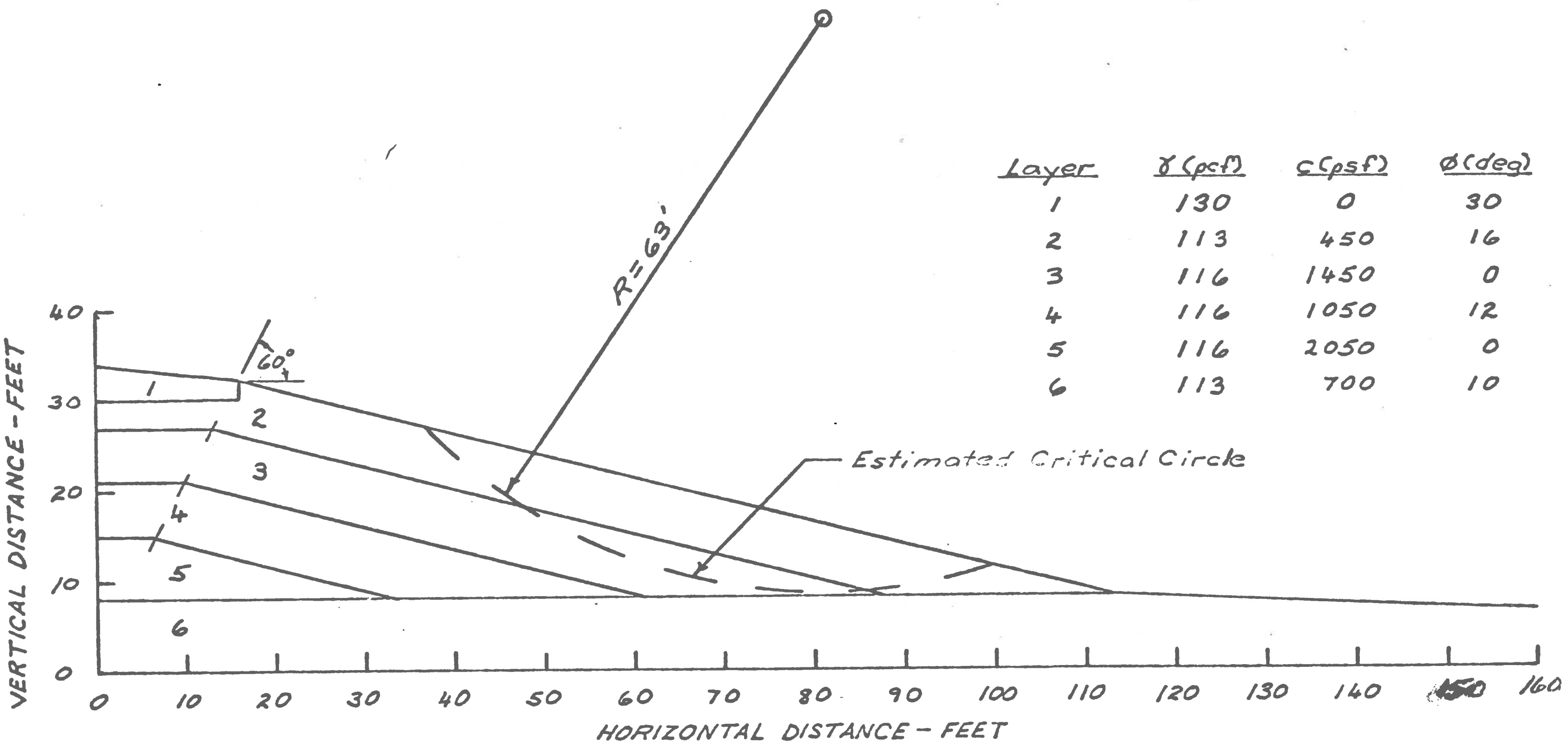
Typical Section Description - Site No. 1



Layer	γ (pcf)	c (psf)	ø (deg)
1	130	0	30
2	111	600	12
3	111	920	12
4	104	1780	0

FIGURE IV-11

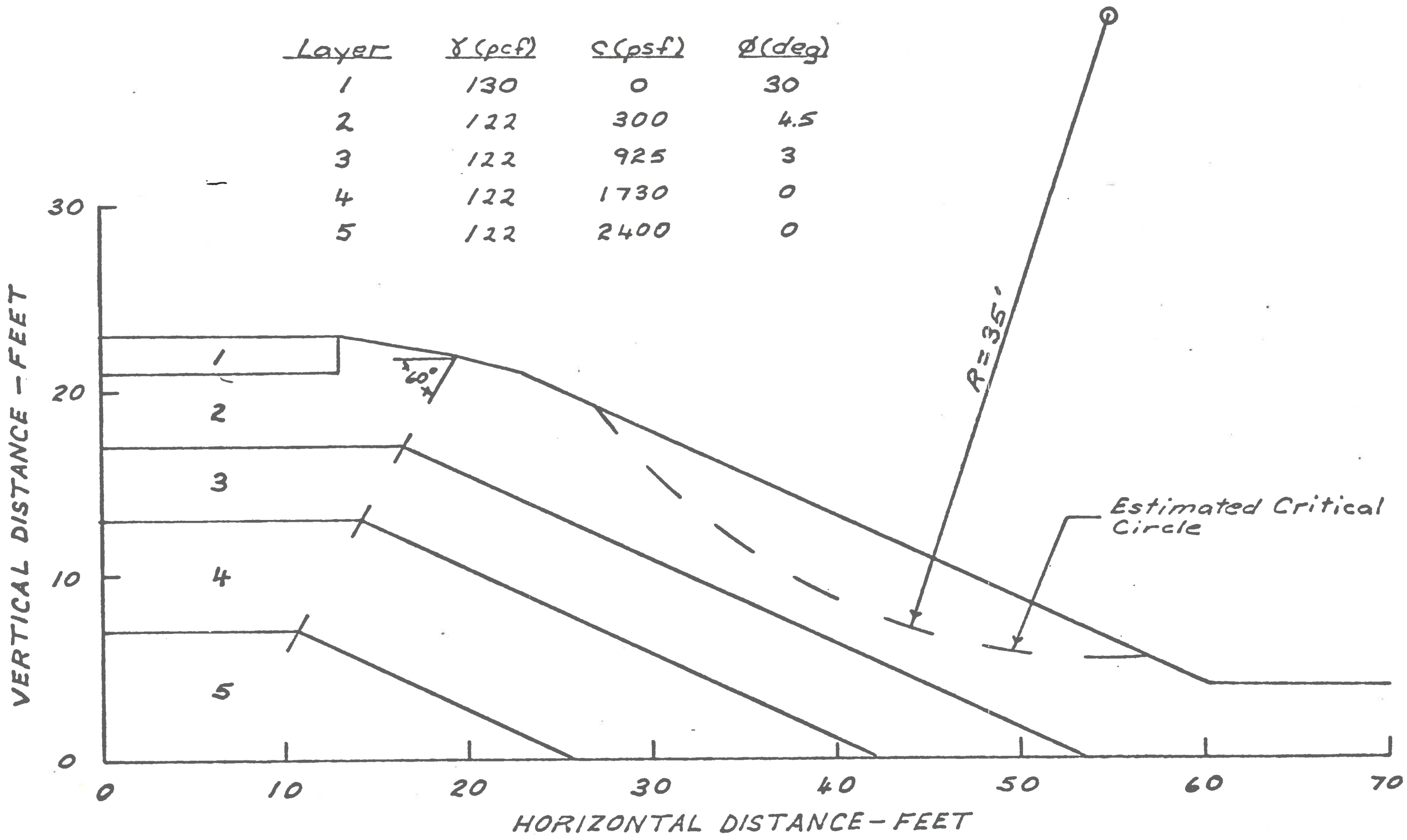
Typical Section Description - Site No. 2



Layer	γ (pcf)	c (psf)	ϕ (deg)
1	130	0	30
2	113	450	16
3	116	1450	0
4	116	1050	12
5	116	2050	0
6	113	700	10

FIGURE IV-12

Typical Section Description - Site No. 3



Layer	γ (pcf)	c (psf)	ø (deg)
1	130	0	30
2	122	300	4.5
3	122	925	3
4	122	1730	0
5	122	2400	0

FIGURE IV-13

Typical Section Description - Site No. 4

This line represents the approximate influence of no soil overburden pressure acting above the slope.

The layers underlying the embankments are selected to be horizontal, with the exception of Site No. 4. Comprehensive information for the natural soil strata are not available. However, strength values of samples obtained from the bottoms of the borings are assigned to the foundation soils. The accuracy of the strength values for the basement layers is questionable, especially for the soils underlying the toes of the slopes. In these areas the assigned strength values are probably much higher than the actual in-situ values. However, most of the failures occur within the slopes and do not involve the foundation soils (Site No. 1 is an exception; some adjustments to the cross section shown in Figure IV-10 may need to be considered). Therefore the strengths of the foundation soils will be of no consequence in the stability analyses.

At Site No. 4 the maximum height of the fill from toe of slope to top of slope is approximately 20 feet. However, underlying the toe of the slope is a 4 to 5 feet thick blanket of additional fill material which overlies natural ground. This blanket of fill is considered to be a part of the embankment that rises above it. For this reason the embankment soil boundaries are extended into the fill foundation soils as shown in Figure IV-13.

Layer one in the generalized cross sections is select material. No test results are available for the material. All that is known is that the select material is sand at each site. The unit weight and angle of internal friction are estimated from this information alone. The accuracy of the estimation is of no consequence since the layer is not thick, and in most cases the failure surface does not pass through it. In any case the select material does not add any significant shearing resistance in stability calculations because the normal pressure on the failure surface at the shallow depth contributes very little to the "$\sigma_n \tan\phi$" term of shear strength (cohesion is very small or equal to zero for the select material).

Estimated critical failure circles are shown in the generalized cross sections. The failure circles are estimated from the exposed failure surfaces.

Slope failure at Site No. 4 in East Central Arkansas may be due to low shearing resistance of the soils underlying the slope. At Site Nos. 1, 2 and 3 in Northeast Arkansas the soil strength appears to be adequate for stability. Conditions other than soil shear strength must be considered. See Chapter V, Section E.

CHAPTER V

SLOPE STABILITY COMPUTER PROGRAMS

Two computer programs are available for use in the stability analyses of the embankment slope failures. The New York State Program, "Computerized Analysis of the Stability of Earth Slopes", is a development of the Bureau of Soil Mechanics, New York State Department of Transportation. The program is a revised and expanded version of two programs currently being used by the Bureau of Soil Mechanics. The other program, LEASE I (Limiting Equilibrium Analysis in Soil Engineering), "A Problem-Oriented Language for Slope Stability Analsis", is one which was developed at the M.I.T. Civil Engineering Systems Laboratory (CESL) and the M.I.T. Soil Mechanics Division. This program is a result of one of the advances made by the Integrated Civil Engineering Systems (ICES) Project being carried out at M.I.T.

Both the New York State and LEASE I programs are adaptable to the IBM System/360 computer. A program listing for the New York State program is contained in Appendix D. LEASE I is written in ICETRAN.

Circular failure surfaces are assumed in the methods of analyses performed by these computer programs. The free bodies above the circular failure surfaces are divided into vertical slices. In accordance with simplifying assumptions driving and resisting moments are determined for each slice. Factors of safety are calculated by determining the ratios of the sums of the resisting moments to the sums of the driving moments, all about trial circle centers.

Where failure occurs within a thin lense or a thin weak layer confined by more competent soils, the computer programs are of little value. Only circular failure surfaces can be analyzed.

For the problem under investigation, where the soils are fairly homogeneous, the New York State and LEASE I programs are satisfactory. Furthermore, these programs can prove to be valuable aids in many problems of highway cut slope and embankment design, if the capabilities and limitations of the programs are understood and if a knowledge of the field conditions is available.

A. New York State Computer Program

The New York State program computes factors of safety against sliding by two methods:

1) The New York State Method which is based on the Normal (Fellenius) Method of Slices where the interslice forces are not taken into consideration.

2) The Simplified Bishop Equation where only the vertical shear forces acting on the sides of the slices are neglected.

1. The New York State Method (2)

Figure V-1 shows a typical slice with all the assumed forces acting on it. The factor of safety by the New York State Method is derived from:

$$\text{FSNYS} = \frac{\Sigma \text{ RESISTING MOMENTS}}{\Sigma \text{ DRIVING MOMENTS}} \qquad 1$$

The effective weight $(\overline{W})$ is assumed to act through the centerline of the slice.

The normal force (P) acting perpendicular to the bottom of the slice is resolved as:

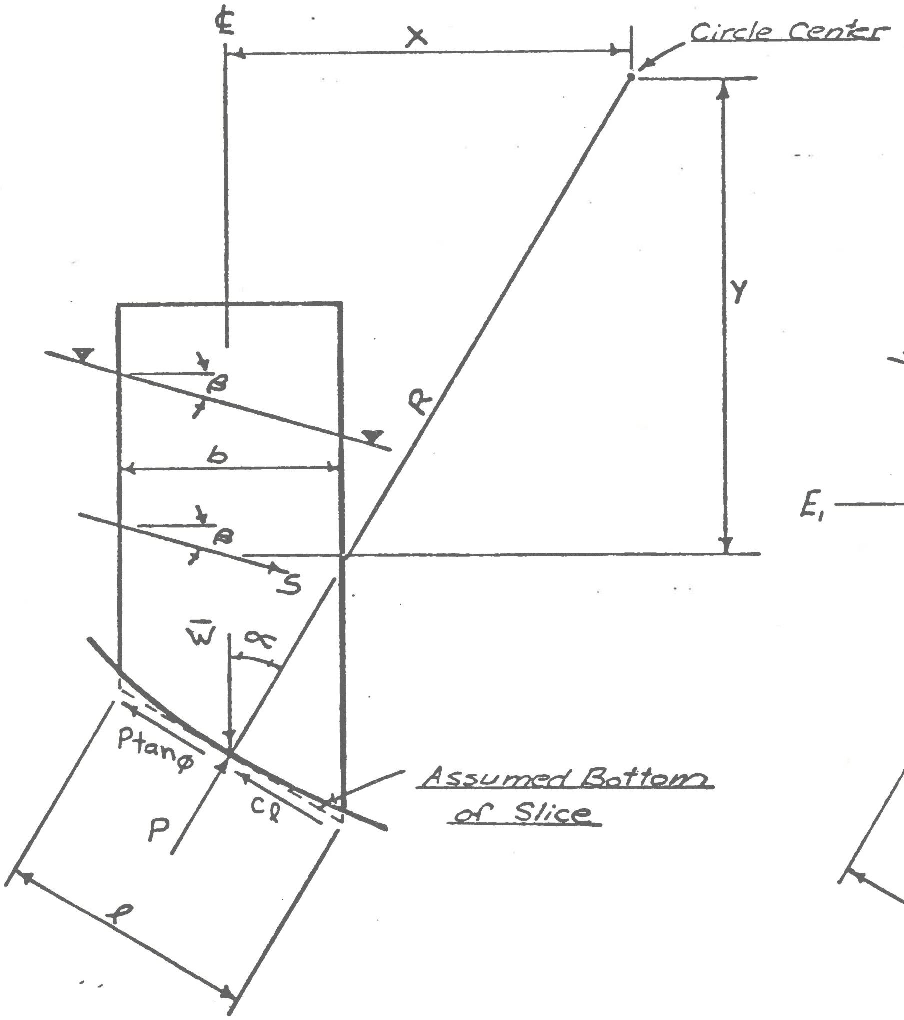


FIGURE V-1

New York State Method

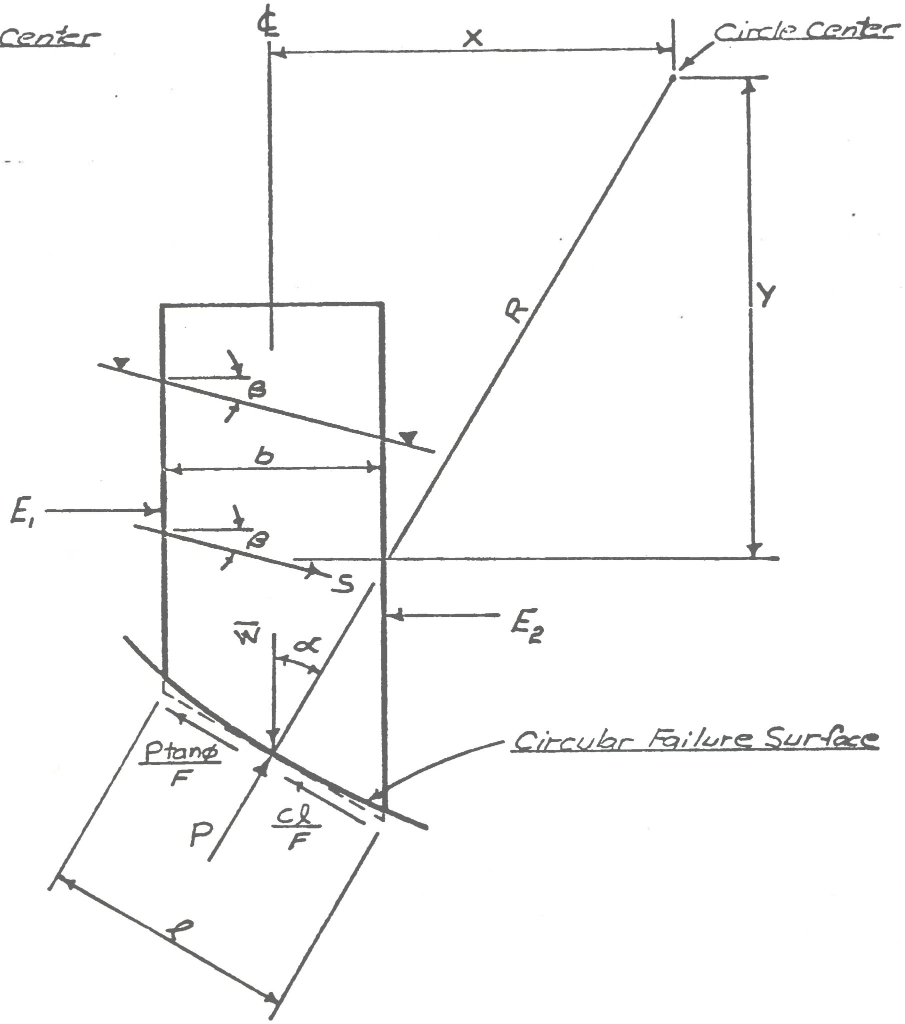


FIGURE V-2

Simplified Bishop Method by NYS Program

$$P = \overline{W} \cos\alpha \quad 2$$

where α is the angle that the radius (R) makes with the slice centerline.

The resisting moment due to friction is determined as:

$$PHIMOM = P(\tan\phi)\, R \quad 3$$

where ϕ is the angle of internal friction at the bottom of the slice.

Slice widths (b) are chosen to be sufficiently thin that a straight line tangent to the bottom of the slice will approximate the failure surface.

The length (ℓ) of the bottom of the slice is then found to be:

$$\ell = \frac{b}{\cos\alpha} \quad 4$$

And the resisting moment due to cohesion (c) is:

$$CHSMOM = c\ell R \quad 5$$

The water table makes an angle (β) with the horizontal. The seepage force (S) is assumed to act through the centroid of the submerged part of the slice and parallel to the surface of the water table:

$$S = \sin\beta \gamma_w V_s \quad 6$$

where $\sin\beta$ is the hydraulic gradient, γ_w is the unit weight of water, V_s is the volume of the submerged portion of the slice.

The seepage force is resolved into horizontal and vertical components. The driving moment due to the seepage force is found as:

$$SEPMOM = S(\sin\beta)x + S(\cos\beta)y \quad 7$$

where x is the horizontal distance from the circle center to the centerline of the slice, and y is the vertical distance from the circle center to the centroid of the submerged portion of the slice.

The small effect of the seepage force on the normal force is neglected.

The driving moment due to the effective weight of the soil is determined as:

$$\mathrm{DRVMOM} = \bar{W}x \qquad 8$$

The driving moment due to the weight of the soil becomes negative when the slice is beyond the circle center on the downslope side.

The equation for the New York State factor of safety now becomes:

$$\mathrm{FSNYS} = \frac{\Sigma\ \mathrm{PHIMOM} + \Sigma\ \mathrm{CHSMOM}}{\Sigma\ \mathrm{SEPMOM} + \Sigma\ \mathrm{DRVMOM}} \qquad 9$$

when equations 3, 5, 7 and 8 are substituted into equation 1.

2. The Simplified Bishop Equation (2)

Figure V-2 is a typical slice used in the derivation of the Simplified Bishop Equation. The side forces, E_1 and E_2, are assumed to be horizontal, i.e., having no vertical shearing components.

Summing moments about the circle center yields:

$$\Sigma\left[(\bar{W} + S\sin\beta)x + (S\cos\beta)y\right] = \Sigma(T\ell R) \qquad 10$$

T is the mobilized shearing resistance and is expressed by:

$$T = \frac{c}{F} + \frac{P\tan\phi}{\ell F} \qquad 11$$

where F is the Bishop factor of safety.

Substituting equation 11 into equation 10 and solving for F results in:

$$F = \frac{R\ \Sigma\left[c\ell + P\tan\phi\right]}{\Sigma\left[(\bar{W} + \sin\beta)x + (S\cos\beta)y\right]} \qquad 12$$

The normal force (P) is found by summing forces on the slice in a vertical direction and solving for P:

$$P = \frac{\bar{W} + S\sin\beta - \frac{c\ell}{F}\sin\alpha}{\cos\alpha + \frac{\tan\phi}{F}\sin\alpha} \qquad 13$$

From the geometry of the slice:

$$x = R \sin \alpha \qquad 14$$

$$\text{and } \ell = \frac{b}{\cos\alpha} \qquad 15$$

Substituting equations 13, 14, and 15 into equation 12 yields:

$$F - F \left\{ \frac{\Sigma \left[\frac{cb + (\overline{W} + S \sin\beta) \tan\phi}{F \cos\alpha + \tan\phi \sin\alpha} \right]}{\Sigma \left[(\overline{W} + S \sin\beta) \sin\alpha + (S \cos\beta) \frac{y}{R} \right]} \right\} = 0 \qquad 16$$

An iterative approach is used to solve the equation since the factor of safety (F) appears both inside and outside the summation.

The Newton-Raphson iterative technique is used and is expressed by:

$$F_1 = F_o - \frac{f(F_o)}{f'(F_o)} \qquad 17$$

where F_o is the assumed factor of safety, F_1 is the computed factor of safety, $f(F_o)$ is a function of F_o that is equal to zero, and $f'(F_o)$ is the partial derivative of $f(F_o)$ with respect to F_o.

Therefore from equation 16:

$$f(F_o) = F_o - F_o \left\{ \frac{\sum \left[\frac{cb + (\overline{W} + S \sin\beta) \tan\phi}{F_o \cos\alpha + \tan\phi \sin\alpha} \right]}{\sum \left[(\overline{W} + S \sin\beta) \sin\alpha + (S \cos\beta) \frac{y}{R} \right]} \right\} \qquad 18$$

Differentiating equation 18 with respect to F_o gives:

$$f'(F_o) = 1 - \frac{\sum \left\{ \frac{\left[cb + (\overline{W} + S \sin\beta) \tan\phi \right] \left[\tan\phi \sin\alpha \right]}{\left[F_o \cos\alpha + \tan\phi \sin\alpha \right]^2} \right\}}{\Sigma \left[(\overline{W} + S \sin\beta) \sin\alpha + (S \cos\beta) \frac{y}{R} \right]} \qquad 19$$

Substituting equations 18 and 19 into equation 17 yields:

$$F_1 = F_o \left\{ \frac{\Sigma \left[(\overline{W} + S \sin\beta) \sin\alpha + (S \cos\beta) \frac{y}{R} \right] - \sum \left[\frac{cb + (\overline{W} + S \sin\beta) \tan\phi}{F_o \cos\alpha + \tan\phi \sin\alpha} \right]}{1 - \Sigma \left[(\overline{W} + S \sin\beta) \sin\alpha + (S \cos\beta) \frac{y}{R} \right] - \sum \left[\frac{\{cb + (\overline{W} + S \sin\beta) \tan\phi\} \tan\phi \sin\alpha}{\{F_o \cos\alpha + \tan\phi \sin\alpha\}^2} \right.} \right. \qquad 20$$

Equation 20 is the form of the Bishop Equation used by the computer program.

The procedure followed by the computer is to calculate the factor of safety by the New York State Method first. 0.20 is added to this factor of safety and set equal to F_o, the assumed factor of safety used in the Bishop Equation. F_1 is calculated by equation 20. If F_1 is not approximately equal to F_o, the computed F_1 is used as F_o in the equation and a new factor of safety is computed. This procedure is followed until the new factor of safety is within 0.001 of the previous factor of safety.

α becomes negative for all slices on the downslope side of the circle center. For α between 0 and -90^o, $\sin\alpha$ is negative and $\cos\alpha$ is positive. If F_o is equal to $\tan\phi$ and $\alpha = -45^o$, the term $\left[F_o\cos\alpha + \tan\phi\sin\alpha\right]$ becomes zero and renders equation 20 invalid. To eliminate the problem in most cases, the program does not continue when a New York State safety factor of less than 0.6 is encountered (FSNYS + 0.2 = F_o in the Bishop Equation). Therefore the lower limit for F_o is 0.8.

B. LEASE I Computer Program

The LEASE I program computes factors of safety by essentially the same methods as the New York State program, i.e., by the Normal Method of Slices and by the Simplified Bishop Equation.

The main differences in the derivations are that seepage forces are not considered, and total weight (W) rather than effective weight ($\overline{W}$) of a slice is used. Therefore pore pressures at the failure surface are introduced into the derivations.

1. The Normal Method of Slices (1)

Figure V-3 shows a typical slice from which the factor of safety for the Normal Method of Slices is derived.

As before the general equation is:

$$F.S. = \frac{\Sigma \text{ RESISTING MOMENTS}}{\Sigma \text{ DRIVING MOMENTS}} \qquad 21$$

The resisting moment is given by:

$$\text{RESIST MOM} = R(c\ell + \overline{P}\tan\phi) \qquad 22$$

where $\overline{P}$ is the effective normal force on the bottom of the slice and ℓ is $\frac{b}{\cos\alpha} = b\sec\alpha$. 23

The total normal force (P) on the bottom of the slice is:

$$P = \overline{P} + U = W\cos\alpha \qquad 24$$

where U is the pore water force normal to the bottom of the slice and W is the total weight of the slice.

$$U = ub\sec\alpha \qquad 25$$

where u is the pore pressure at the bottom of the slice.

Therefore from equations 24 and 25:

$$\overline{P} = W\cos\alpha - ub\sec\alpha \qquad 26$$

The resisting moment now becomes:

$$\text{RESIST MOM} = R\left[cb\sec\alpha + (W\cos\alpha - ub\sec\alpha)\tan\phi\right] \qquad 27$$

The driving moment is:

$$\text{DRIV MOM} = Wx = WR\sin\alpha \qquad 28$$

Substituting equations 27 and 28 into equation 21 gives the factor of safety by the Normal Method of Slices:

$$F.S. = \frac{\Sigma\left[cb\sec\alpha + (W\cos\alpha - ub\sec\alpha)\tan\phi\right]}{\Sigma W\sin\alpha} \qquad 29$$

The radius (R) cancels.

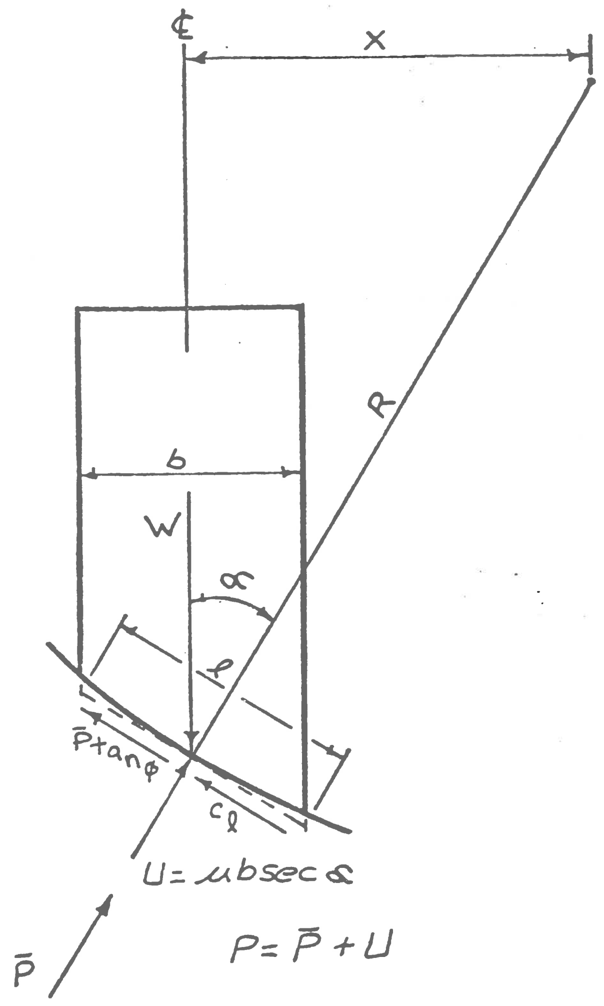


FIGURE V-3
Normal Method

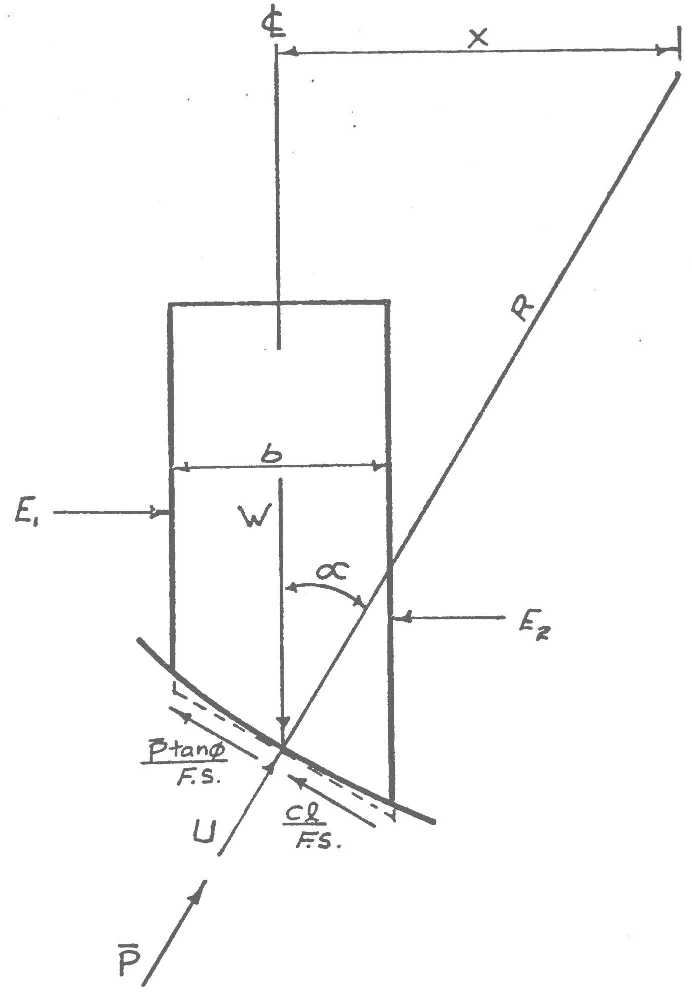


FIGURE V-4
Simplified Bishop Method by LEASE I Program

When water submerges the toe of a slope as shown in Figure V-5, equation 29 must be altered to take into consideration the resisting moment contributed by the standing water. For this case the safety factor becomes:

$$F.S. = \frac{\Sigma\left[cb\sec\alpha + (W\cos\alpha - ub\sec\alpha)\tan\phi\right]}{\Sigma(W\sin\alpha) - F\,\frac{d}{R}} \qquad 30$$

The weight of standing water on the slope should be included in the total weight of the submerged slices.

2. The Simplified Bishop Equation (1)

Figure V-4 shows a typical slice for the Simplified Bishop Method. The difference in this derivation from the foregoing one is in the evaluation of the effective normal force ($\overline{P}$). $\overline{P}$ is found from the vertical equilibrium of the forces on the slice.

Summing forces vertically yields:

$$W = P\cos\alpha + \left(\frac{c\ell}{F.S.} + \frac{\overline{P}\tan\phi}{F.S.}\right)\sin\alpha \qquad 31$$

Substituting equations 23, 24, and 25 into equation 31 gives:

$$W = ub + \overline{P}\cos\alpha + \frac{1}{F.S.}\,(cb\sec\alpha + \overline{P}\tan\phi)\sin\alpha \qquad 32$$

and solving for $\overline{P}$ results in:

$$\overline{P} = \frac{W - ub - cb\tan\alpha/F.S.}{\cos\alpha + \tan\phi\,\sin\alpha/F.S.} \qquad 33$$

By substituting equation 33 into equation 22 the resisting moment becomes:

$$\text{RESIST MOM} = R\left[cb + (W - ub)\tan\phi\right]\frac{1}{\cos\alpha + \frac{\tan\phi\sin\alpha}{F.S.}} \qquad 34$$

From equations 28 and 34 the Bishop factor of safety results:

$$F.S. = \frac{\Sigma\left[cb + (W - ub)\tan\phi\right]\frac{1}{\cos\alpha + \frac{\tan\phi\sin\alpha}{F.S.}}}{\Sigma\, W\sin\alpha} \qquad 35$$

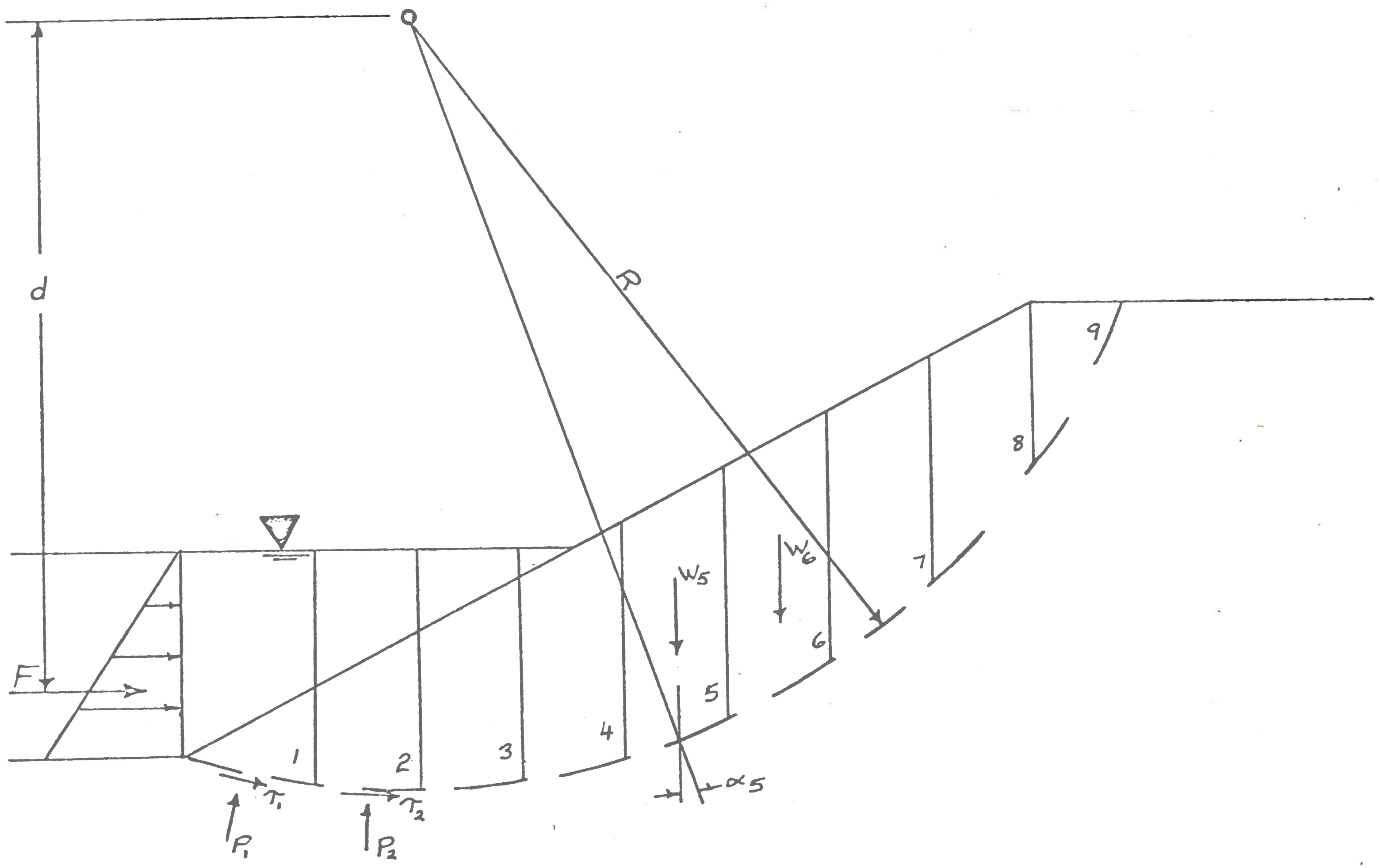


FIGURE V-5

Submerged Toe of Slope

C. Some Comments on the New York State and LEASE I Programs (1), (8)

In addition to the assumptions stated in the derivations several other assumptions are inherent. These are:

1) The shearing resistance is fully mobilized along the circular failure arc.

2) The factors of safety of the cohesive components of strength are equal to those of the frictional components of strength.

3) The factor of safety is the same for all slices.

Either total stress or effective stress analysis may be used with either program by inputting the appropriate strength parameters, i.e., $\overline{c}$ and $\overline{\phi}$ for effective stress analysis and c and ϕ for total stress analsis.

The methods of analyses used are simplified methods and therefore the computed factors of safety contain some error. The error is introduced because the statics of the slices is not completely satisfied. The greatest source of error arises from the method of evaluating the normal force at the bottom of the slice. In the Simplified Bishop Method where the vertical shear forces on the slice are ignored, the error introduced in most cases ranges from less than 2 percent (usually) to 7 percent of the most accurate solution. However, the error is much greater in the Normal Method of Slices where all side forces are ignored. In extreme cases it can be as little as 40 percent of the most correct solution. The large errors usually occur where the slopes are submerged and the total weight of a slice is used together with pore pressures on the failure surface. In this case the error can be minimized by using buoyant weights. However, a significant amount of error remains due to the approximate method for computing the normal force.

D. Operation and Use of the New York State and LEASE I Programs

An example problem is used to illustrate the operation and use of the New York State and LEASE I programs. See Figure V-6. The example is analogous to the embankment slopes under investigation. The embankment is 20 feet high and has a slope of 2.5 horizontal to 1 vertical. The ground water table is one foot below the original ground surface. After a boring, sampling and testing program, the embankment soil properties are evaluated. The embankment section is divided into layers or zones of characteristic soil properties. These properties are shown in Figure V-6.

1. Example Analysis by the New York State Program (2)

Figure V-7 shows the cross sectional and soil property information that must be considered in the New York State Program. The soil boundary and water table lines are described by a series of numbered straight lines. The soil boundary lines are denoted by the circled numbers (e.g., ①) and the water tables lines by the squared numbers (e.g., $\boxed{1}$).

The number of soil boundary lines is limited to 50. The number of water table lines is limited to 10.

The straight line segments must be numbered in specific order, i.e., no soil line should have a lower number than the soil line directly above it, and all soil and water table lines should be numbered from left to right.

The straight line segments are defined by a coordinate system with the highest point on the embankment section designated as the origin (see Figure V-7). Therefore, the horizontal coordinate increases in a down-slope direction. The vertical coordinates are zero or negative.

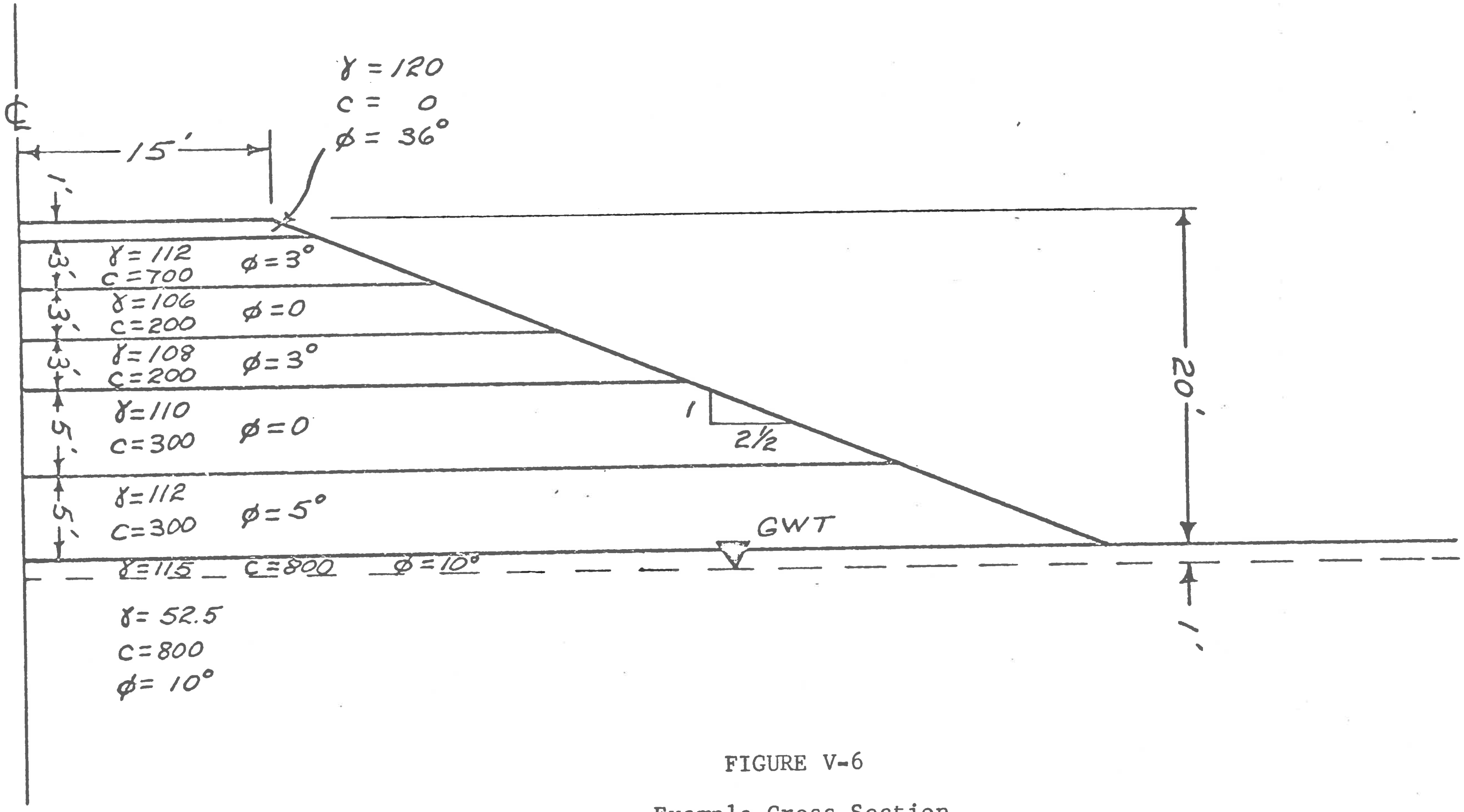


FIGURE V-6

Example Cross Section

Soil materials are described by assigning soil properties to the soil lines that lie directly above the soil. The soil properties that must be assigned to each soil line are the effective unit weight (buoyant unit weight when below water table) in pounds per cubic foot, the unit cohesion in pounds per square foot, and the angle of internal friction in degrees.

To prevent the program from analyzing trial circles to an infinite depth a soil of great strength beneath the embankment must be input (soil underlying soil line ⑯ in Figure V-7).

Table V-1 defines the variables used to describe the cross section and soil properties in the computer program.

An initial circle center of the failure surface must be described before a search for minimum factor of safety can be made. This initial circle center should be a reasonable estimate of the critical circle center. Its coordinates are referenced to the same origin as the soil lines and water lines. The initial circle center is described by HORZON, the horizontal coordinate of the circle center in feet (25 feet in example, see Table V-2), VERTCL, the vertical coordinate in feet (0 feet in example), and RADIUS, the radius of the circle in feet (20 feet in example). No part of the failure surface can be higher than the circle center. Therefore, in most cases the vertical coordinate is zero or positive.

The New York State Program searches for the minimum factor of safety by varying the circle radius and the location of the circle center. (The program determines slice widths from the geometry of the cross section and the radius of the trial circle. See Reference 2.) After the factor of safety has been found for the initial radius,

TABLE V-1

Cross Section and Soil Data

Name	Explanation
SOILHL(I)	Leftmost horizontal coordinate of soil line I, in feet.
SOILVL(I)	Leftmost vertical coordinate of soil line I, in feet.
SOILHR(I)	Rightmost horizontal coordinate of soil line I, in feet.
SOILVR(I)	Rightmost vertical coordinate of soil line I, in feet.
WEIGHT(I)	Effective unit weight of soil beneath soil line I, in pounds per cubic foot.
PHI(I)	Angle of internal friction of soil beneath soil line I, in degrees.
COHES(I)	Cohesion of soil beneath soil line I, in pounds per square foot.
WATRHL(I)	Leftmost horizontal coordinate of water table line I, in feet.
WATRVL(I)	Leftmost vertical coordinate of water table line I, in feet.
WATRHR(I)	Rightmost horizontal coordinate of water table line I, in feet.
WATRVR(I)	Rightmost vertical coordinate of water table line I, in feet.

the initial radius is increased by RADINC, the radius increment in feet (2 feet in example), and a new factor of safety is computed. This process is continued until a safety factor greater than the previous one is computed (note reason for underlying soil of great strength). The previous safety factor, which is the minimum, is stored.

The horizontal coordinate (HORZON) of the initial circle center is then increased by GRID, the grid system increment in feet (2 feet in example), and the minimum safety factor at the new circle center location is computed by increasing the radius as described above. The horizontal coordinate is again increased by GRID until the computed minimum factor of safety at the new circle center is greater than the previous minimum factor of safety.

The search now goes back to the original circle center and proceeds similarly in the opposite direction, i.e., decreasing the horizontal coordinate by GRID and calculating the minimum safety factors at the new circle centers.

After a minimum factor of safety is located on the horizontal line, the vertical coordinate is increased by GRID, and a search for minimum safety factor is made on the new horizontal line, starting at a horizontal coordinate equal to that of the critical circle previously located. The procedure continues until the minimum safety factor on a horizontal line is greater than the minimum on the horizontal line one grid increment below. The initial vertical coordinate is not decreased during the search to prevent the program from analyzing circles which are inconsistent with actual failure circles. Therefore, the initial vertical coordinate should be somewhat less than that of the anticipated critical circle center.

The search pattern is complete when a minimum safety factor is less than all the minimums at the 8 grid points surrounding it. If the critical circle center happens to be at the elevation of the initial circle center, the program will search only five surrounding locations since the search never proceeds in a downward direction from the original circle center.

The area of the search pattern is limited to 20 grid increments in the horizontal direction and 10 grid increments in the vertical direction.

It is possible for the critical circle center to lie outside the search area of the initial circle center. However, more than one initial circle center may be input. In the initialization data NUMCEN defines the number of starting centers (one in the example).

Other initialization data required are:

NSL	the number of soil boundary lines. (16 in the example)
NWL	the number of water lines. (one in the example)
INPUT	option to print out input data, 0 - No input data will be output. 1 - All input data will be output. (one in the example)
IALLFS	option to print out all safety factors, 0 - Only minimum safety factors will be output. 1 - All computed safety factors will be output. (one in the example)
ITER	option to search for minimum safety factor, 0 - Search on New York State safety factor. 1 - Search on Bishop safety factor. (one in the example)

Table V-2 summarizes all the input data required for analyzing the Example Problem with the New York State Program. The table explains where the data is to be punched on the computer cards. The correct order of data is as shown in the table, i.e., initialization data--first, cross section and soil data--second, etc.

If NUMCEN had been two, an additional Initial Circle Data card would have been required to describe the second initial circle center.

Appendix E contains the output for the Example Problem by the New York State Program.

The first information listed is a reprint of the input data. This information could have been omitted by inputting a "0" for INPUT on the Initialization Data card.

Below the input data all computed factors of safety by both the New York State and the Bishop methods are printed. The coordinates and radius of all the trial circles analyzed are noted also. The option not to print this information could have been made by inputting "0" for IALLFS in the Initialization Data.

Finally, the minimum factor of safety (1.258) and the coordinates and radius of the critical circle are printed. The search was by the Bishop Factor of Safety. Had a search by the New York State Factor of Safety been desired, a "0" could have been punched for ITER on the Initialization Data card.

Looking closer at the final results of the program, it can be seen that the minimum factor of safety equal to 1.258 is erroneous. The critical circle center coordinates (HORZON = 25', VERTCL = 38') and radius (RADIUS = 58') describes a circular arc which does not intersect the described embankment surface twice, i.e., a portion of the

TABLE V-2

NYS Card Input Data for Example Problem

Initialization Data (Each term occupies two columns - FORMAT 6I2)

NSL	NWL	INPUT	IALLFS	ITER	NUMCEN
16	1	1	1	1	1

No. cards = 1

Cross Section And Soil Data (Each term occupies ten columns - FORMAT 7F10.4)

SOILHL	SOILVL	SOILHR	SOILVR	WEIGHT	PHI	COHES
-15.	0.	0.	0.	120.	36.	0.
0.	0.	2.5	-1.	120.	36.	0.
-15.	-1.	2.5	-1.	112.	3.	700.
2.5	-1.	10.	-4.	112.	3.	700.
-15.	-4.	10.	-4.	106.	0.	200.
10.	-4.	17.5	-7.	106.	0.	200.
-15.	-7.	17.5	-7.	108.	3.	200.
17.5	-7.	25.	-10.	108.	3.	200.
-15.	-10.	25.	-10.	110.	0.	300.
25.	-10.	37.5	-15.	110.	0.	300.
-15.	-15.	37.5	-15.	112.	5.	300.
37.5	-15.	50.	-20.	112.	5.	300.
-15.	-20.	50.	-20.	115.	10.	800.
50.	-20.	70.	-20.	115.	10.	800.
-15.	-21.	70.	-21.	52.5	10.	800.
-15.	-35.	70.	-35.	90.	40.	5000.

No. cards = No. soil lines

continued next page

TABLE V-2 (continued)

NYS Card Input Data for Example Problem

Water Table Description (Each term occupies ten columns - FORMAT 4F10.4)

WATRHL	WATRVL	WATRHR	WATRVR	
-15.	-21.	70.	-21.	No. cards = No. water lines

Initial Circle Data (Each term occupies ten columns - FORMAT 5F10.4)

HORZON	VERTCL	RADIUS	RADINC	GRID
25.	0.	20.	2.	2.

No. cards = No. initial circle centers

circular arc lies to the left of the embankment section that was input. (The problem cannot occur in the LEASE I Program.) This portion of the circular arc lies in an area which offers no weight or shearing resistance because no soil was input in this area. The problem could be remedied by extending the soil lines farther horizontally to the left. However, the correct minimum safety factor and critical circle can be found by searching through the printed factors of safety in the output. (This is one advantage of having all computed factors of safety output.) The lowest factor of safety for which the critical circle intersects the described embankment surface twice is 1.377. The critical circle is shown in Figure V-8.

2. Example Analysis by the LEASE I Program (1)

Figure V-9 illustrates the example embankment section as described for the LEASE I program. The problem is defined by an X-Y coordinate plane. The X-direction must be horizontal and positive. The Y-direction must be positive upward.

The cross section is described by arbitrarily selected points connected by straight line segments representing the embankment surface and soil boundaries.

Each point is assigned a unique identifying number (Circled number, see Figure V-9) and must have X and Y coordinates. There are no restrictions on the set of identifying point numbers except that none may exceed 17258 in magnitude. Each identifying point and its coordinates must be input on a separate card. The Point Data may be input as follows:

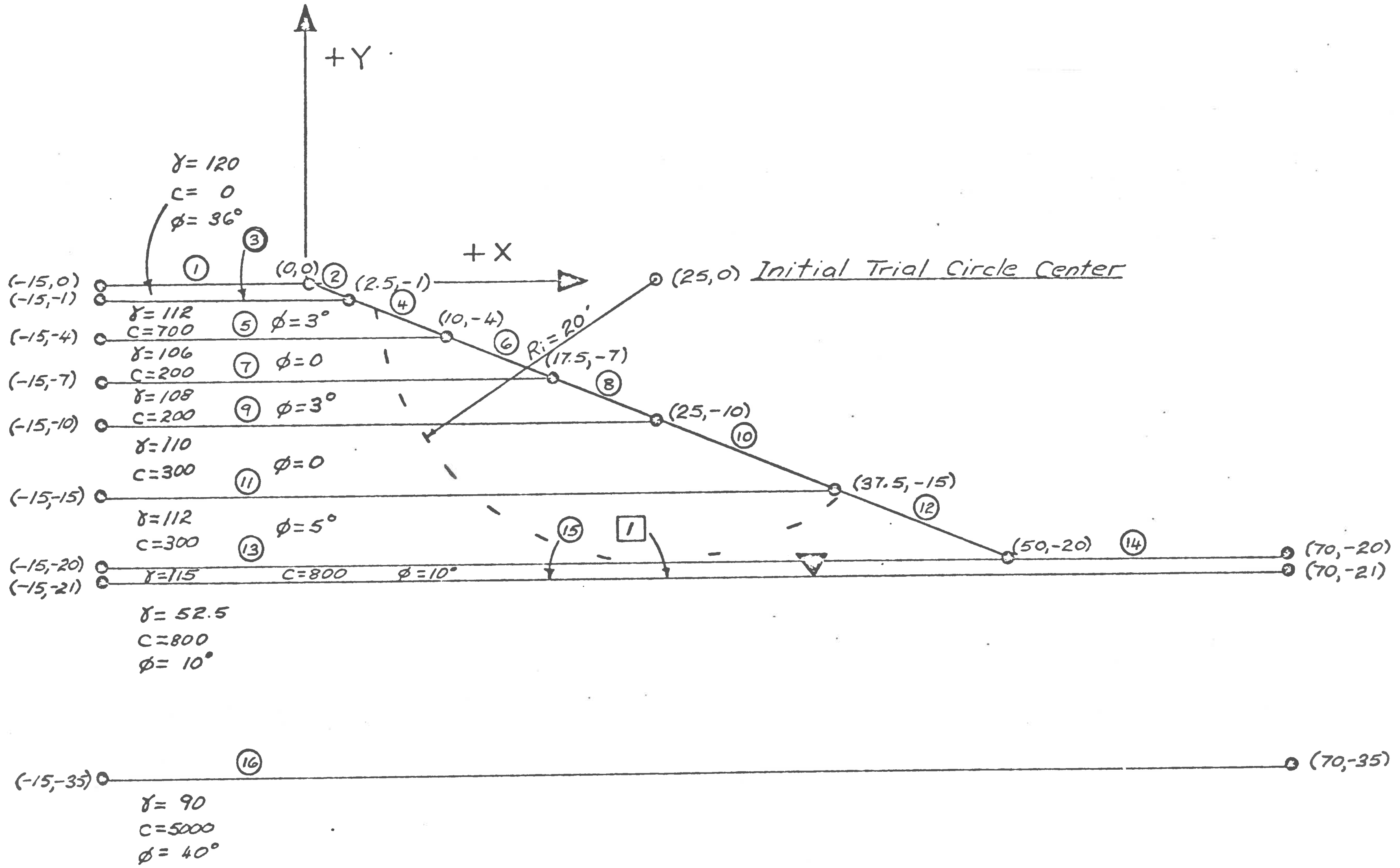


FIGURE V-7

Section Description by NYS Program

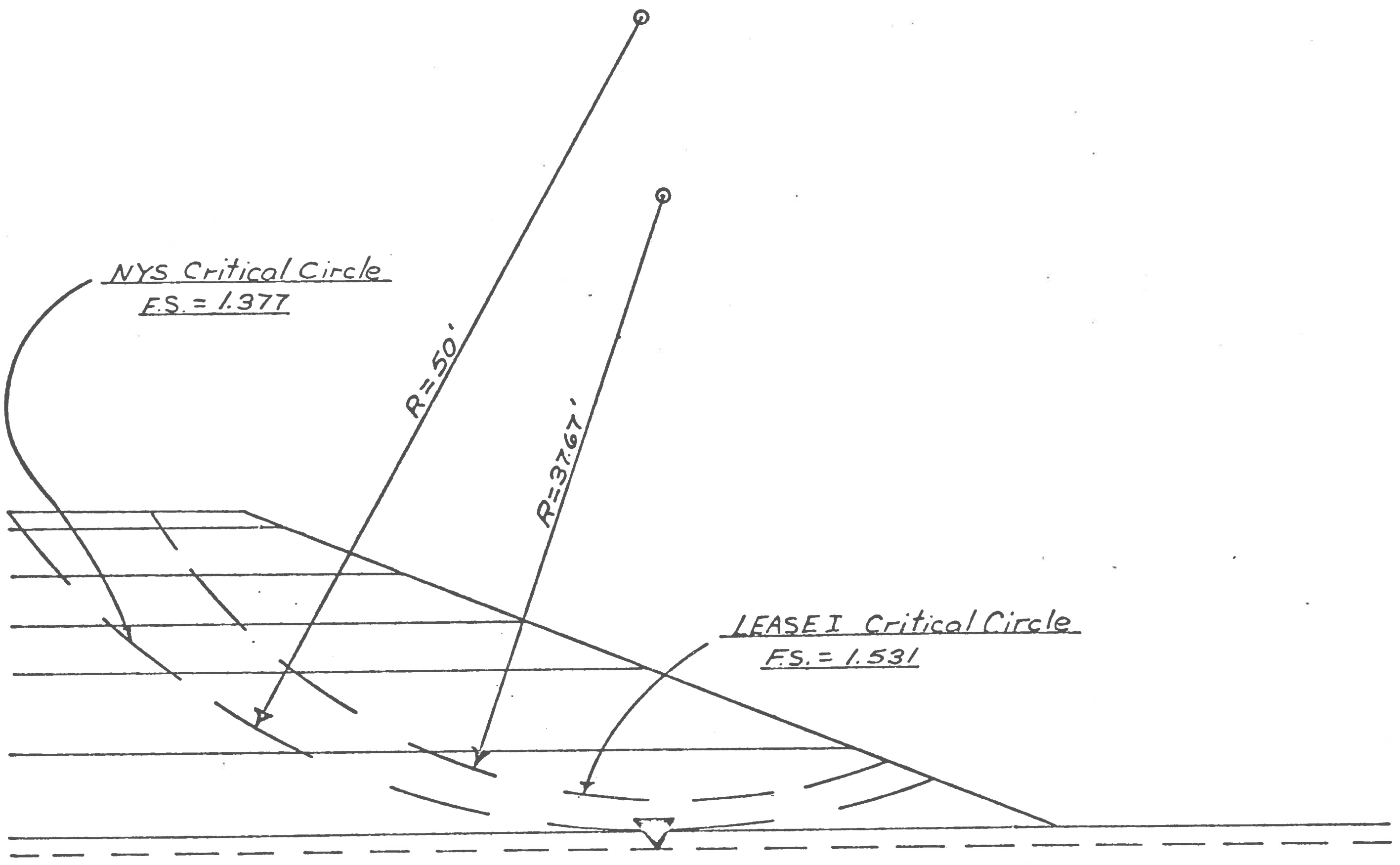


FIGURE V-8

NYS And LEASE I Critical Circles

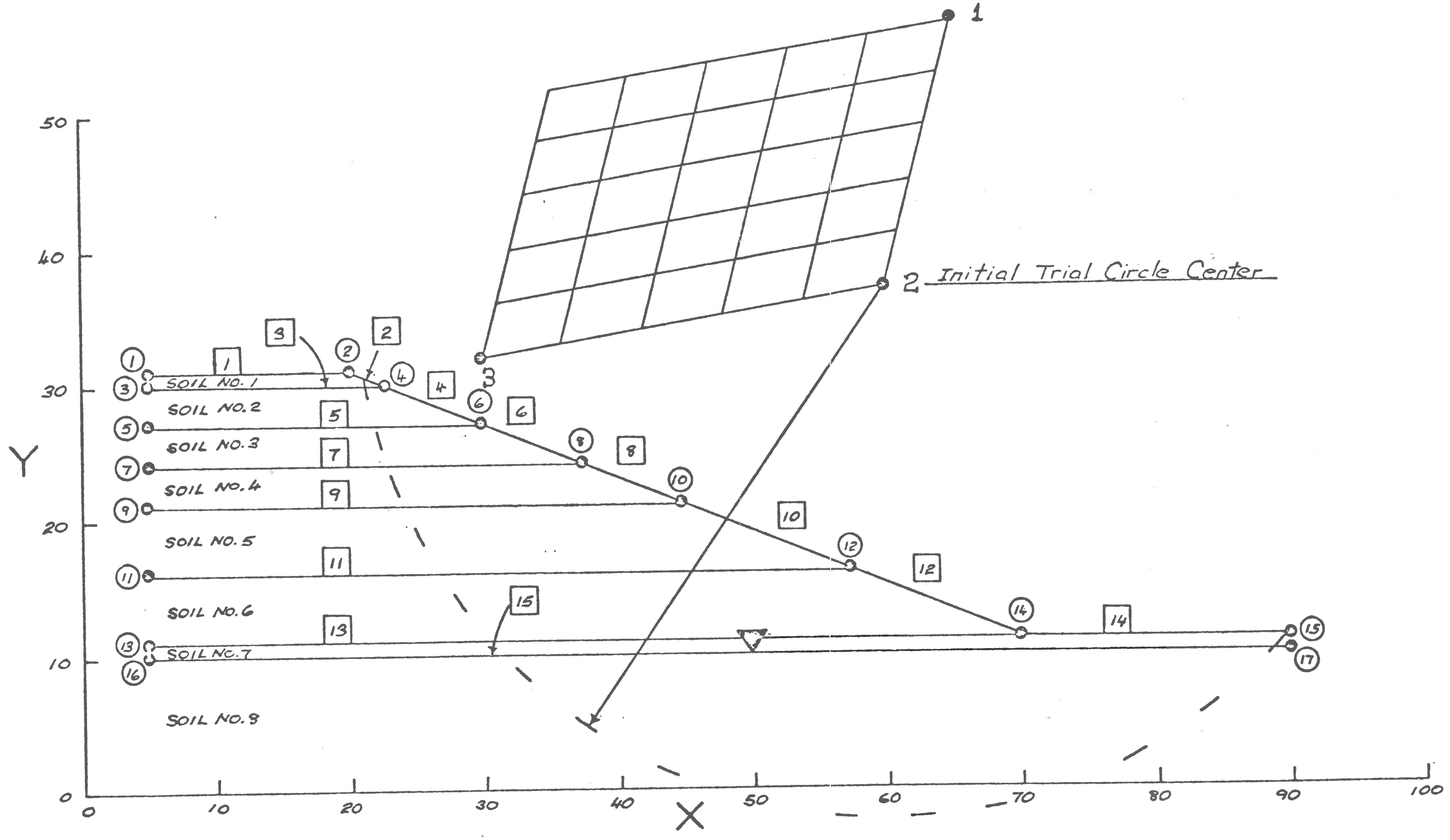


FIGURE V-9

Section Description by LEASE I Program

POINT DATA (See Table V-3)

$$\begin{array}{ccc} a_1 & X_1 & Y_1 \\ a_2 & X_2 & Y_2 \\ a_3 & X_3 & Y_3 \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot \\ a_n & X_n & Y_n \end{array}$$

where a_i is the identifying number of the point and X_i, Y_i are the coordinates of the point.

Each line segment must be assigned an identifying number (squared number in Figure V-9). Line identifying numbers may duplicate point identifying numbers.

Line Data may be input as follows:

LINE DATA

$$\begin{array}{cccc} a_1 & b_1 & c_1 & d_1 \\ a_2 & b_2 & c_2 & d_2 \\ a_3 & b_3 & c_3 & d_3 \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ a_n & b_n & c_n & d_n \end{array}$$

where a_i is the identifying number of the line, b_i is the identifying number of the point at either end of the line, c_i is the identifying number of the point at the other end of the line, and d_i is the identifying number of the soil lying directly beneath the line (e.g., soil No. 2 beneath line 4 in Figure V-9).

One restriction to the Line Data is that no line should be input that is not immediately underlain by soil. This problem occurs with overhanging slopes. A remedy is to treat the void beneath the overhang as a soil with no weight or strength.

Vertical lines that are segments of the embankment surface must be input. The fourth item of information on the Line Data cards (d_i), designating the soil underlying the line, is left blank in this case. Vertical lines that represent only soil boundaries (not surface boundaries) within the embankment should not be input since this information is unnecessary for proper analysis.

Another limitation is that the line having the highest Y-coordinate must be a segment of the embankment surface.

"Soil" is defined as the material underlying the line segments. This material is normally soil but may be concrete, air, etc.

Soil Data input required are unit weight and the strength parameters, ϕ and c. If effective stress analysis is used, pore pressure information is also required. See Reference 1 for discussion of how pore pressures are handled.

For total stress analysis the Soil Data input is:

$$\begin{array}{cccc} \multicolumn{4}{c}{\text{SOIL DATA}} \\ i_1 & a_1 & b_1 & c_1 \\ i_2 & a_2 & b_2 & c_2 \\ i_3 & a_3 & b_3 & c_3 \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ i_n & a_n & b_n & c_n \end{array}$$

where i_i is the identifying number for the soil used on the Line Data cards, a_i is the unit weight in force per distance cubed, b_i is the cohesion in force per distance squared, and c_i is the friction angle in degrees.

Two options are available for controlling the trial circle centers.

In the first a grid for centers of trial circles is specified. The grid is described by the following input:

GRID 1 X_1 Y_1 2 X_2 Y_2 3 X_3 Y_3 a b

where 1, 2 and 3 are the defining points of the grid shown on Figure V-9, X_i, Y_i are the coordinates of the labeled points 1, 2 and 3, "a" is the number of increments from point 2 to point 1, and "b" is the number of increments from point 2 to point 3.

The initial center where factors of safety are computed is at point 2. The grid is covered by rows parallel to line 2-1 with the first center in each row on line 2-3.

The second option makes use of a search outline. A search is made for the factor of safety that has a smaller value than at any adjacent trial center.

The card input is:

BEGIN AT X Y a b

where X, Y are the coordinates of the initial center and "a", "b" are the size of step in the X-direction and the Y-direction, respectively.

The search is identical to that described in the New York State Program. The step sizes "a" and "b" are equivalent to GRID in the New York State Program. However, in the LEASE I search when a safety factor is found which is smaller than at the adjacent trial centers, the step sizes "a" and "b" are divided by four and the search repeated using the smaller step sizes. It should be mentioned that this search procedure may locate a relative minimum rather than an absolute minimum factor of safety. Therefore, a grid should be used in the initial analysis to locate the approximate area of the critical circle center. The search routine should then be used to refine the analysis.

Individual circles may be analyzed by using the Do Only command:

DO ONLY X Y r

where X, Y are the coordinates of the circle center and r is the radius of the circle. Any number of these commands may be input consecutively.

Stored slice data are used in the computations of factors of safety for each trial circle. See Reference 1.

At each trial circle center the first circle analyzed has a maximum radius. This maximum radius is the largest radius that will intersect the described embankment surface twice. The radius is successively shortened by:

$$R = 0.06(R_{max} - R_{tan}) \tag{36}$$

where R_{max} is the largest radius, and R_{tan} is the radius that will just touch the slope surface.

The smallest circle analyzed is slightly larger than necessary to just touch the slope because of the magnitude of the decrements to the radius.

Options are available for restricting the maximum or minimum radius. See Reference 1.

The total input required to analyze the Example Problem is shown in Table V-3. Note in Figure V-9 and in Table V-3 that the water table is treated as soil boundary and the buoyant unit weight of the soil underlying the water table is used. Also note that a grid is specified for trial circle centers.

The first card of the data deck must contain the statement, LEASE, punched in columns one through five. The last card must contain FINISH, punched in columns one through six.

TABLE V-3

LEASE I Card Input Data for Example Problem

```
LEASE            . . . . . . . . . . One card.  Statement begins col. 1.
POINT DATA       . . . . . . . . . . One card.  Statement begins col. 7.

 1    5     31 . . . . . . . . . . . No. cards = No. points
 2   20     31 . .                   1st term occupies cols. 7-10.
 3    5     30                       2nd term occupies cols. 11-15.
 4   22.5   30                       3rd term occupies cols. 16-20.
 5    5     27
 6   30     27
 7    5     24
 8   37.5   24
 9    5     21
10   45     21
11    5     16
12   57.5   16
13    5     11
14   70     11
15   90     11
16    5     10
17   90     10

LINE DATA          . . . . . . . . . One card.  Statement begins col. 7.

 1    1    2   1 . . . . . . . . . . No. cards = No. soil lines
 2    2    4   1                     1st term occupies cols. 7-10.
 3    3    4   2                     2nd term occupies cols. 11-15.
 4    4    6   2                     3rd term occupies cols. 16-20.
 5    5    6   3                     4th term occupies cols. 21-25.
 6    6    8   3
 7    7    8   4
 8    8   10   4
 9    9   10   5
10   10   12   5
11   11   12   6
12   12   14   6
13   13   14   7
14   14   15   7
15   16   17   8
```

(continued on next page)

TABLE V-3
(continued)
LEASE I Card Input Data for Example Problem

```
SOIL DATA              . . . . . . . One card.  Statement begins col. 7.

1   120        0   36 . . . . . . . No. cards = No. soils.
2   112      700    3               1st term occupies cols. 7-10.
3   106      200    0               2nd term occupies cols. 11-15.
4   108      200    3               3rd term occupies cols. 16-20.
5   110      300    0               4th term occupies cols. 21-25.
6   112      300    5
7   115      800   10
8    52.5    800   10

GRID  1  65  57  2  60  37  3  30  32  5  5  . . One card.  Statement
                                   begins col. 7.  Each term spaced
                                   by two blank cols.

FINISH . . . . . . . . . . . . . . One card.  Statement begins col. 1.
```

All cross section and soil data input prior to GRID, BEGIN AT, or DO ONLY may be input in any order.

The LEASE I output for the Example Problem is contained in Appendix F.

The input data is printed out first. The second information printed is the ORDERED LINE ARRAY and the BNDS ARRAY. This information has to do with the organization of cross section data that may have been input out of order. The operation is necessary before factors of safety can be computed. See Reference 1.

Computed factors of safety at each trial center are printed next. The factors of safety by both the Normal and Bishop Methods are recorded.

The minimum factor of safety by the Bishop Method (1.531) and the coordinates and radius of the critical circle are reported at the end of the print out. The critical circle is shown in Figure V-8.

3. Some Comments on the Example Problem

The minimum factors of safety and critical circles computed by the two programs appear not to compare favorably. See Figure V-8. However, the discrepancy arises from the different search methods used by the programs. The NYS Program used a search routine whereas the LEASE I Program used an explicitly described grid. The LEASE I search analyzed circles at trial centers which were more widely spaced. The trial circle centers were located at the grid intersections which were spaced four feet parallel to line 2-3 and six feet parallel to line 2-1. The NYS search covered a larger area, and the spacing of trial circle centers was much closer. . . two feet. It should be noted that the NYS critical circle center lies outside the LEASE I grid search area. This is the reason a lower factor of safety was computed by the NYS program.

A better comparison of the two programs results if a NYS trial circle is made to almost match the LEASE I critical circle. A comparable circle is contained in the printed output of the NYS Program. See Appendix E. Figure V-10 shows the comparison. The NYS safety factor (1.544) compares well with the LEASE I safety factor (1.531). If the circles were made to exactly match, the computed factors of safety would be almost identical.

Further explanation of the development and use of the slope stability computer programs may be consulted in References 1 and 2.

E. Considerations for the Analysis of Embankment Slopes in Northeast Arkansas

An interesting result of the computer analyses of the Example Problem is that both programs found the slope to be "safe" even though low strength values were input for the embankment soils. The strength values for the embankments under investigation are considerably higher than those in the Example. . . yet these embankment slopes failed. The evidence suggests that something more entered into the mechanics of failure, other than low strength soils.

Observations indicate that the soil in Northeast Arkansas is not volumetrically stable, i.e., the soil undergoes shrinkage and cracking during the dry season. Crack development at the top of an embankment slope is the probable first step in the mechanism of failure. During the wet season the cracks fill with water. The shearing resistance along the lengths of the cracks is very small or zero. The water in the cracks exerts a hydraulic pressure against a potential failure plane. The soil at the base of the cracks becomes saturated and softens. If the crack development is deep, the hydraulic force great, and the

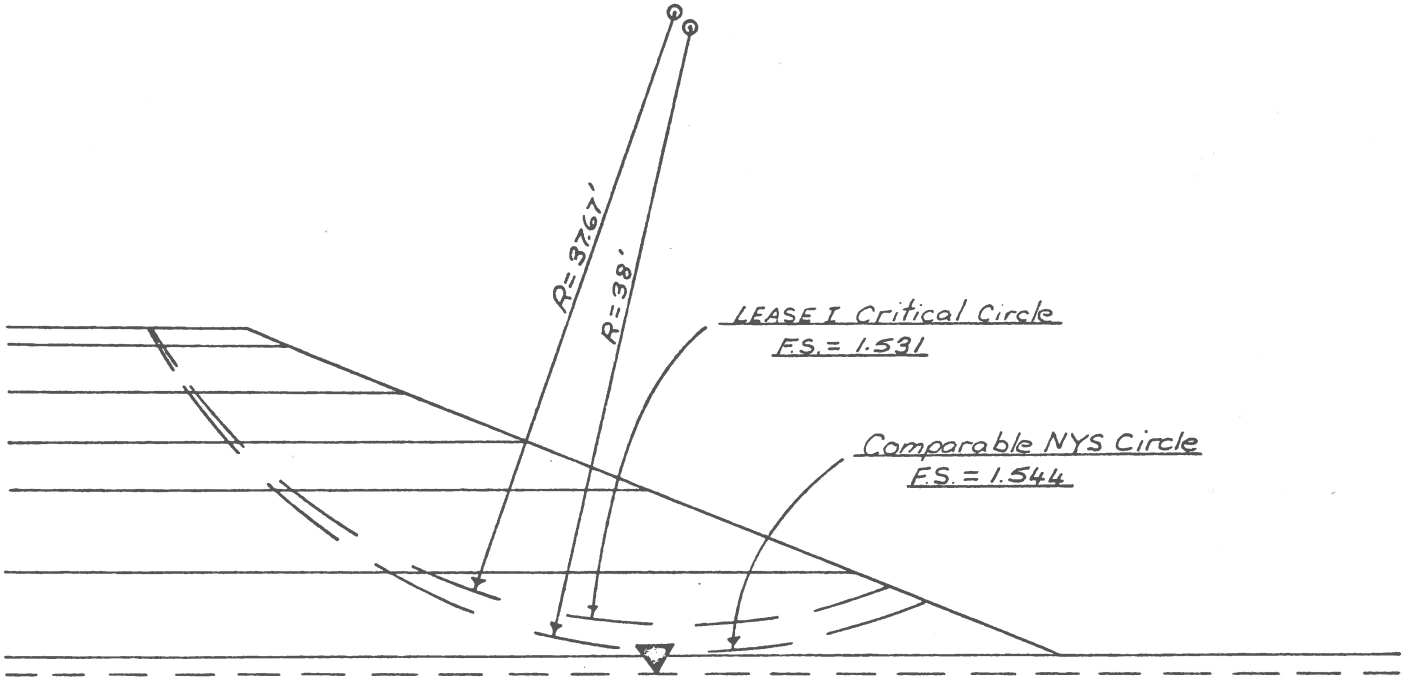


FIGURE V-10

Comparison of NYS and LEASE I Analyses

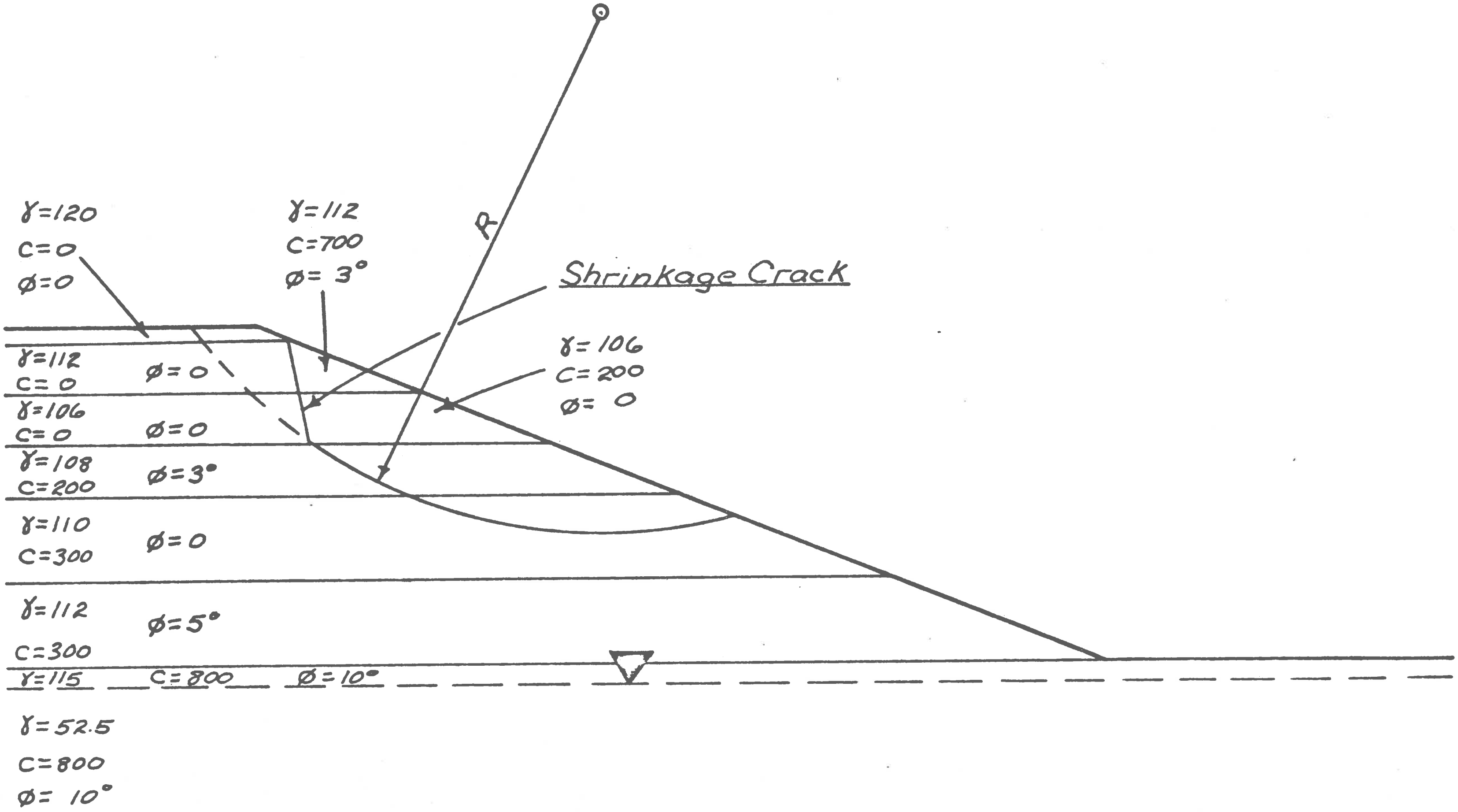


FIGURE V-11

Shrinkage Crack Consideration in Analysis soil softened enough, failure ensues. For a reasonable stability analysis to be made on the embankment slopes of Northeast Arkansas, this failure mechanism should be kept in mind.

Figure V-11 shows a possible way of considering the problem for analysis with the computer programs. A crack is input as a soil boundary in the cross section, the depth of crack being estimated from cross sections of the failed slope. The soil lying behind the crack is assigned unit weight but no strength values. Figure V-11 shows the critical circle that may result. The strengthless soil within the dashed portion of the critical circle would act as a driving force in the computation of the minimum safety factor. This would partially compensate for the lack of a hydraulic force. The actual failure surface would follow the crack down to the solid portion of the critical circle. To prevent circles from being analyzed which are inconsistent with actual failure surfaces, a zone of strengthless soil of specified width behind the crack may need to be input. See Figure V-12. The width of this zone may be the estimated width of crack development at the top of the slope.

The considerations outlined above should result in computed factors of safety which more closely represent the conditions at the times of failure. The procedure and results of the stability analyses on the failures being studied will be presented in a subsequent paper.

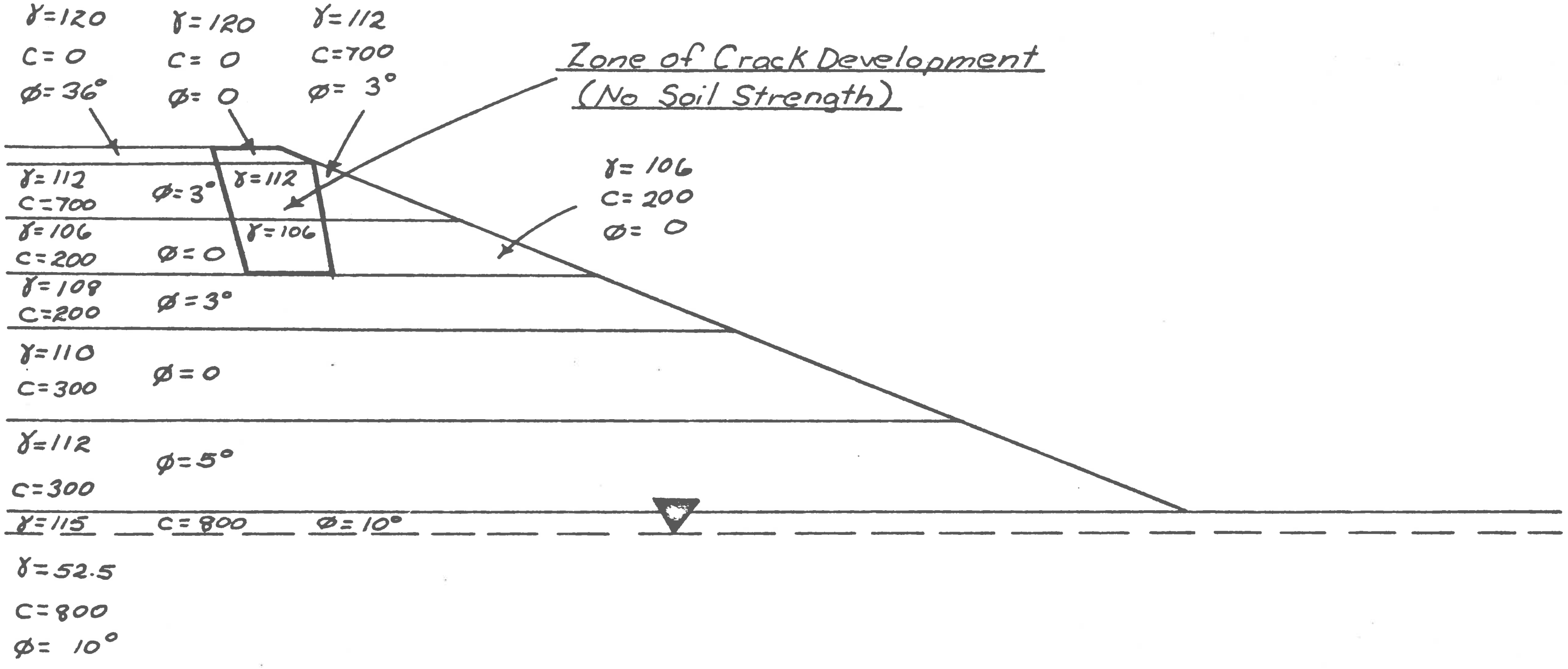


FIGURE V-12

Further Refinement of Analysis

REFERENCES

1. Bailey, William A., and Christian, John T., "A Problem-Oriented Language for Slope Stability Analysis", Soil Mechanics Division and Civil Engineering Systems Laboratory, Department of Civil Engineering, Massachusetts Institute of Technology, 56 pages, April, 1969.

2. Leary, Robert M., "Computerized Analysis of the Stability of Earth Slopes", New York State Department of Transportation, Bureau of Soil Mechanics, in cooperation with the Bureau of Electronic Data Processing, 119 pages, October, 1970.

3. Stephenson, Lloyd W., and Crider, Albert F., "Geology and Ground Waters of Northeastern Arkansas", Department of the Interior, U.S.G.S. Water-Supply Paper 399, pages 13-14, 22-29, 100-122, 129-132, 174-178, 224-228, 250-253, 1916.

4. "Climates of the States: Arkansas", U.S. Environmental Data Service, U.S. Department of the Commerce, June, 1969.

5. "Soil Survey of Mississippi County, Arkansas", U.S. Department of Agriculture, Soil Conservation Service, in cooperation with the Arkansas Agricultural Experiment Station, June, 1971.

6. "Soil Association Map, State of Arkansas", U.S. Department of Agriculture, Soil Conservation Service, in cooperation with the University of Arkansas Agricultural Experiment Station, April, 1959.

7. "Climatic Summary of the United States. Arkansas, North of the Arkansas River", U.S. Department of Agriculture, Weather Bureau, 1930.

8. Whitman, Robert V., and Bailey, William A., <u>Stability and Performance of Slopes and Embankments</u>, Soil Mechanics and Foundations Division, American Society of Civil Engineers, pages 529-536, August, 1969.

9. Bruce, Richard L., and Scully, John, "Manual of Landslide Recognition in Pierre Shale, South Dakota", in cooperation with U.S. Department of Transportation, Bureau of Public Roads, South Dakota Department of Highways, South Dakota Geological Survey, December, 1966.

10. "Design Considerations for Slopes in Clay Shales", Kansas Highway Commission, unpublished study, 1970.

11. "Slope Study, Gordon Whitfield Counties", Division of Materials and Tests, State Highway Department of Georgia, Interdepartment Correspondence, 1963-64.

12. Deen, Robert C., and Havens, James H., "Landslides in Kentucky", Division of Research, Kentucky Department of Highways, September, 1968.

13. Long, Donald C., and Stinnett, Barney C., "Landslide Recognition and Control on West Virginia Highways", West Virginia State Road Commission, paper, February, 1969.

14. Williams, Dennis A., and Clark, Charlie H., "Landslide Research", Materials Division, Montana Highway Commission, in cooperation with U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads.

APPENDIX A

Stress-Strain Computer Program Listing

NOTATION

XLO = length of test specimen in inches.

A0 = initial area of test specimen in inches squared.

SIGMA3 = confining pressure in pounds per square inch.

NPTS = number of test points.

SAMP = sample number.

SPEC = specimen number.

LOC = location of test site.

DATE = date of test.

DIALST = displacement dial readings in 0.001 inches.

DIALPR = proving ring dial readings in 0.0001 inches.

DELTAL = change in specimen length in inches.

E = vertical strain in inch per inch.

A = corrected area in inches squared.

P = axial load in pounds.

DEVSTR = deviator stress in pounds per square inch.

SIGMA1 = major principal stress in pounds per square foot.

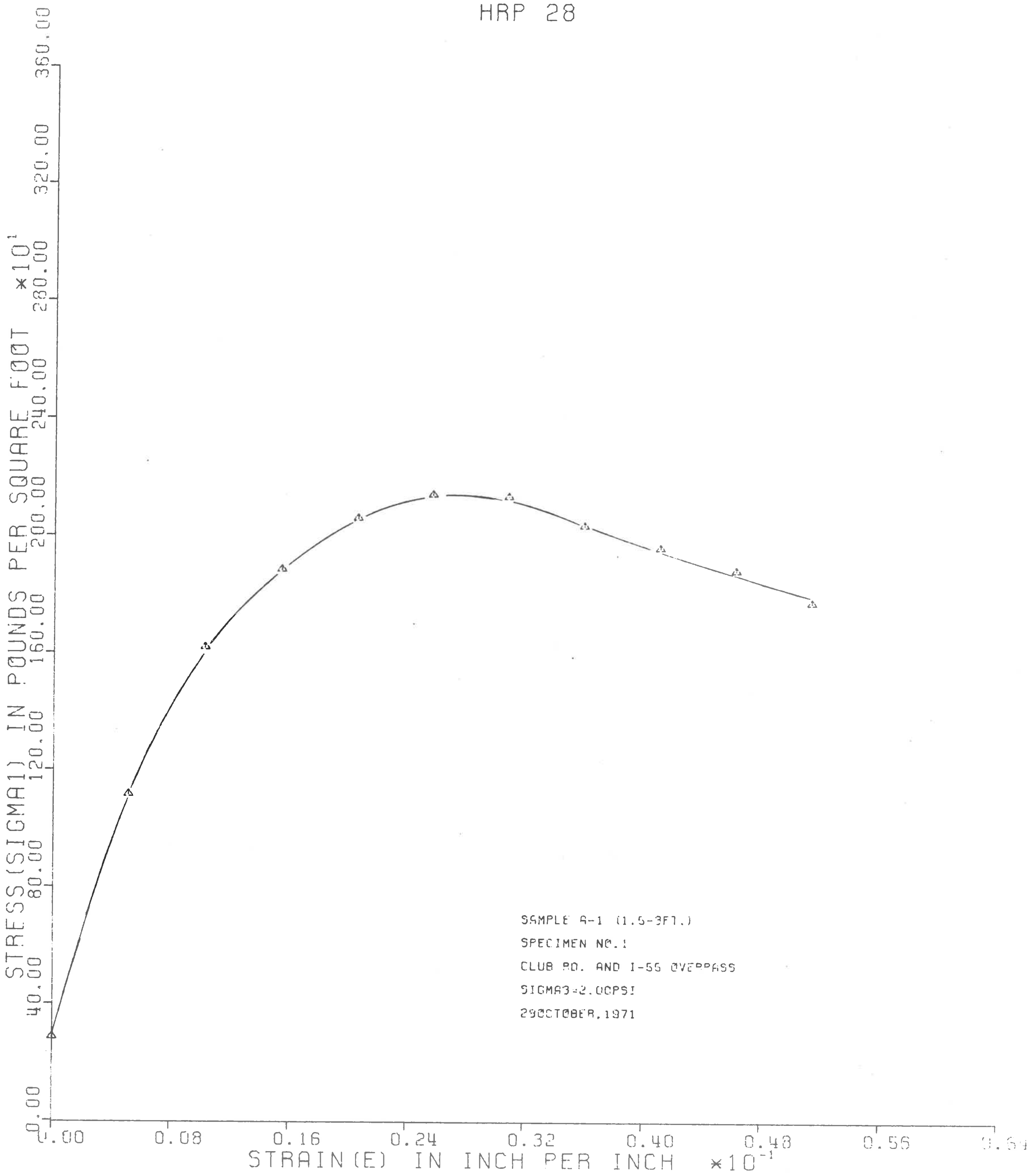
```
FORTRAN IV G LEVEL  20                 MAIN              DATE = 72033          20/25/40            PAGE

                DIMENSION X(102),Y(102),IBUF(1500),LOC(8),DATE(5),SAMP(6),SPEC(6)
                CALL PLOTS(IBUF,1500,LDEV)
                CALL PLOT(0.0,-30.0,3)
                CALL PLOT(0.0,-29.5,-3)
             11 READ (5,1,END=100) XLO,AO,SIGMA3,NPTS
              1 FORMAT (3F15.0,I15)
                READ(5,125) SAMP,SPEC
            125 FORMAT (6A4,6A4)
                READ(5,25) LOC,DATE
             25 FORMAT (8A4,5A4)
             19 WRITE (6,20)
             20 FORMAT (1H1,(14X,6HDIALST,14X,6HDIALPR,19X,1HE,14X,6HSIGMA1))
              2 DO 5 I=1,NPTS
              3 READ (5,4) DIALST,DIALPR
              4 FORMAT (2F15.0)
                DELTAL = 0.001*DIALST
                E = DELTAL/XLO
                A = AO/(1-E)
                IF(DIALPR-783.0) 8, 8, 9
              8 P = 0.881012*DIALPR
                GO TO 10
              9 P = 2.135142*(DIALPR - 783.0) + 690.0
             10 DEVSTR = P/A
                SIGMA1 =  (DEVSTR + SIGMA3)*144.0
             12 WRITE (6,6) DIALST,DIALPR,E,SIGMA1
              6 FORMAT (11X,F10.3,11X,F10.3,11X,F10.3,9X,F10.3)
                X(I)=E
                Y(I)=SIGMA1
              5 CONTINUE
                CALL GRAPH(X,Y,NPTS,IBUF,LOC,SAMP,SPEC,SIGMA3,DATE)
                GO TO 11
            100 CALL PLOT(0.0,0.0,999)
                STOP
                END

*OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
*OPTIONS IN EFFECT*  NAME = MAIN    , LINECNT =       50
*STATISTICS*    SOURCE STATEMENTS =       34,PROGRAM SIZE =     8040
*STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G LEVEL  20                  GRAPH               DATE = 72033          20/25/40                 PAGE

 0001                SUBROUTINE GRAPH(XARRAY,YARRAY,NPTS,IBUF,LOC,SAMP,SPEC,SIGMA3,DATE
                    1)
 0002                DIMENSION IBUF(1500),XARRAY(102),YARRAY(102),LOC(8),DATE(5),SAMP(6
                    1),SPEC(6)
 0003                LDEV=50
 0004                CALL SCALE(XARRAY,8.0,NPTS,1)
 0005                CALL SCALE(YARRAY,9.0,NPTS,1)
 0006                CALL AXIS(0.0,0.0,26HSTRAIN(E) IN INCH PER INCH,-26,8.0,0.0,XARRAY
                    1(NPTS+1),XARRAY(NPTS+2))
 0007                CALL AXIS(0.0,0.0,40HSTRESS(SIGMA1) IN POUNDS PER SQUARE FOOT,+40,
                    1 9.0,90.0,YARRAY(NPTS+1),YARRAY(NPTS+2))
 0008                CALL LINE(XARRAY,YARRAY,NPTS,1,-1,2)
 0009                CALL SYMBOL(1.06,10.0,0.14,42HMAJOR PRINCIPAL STRESS VS. VERTICAL
                    1STRAIN,0.0,42)
 0010                CALL SYMBOL(3.09,9.7,0.14,13HCOHESIVE SOIL,0.0,13)
 0011                CALL SYMBOL(3.58,9.4,0.14,6HHRP 28,0.0,6)
 0012                CALL SYMBOL(4.0,1.3,0.07,LOC,0.0,32)
 0013                CALL SYMBOL(4.0,1.7,0.07,SAMP,0.0,24)
 0014                CALL SYMBOL(4.0,1.5,0.07,SPEC,0.0,24)
 0015                CALL SYMBOL(4.0,1.1,0.07,7HSIGMA3=,0.0,7)
 0016                CALL NUMBER(999.,999.,0.07,SIGMA3,0.0,2)
 0017                CALL SYMBOL(999.,999.,0.07,3HPSI,0.0,3)
 0018                CALL SYMBOL(4.0,0.9,0.07,DATE,0.0,20)
 0019                CALL PLOT(12.0,0.0,-3)
 0020                RETURN
 0021                END


  *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = GRAPH    , LINECNT =       50
  *STATISTICS*    SOURCE STATEMENTS =        21,PROGRAM SIZE =      1402
  *STATISTICS*  NO DIAGNOSTICS GENERATED

  *STATISTICS*  NO DIAGNOSTICS THIS STEP 0
```

APPENDIX B

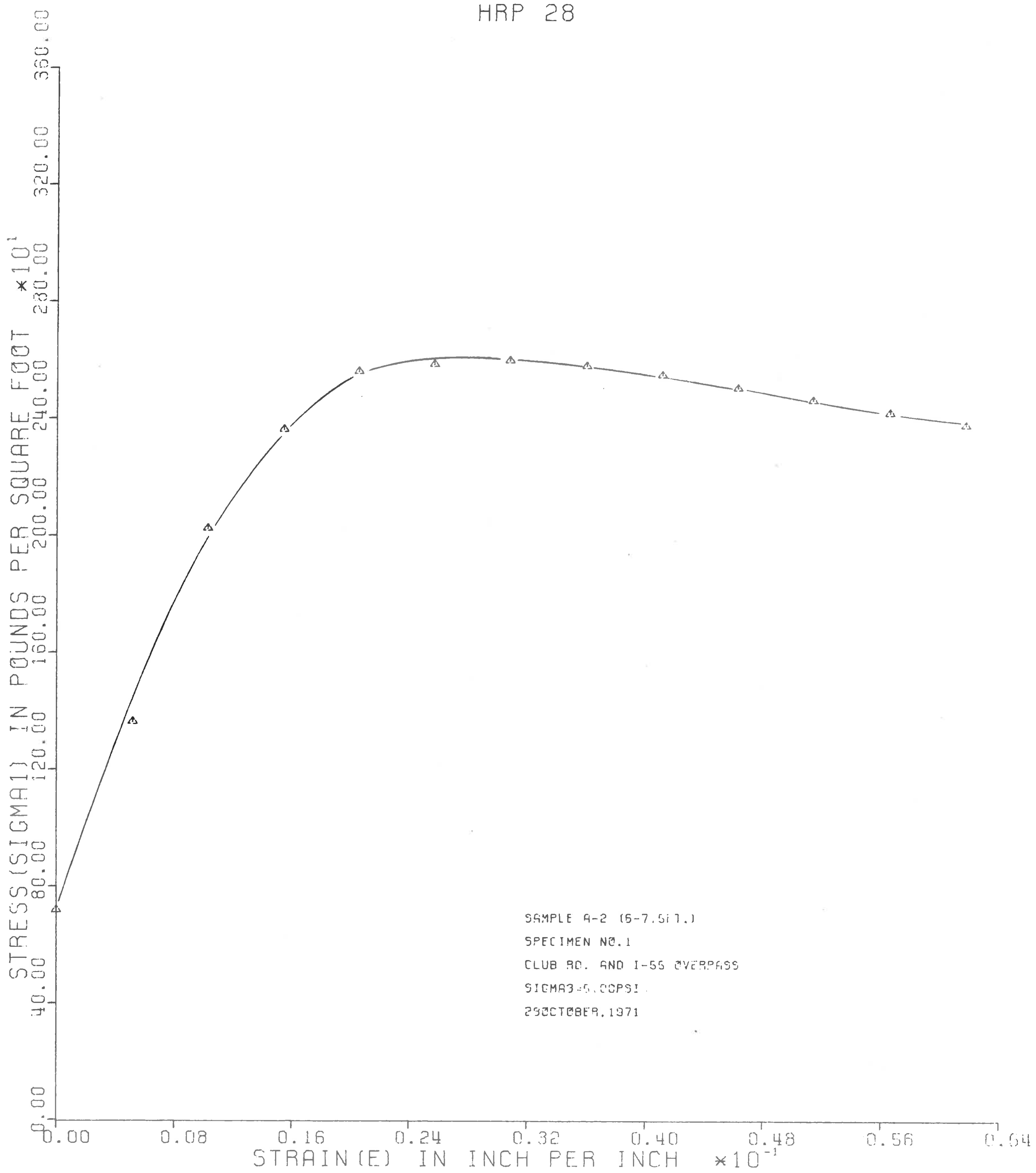
Stress-Strain Curves

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

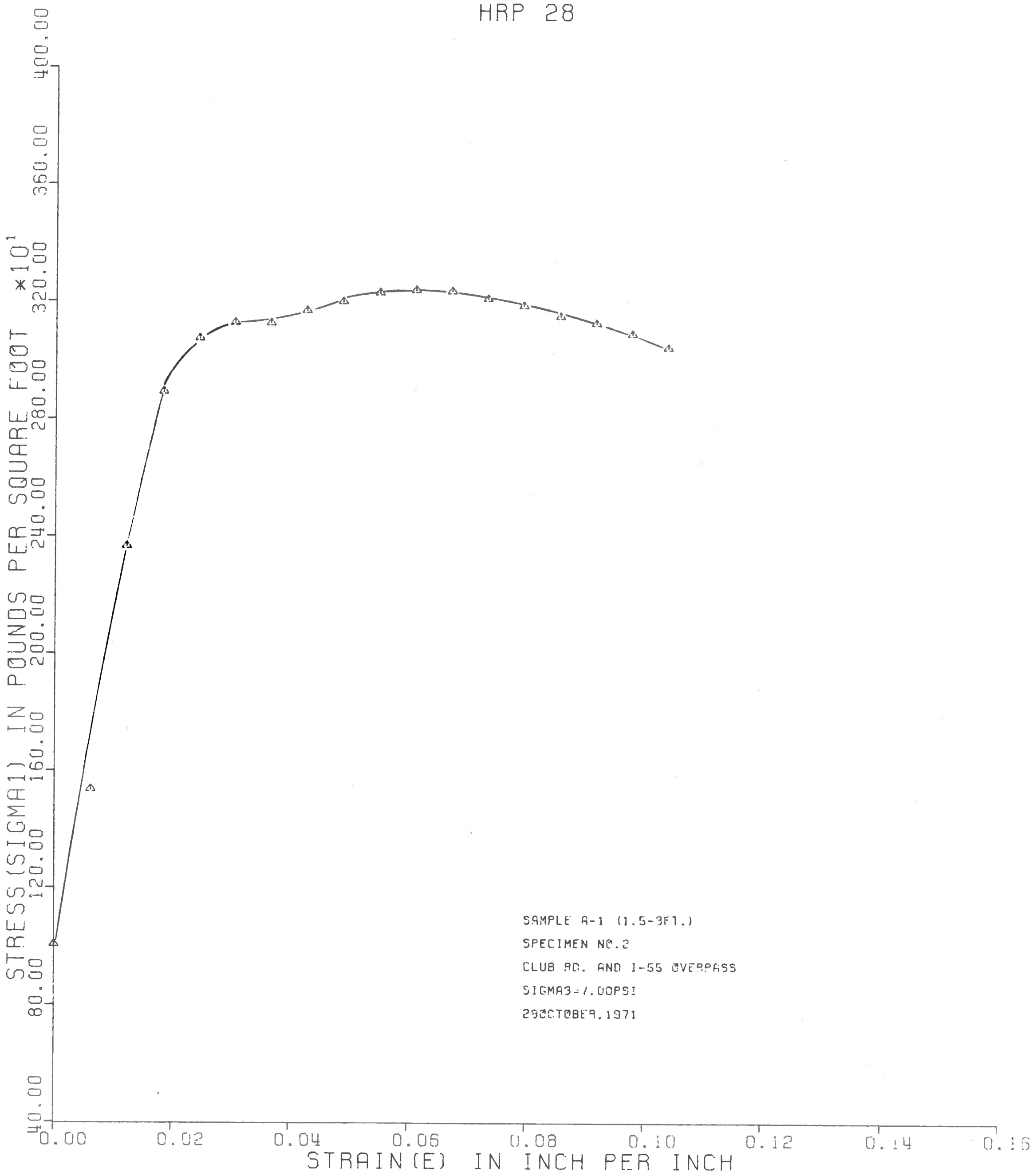


SAMPLE A-1 (1.5-3FT.)
SPECIMEN NO.1
CLUB RD. AND I-55 OVERPASS
SIGMA3=2.00PSI
29OCTOBER,1971

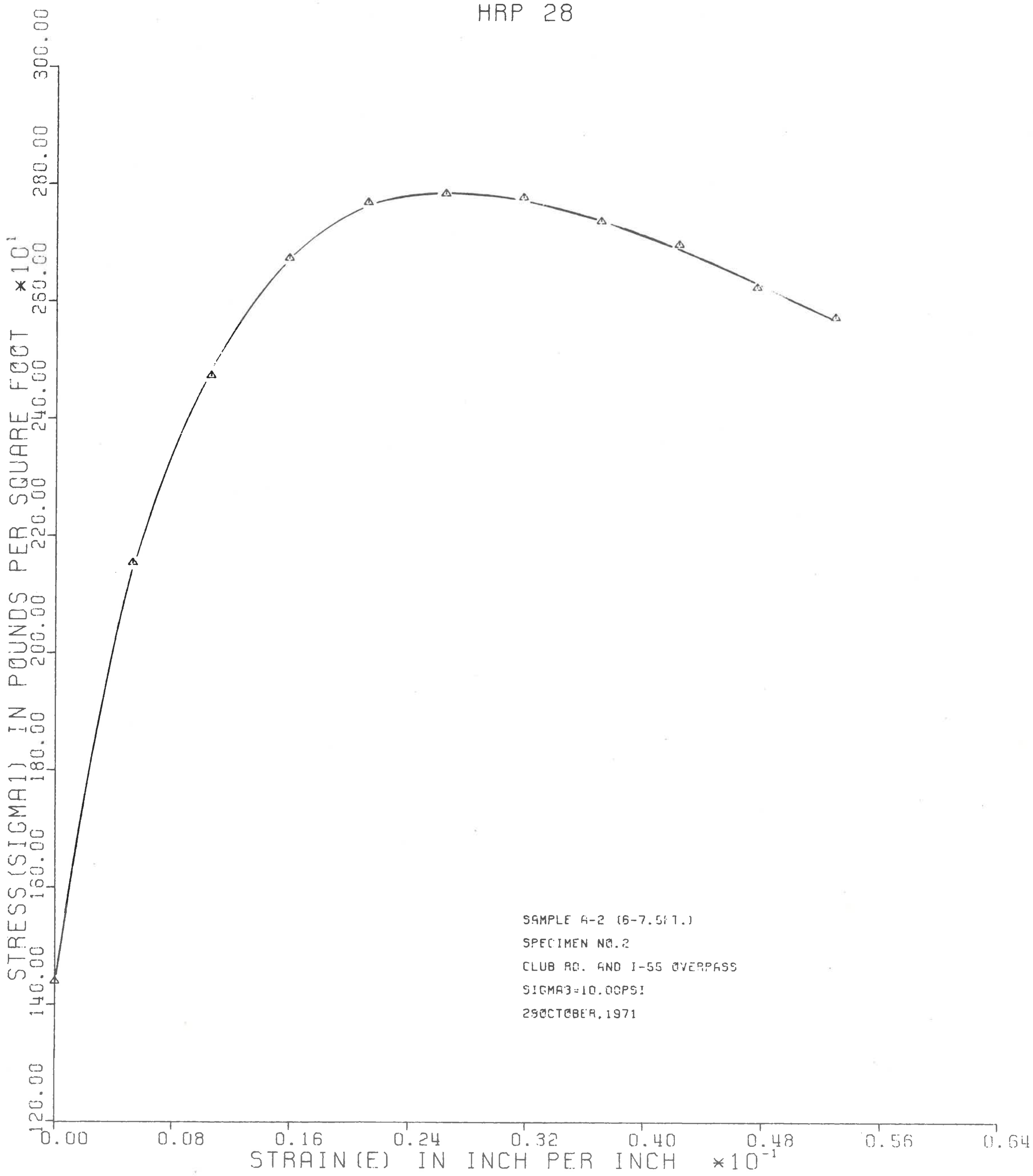
MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



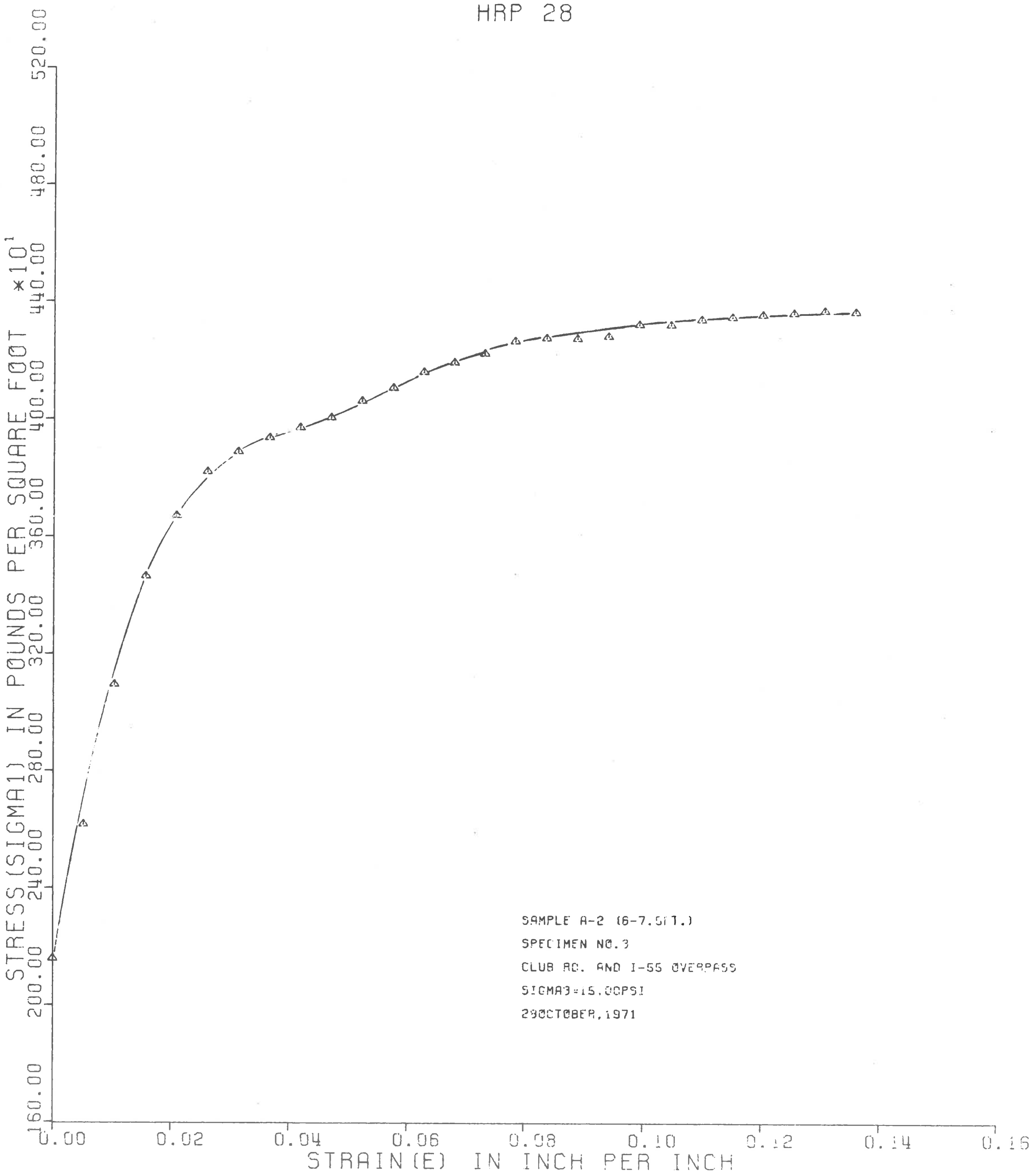
MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



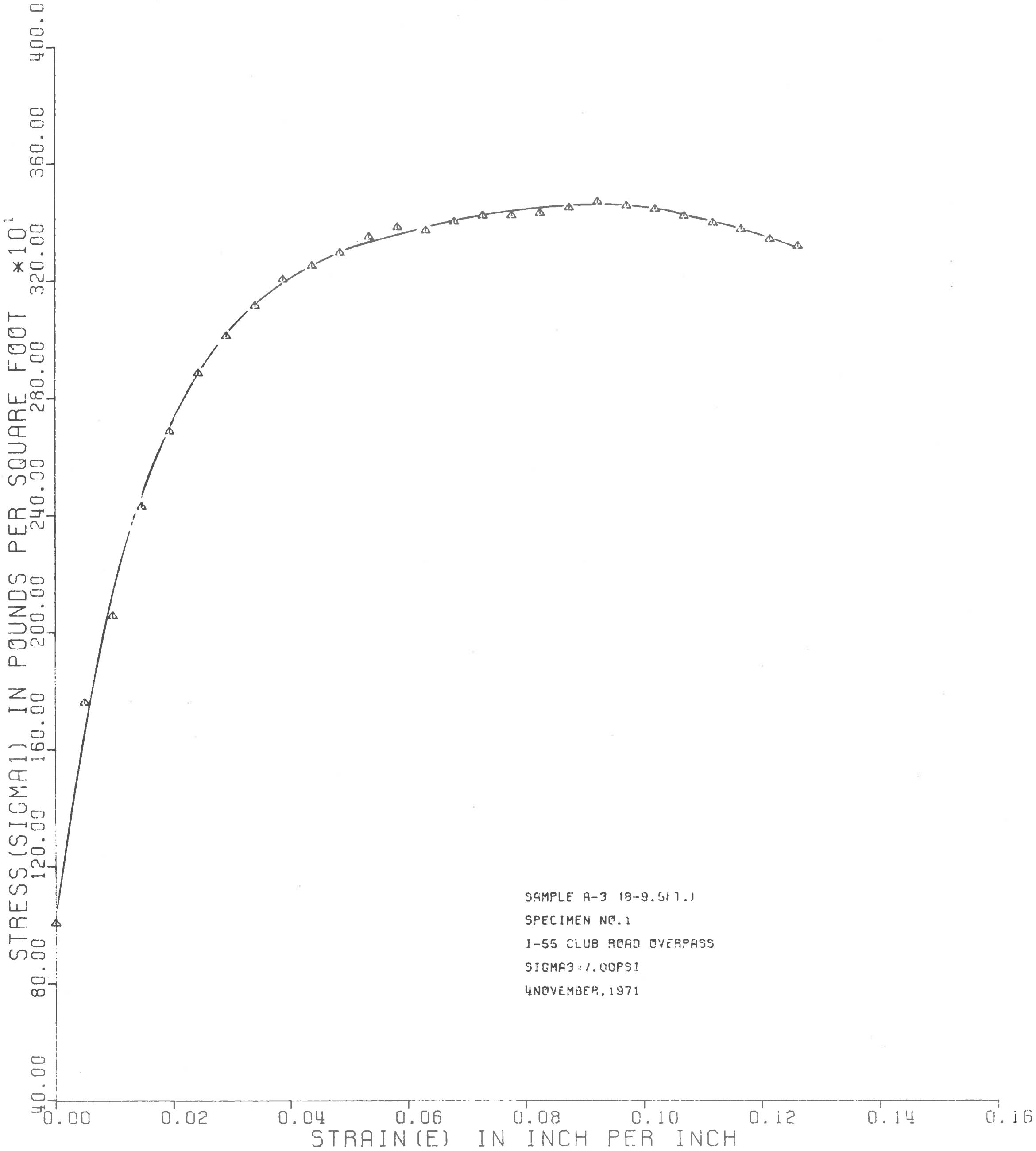
MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

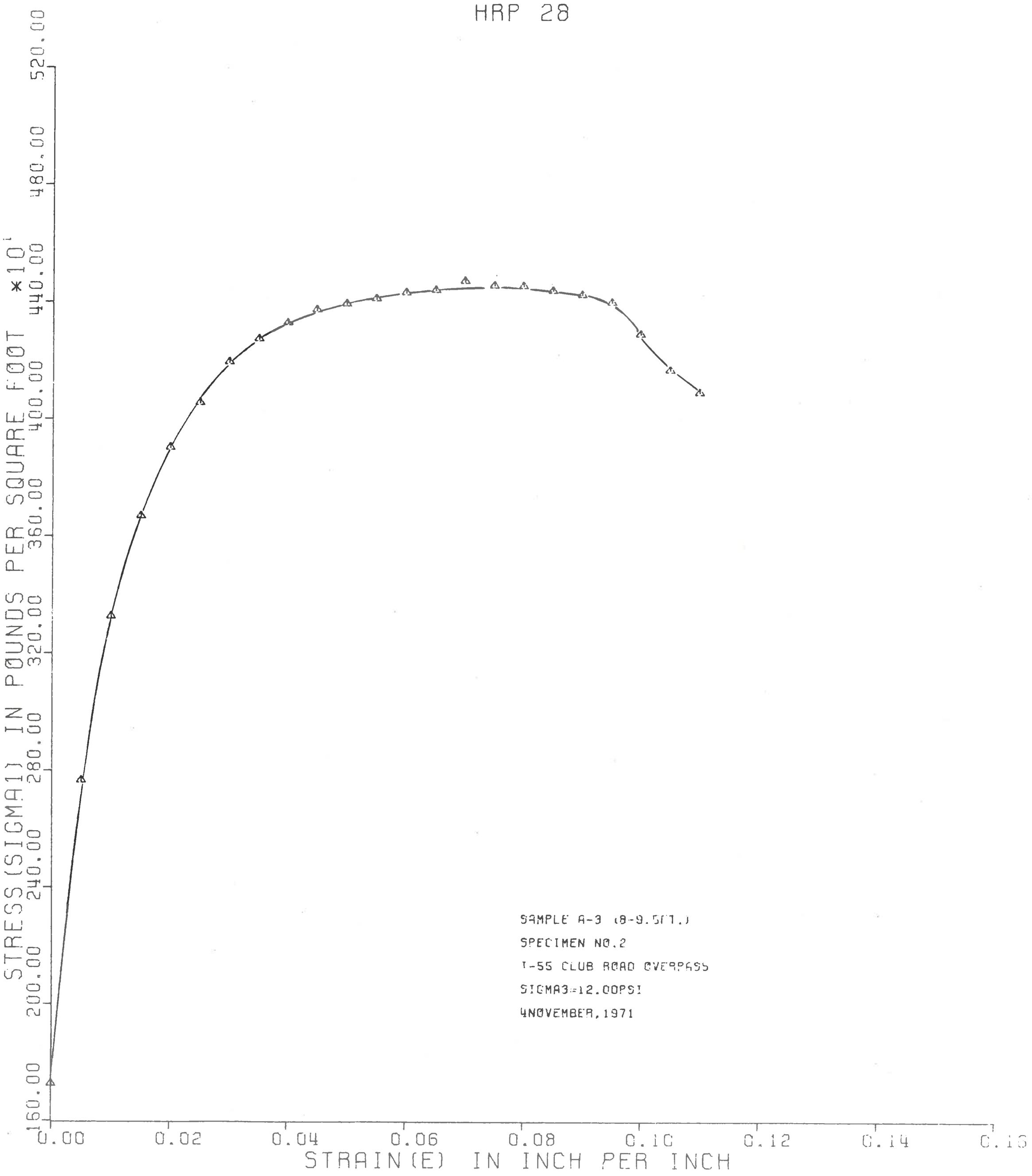


MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



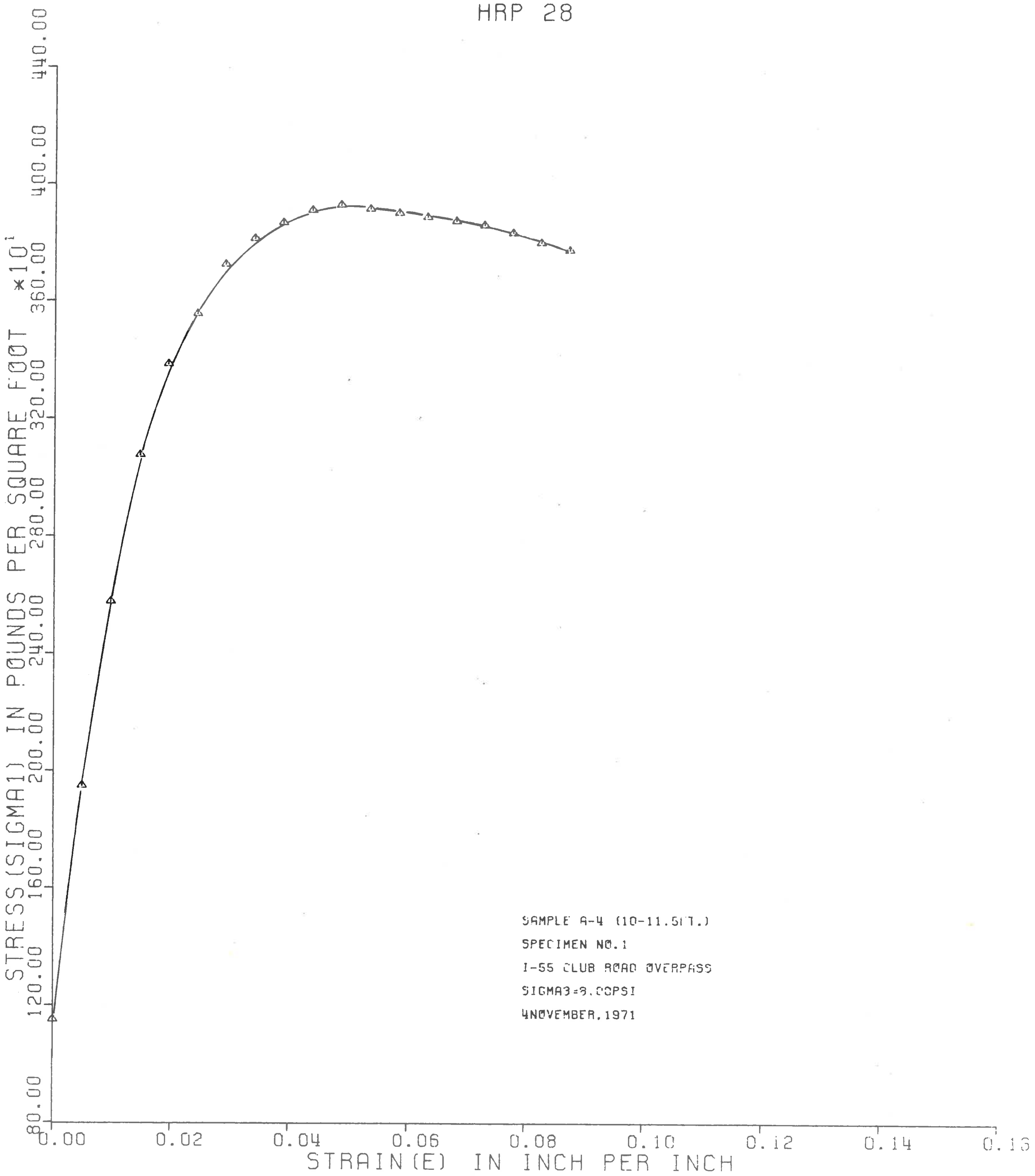
SAMPLE A-3 (8-9.5FT.)
SPECIMEN NO.1
I-55 CLUB ROAD OVERPASS
SIGMA3=7.00PSI
4NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

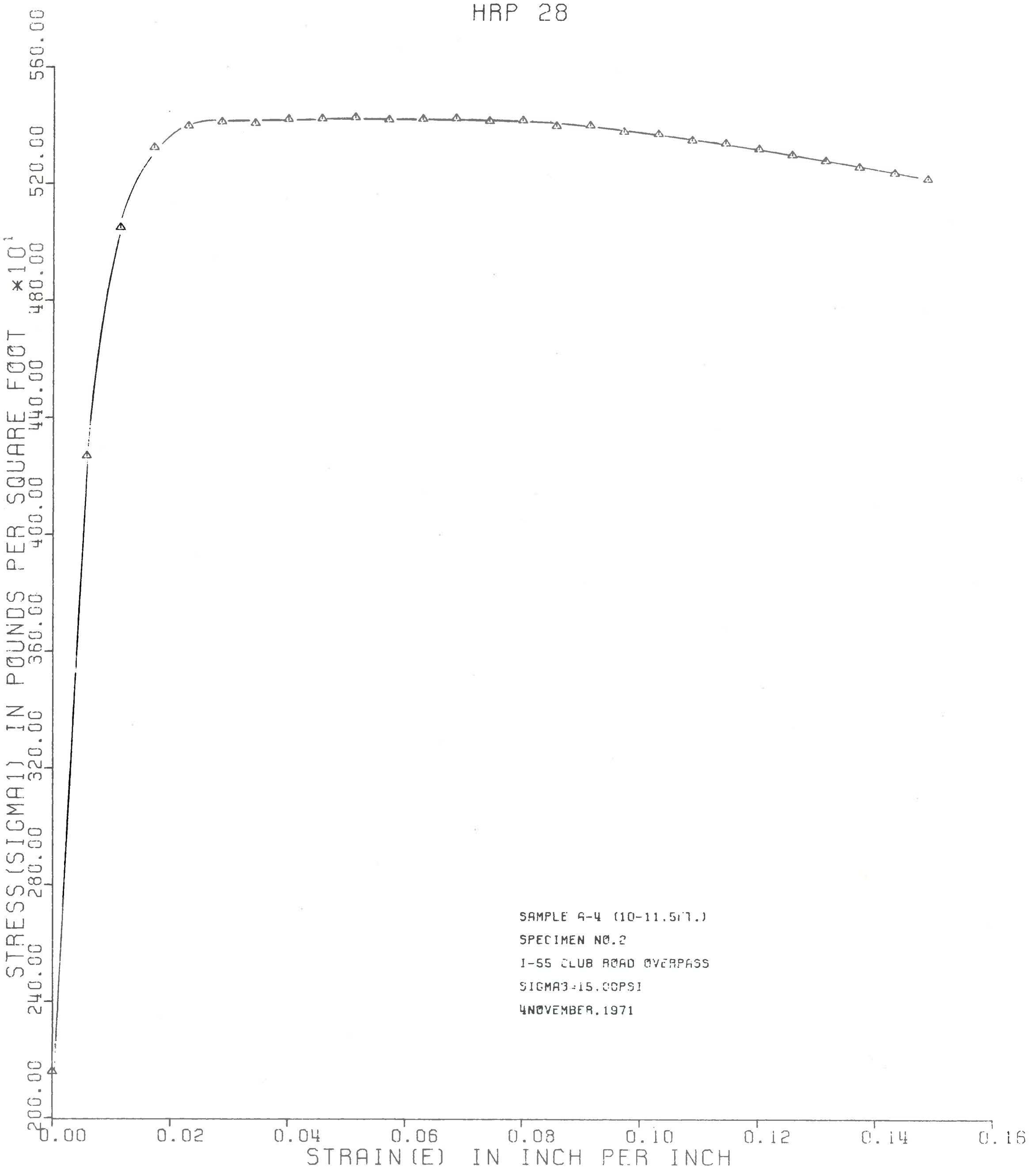


SAMPLE A-3 (8-9.5FT.)
SPECIMEN NO.2
I-55 CLUB ROAD OVERPASS
SIGMA3=12.00PSI
4NOVEMBER,1971

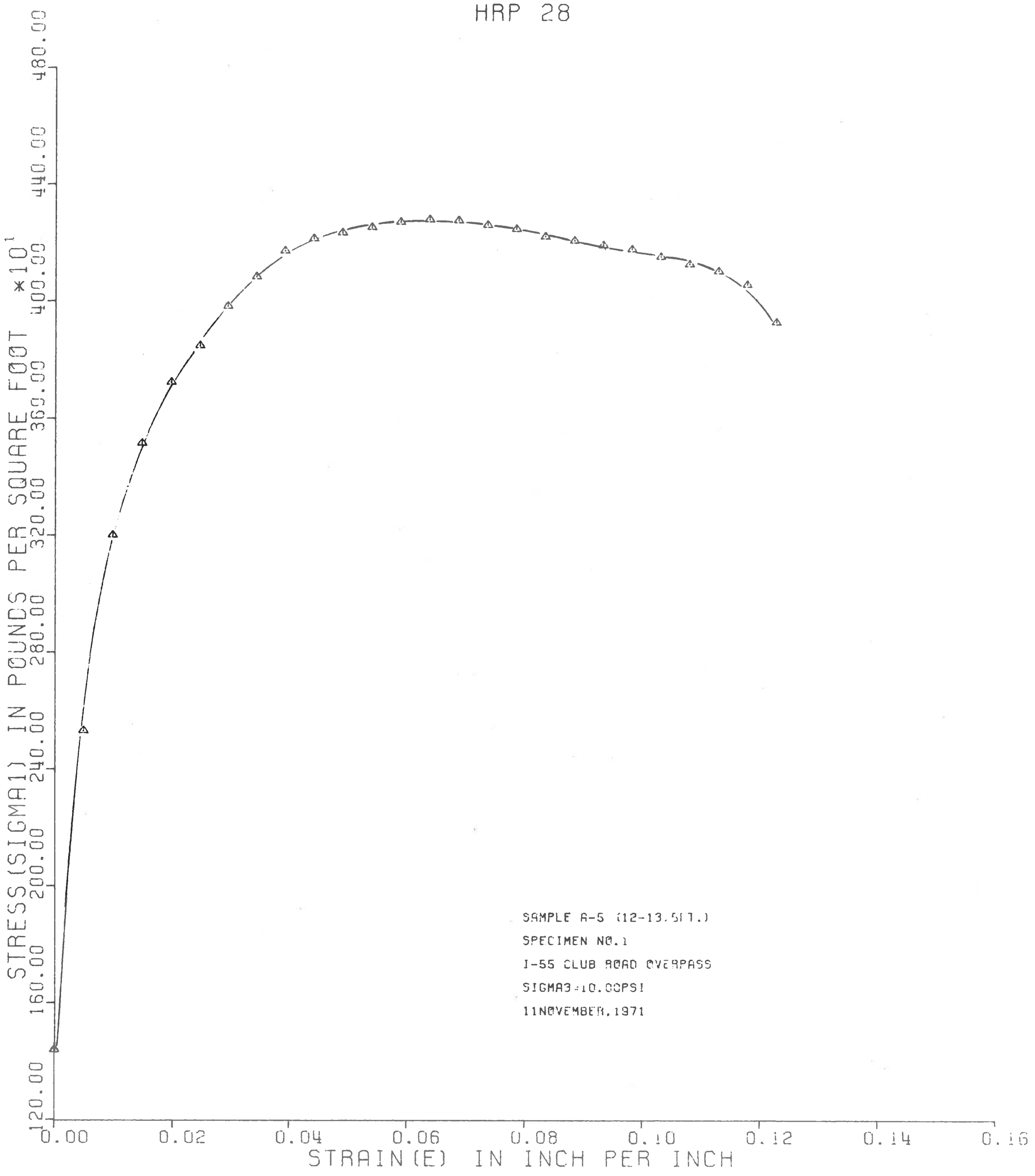
MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

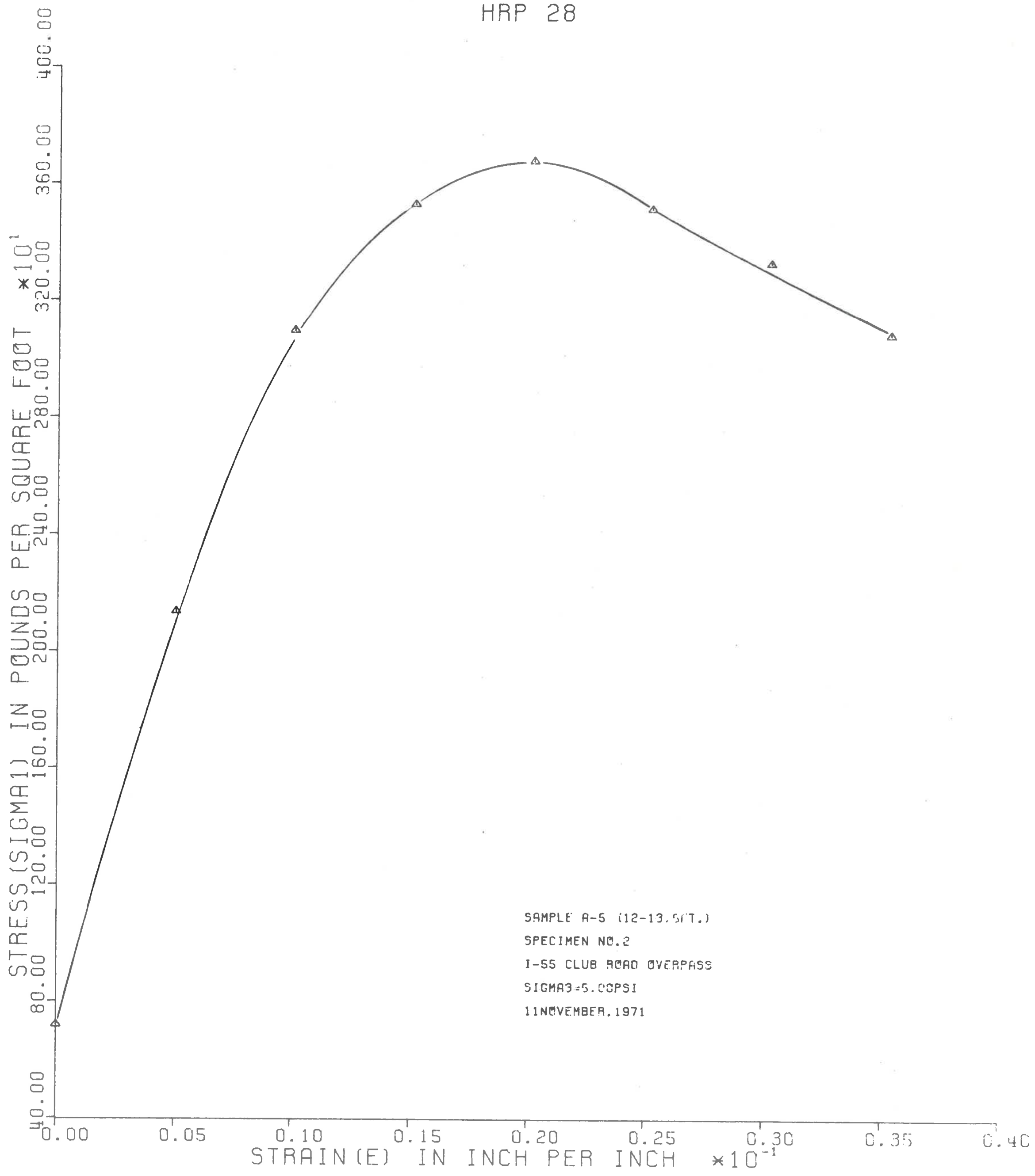


MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



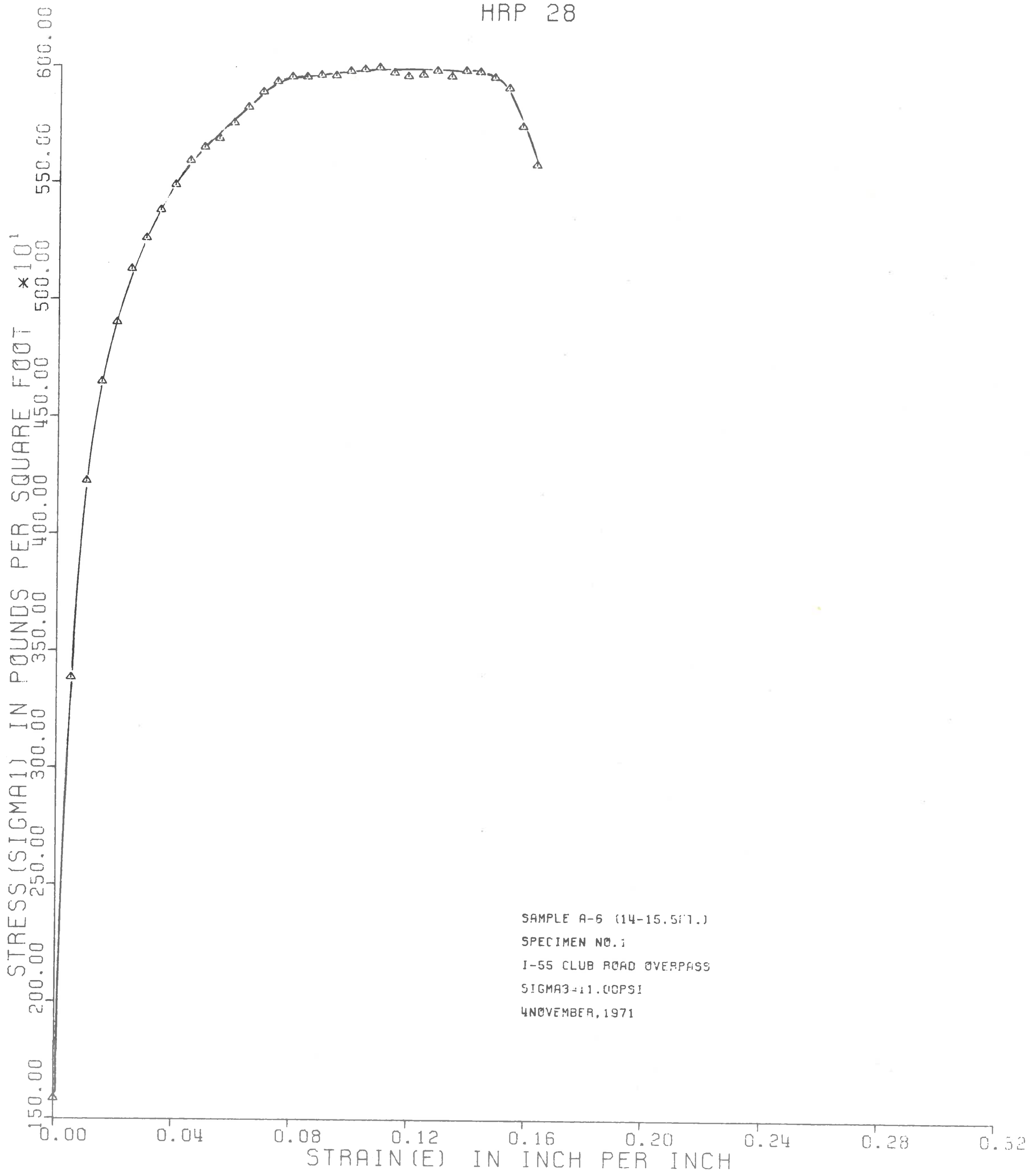
SAMPLE A-5 (12-13.5FT.)
SPECIMEN NO.1
I-55 CLUB ROAD OVERPASS
SIGMA3=10.00PSI
11NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

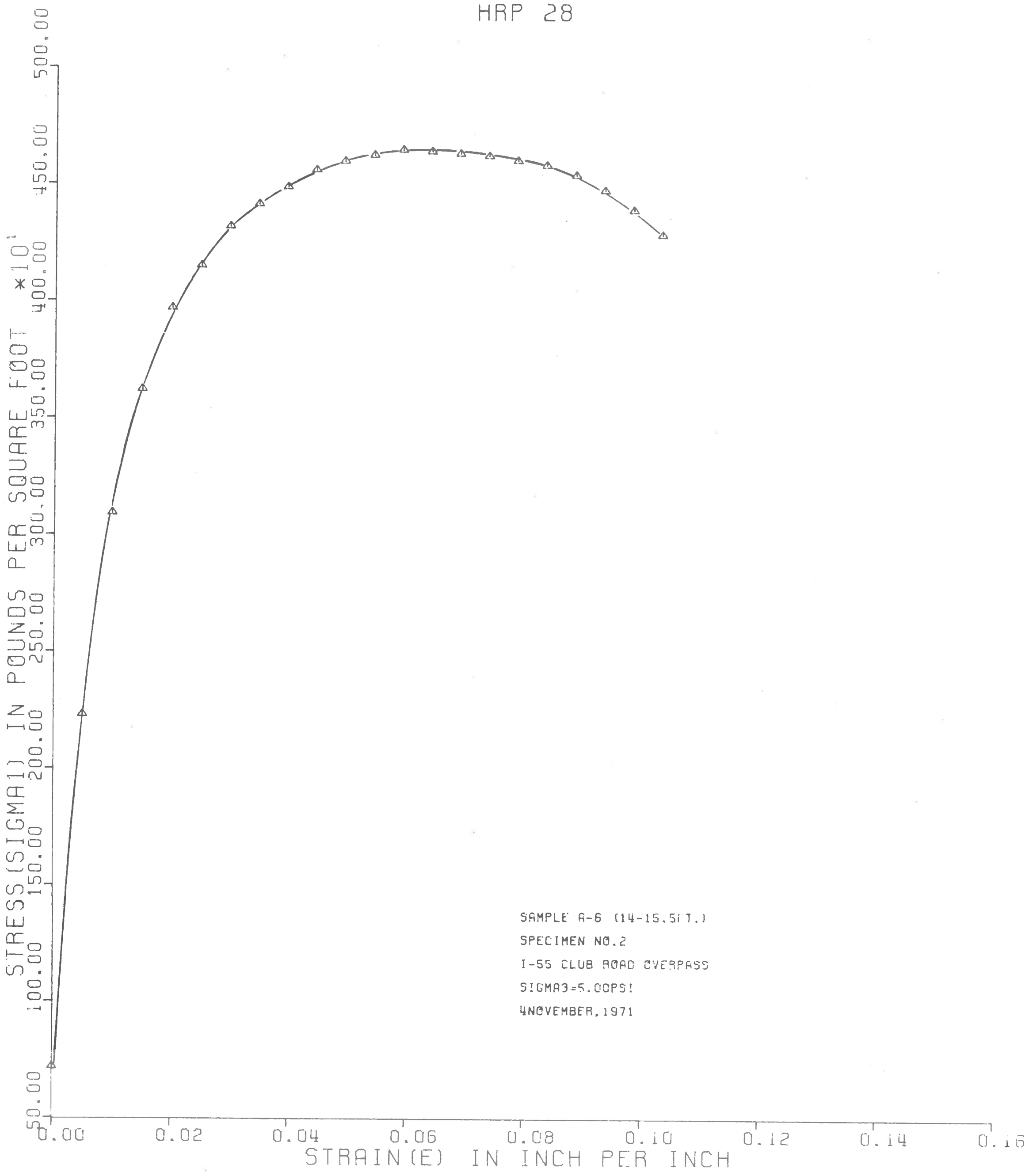


SAMPLE A-5 (12-13.5FT.)
SPECIMEN NO.2
I-55 CLUB ROAD OVERPASS
SIGMA3=5.00PSI
11NOVEMBER,1971

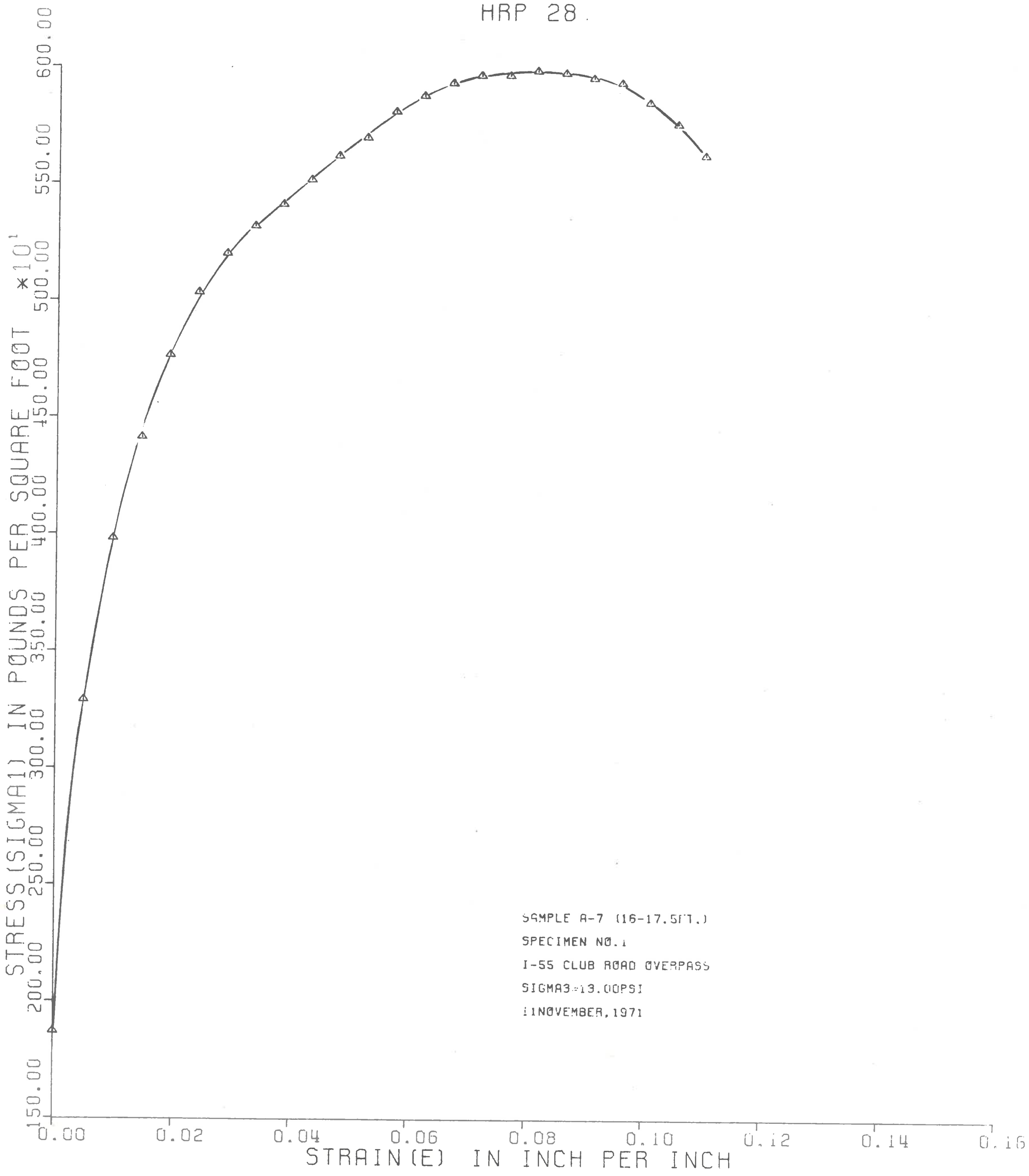
MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

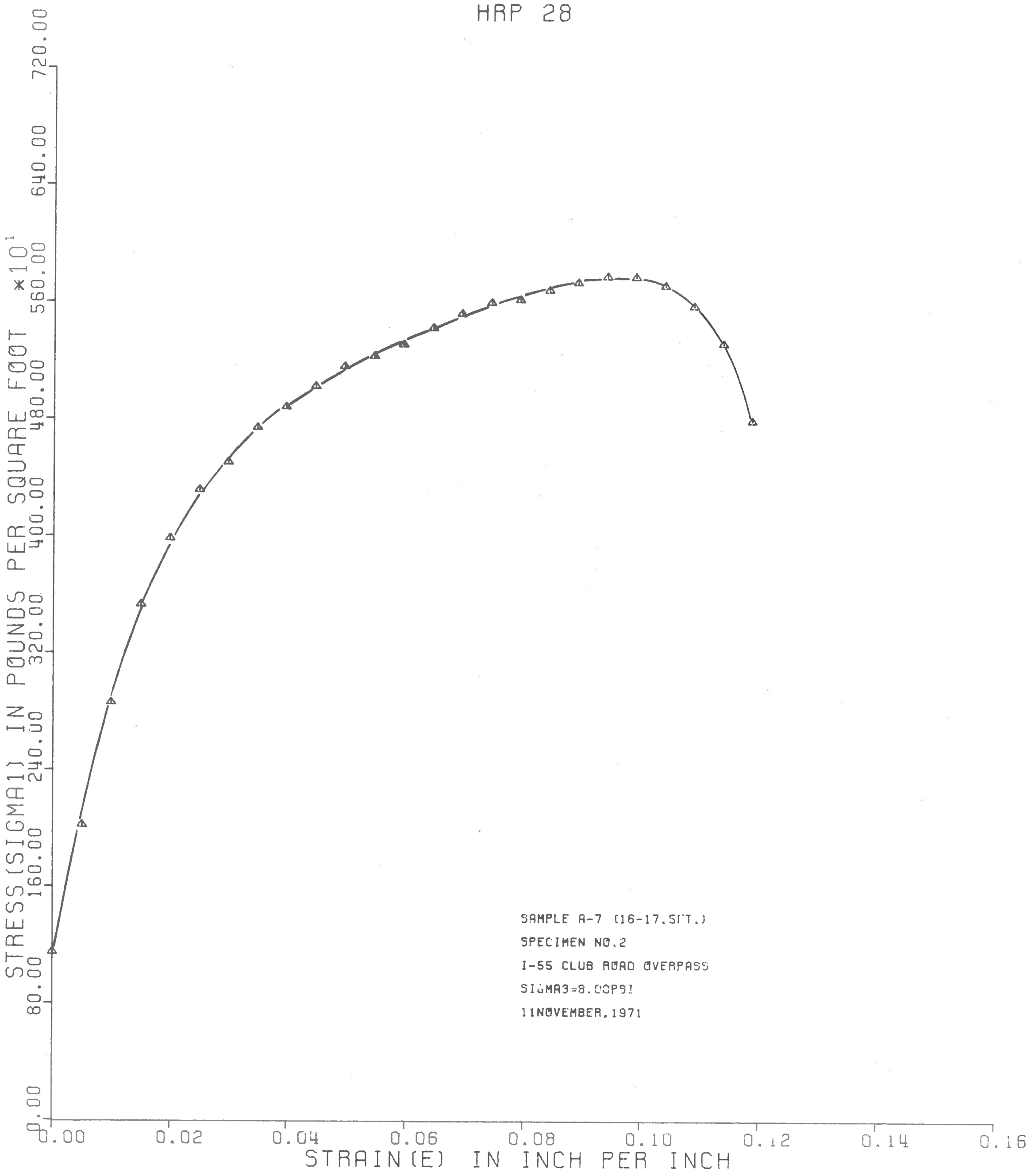


MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



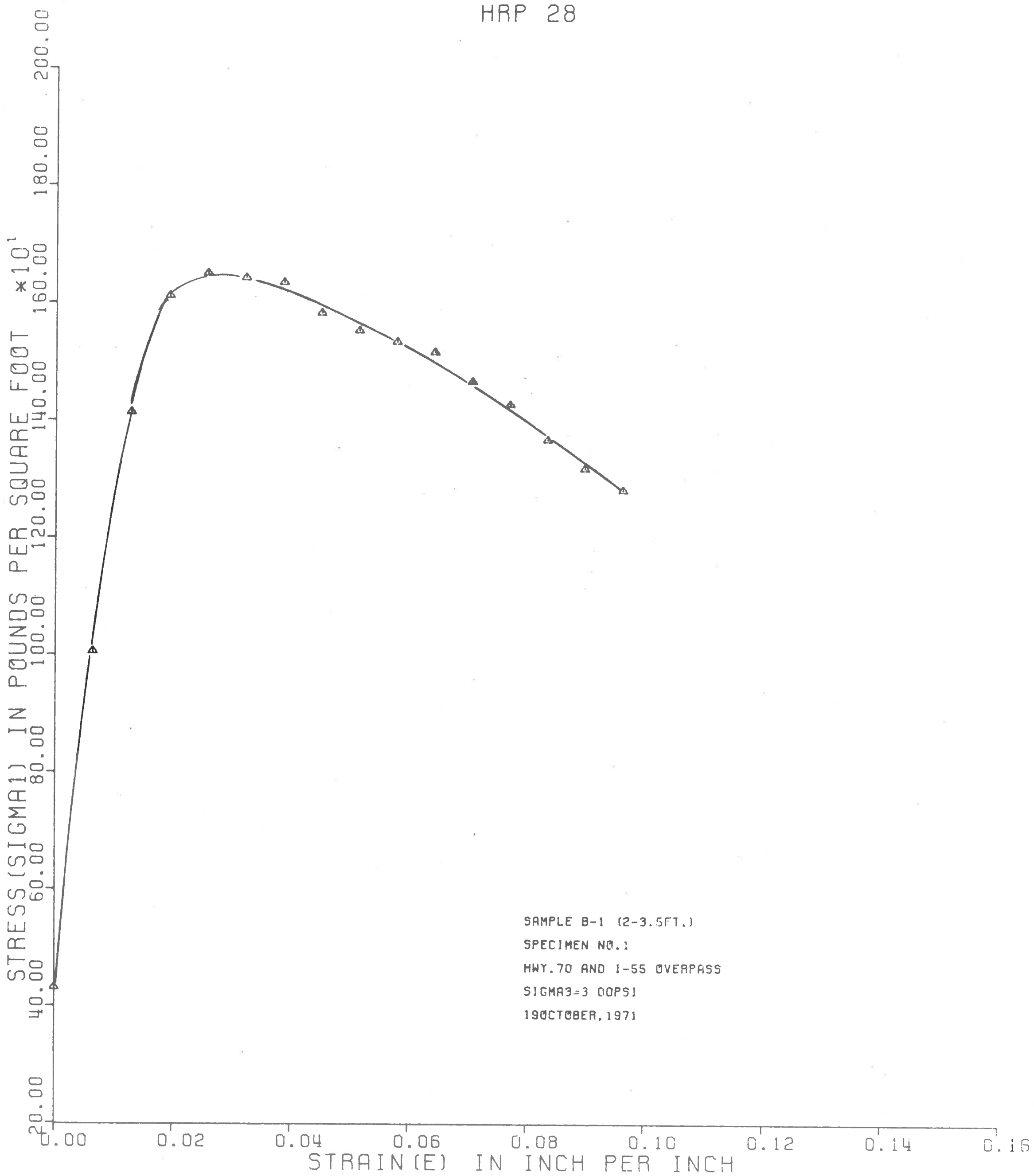
SAMPLE A-7 (16-17.5FT.)
SPECIMEN NO.1
I-55 CLUB ROAD OVERPASS
SIGMA3=13.00PSI
11NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



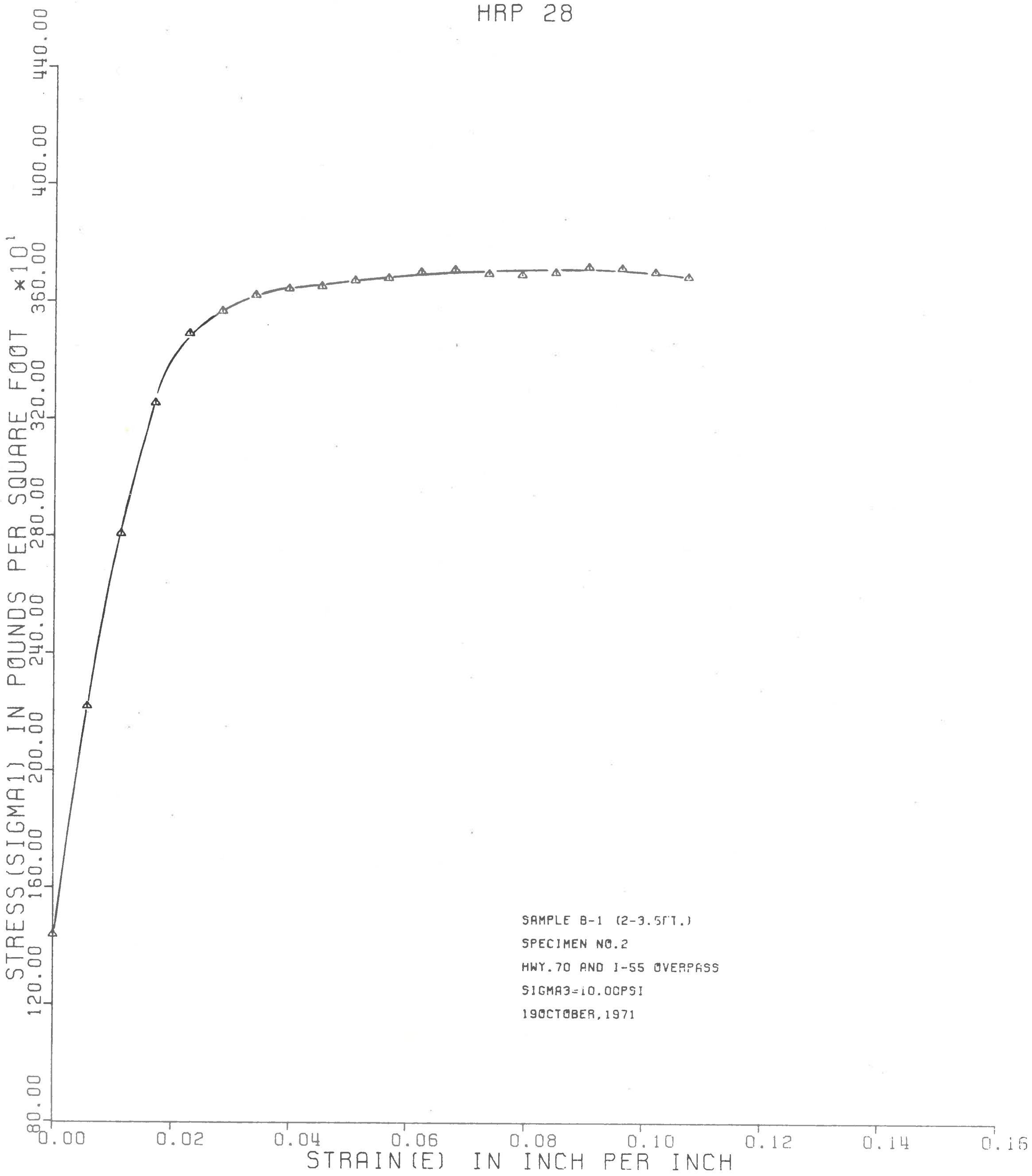
SAMPLE A-7 (16-17.5FT.)
SPECIMEN NO.2
I-55 CLUB ROAD OVERPASS
SIGMA3=8.00PSI
11NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



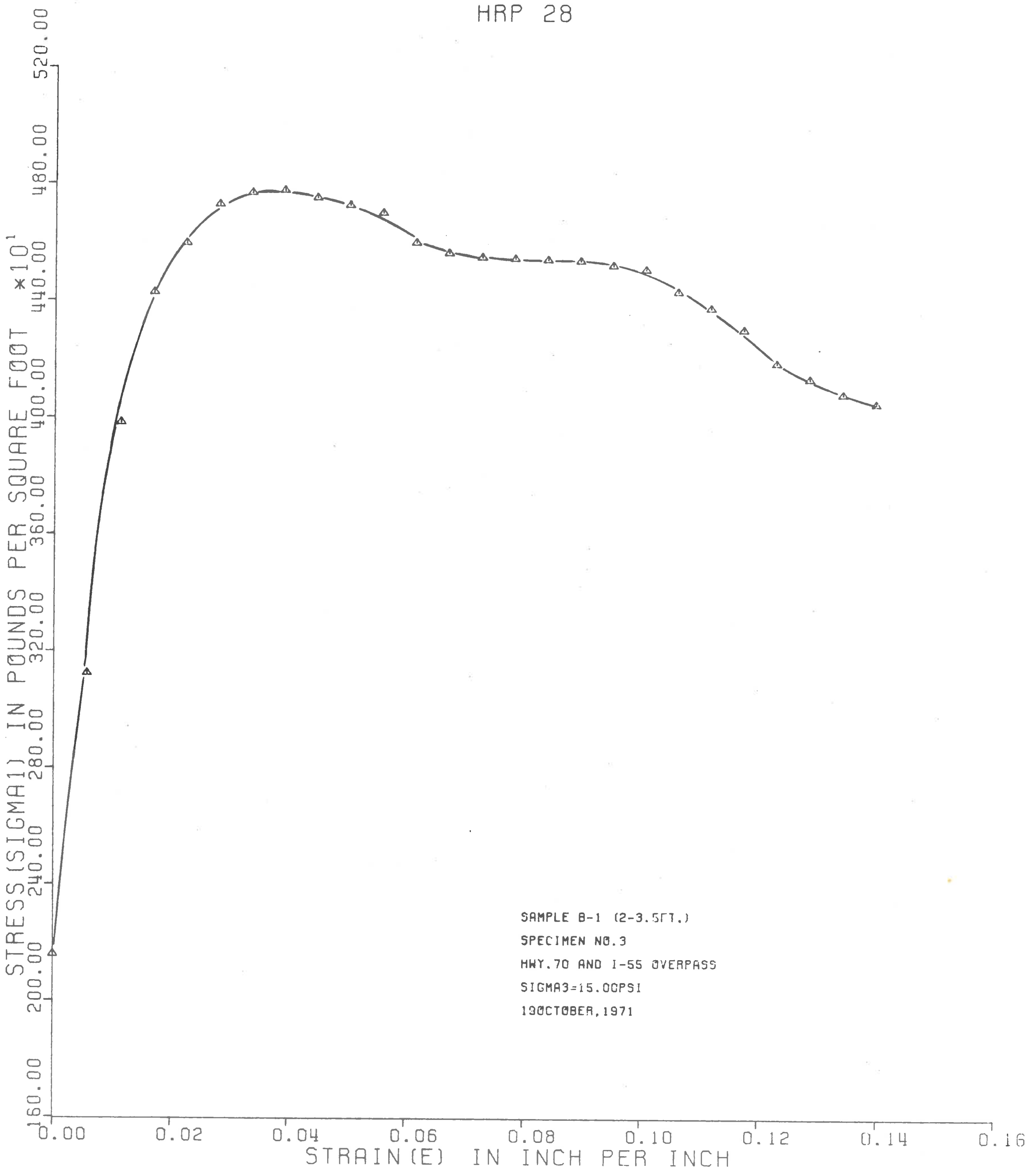
SAMPLE B-1 (2-3.5FT.)
SPECIMEN NO.1
HWY.70 AND I-55 OVERPASS
SIGMA3=3.00PSI
19OCTOBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



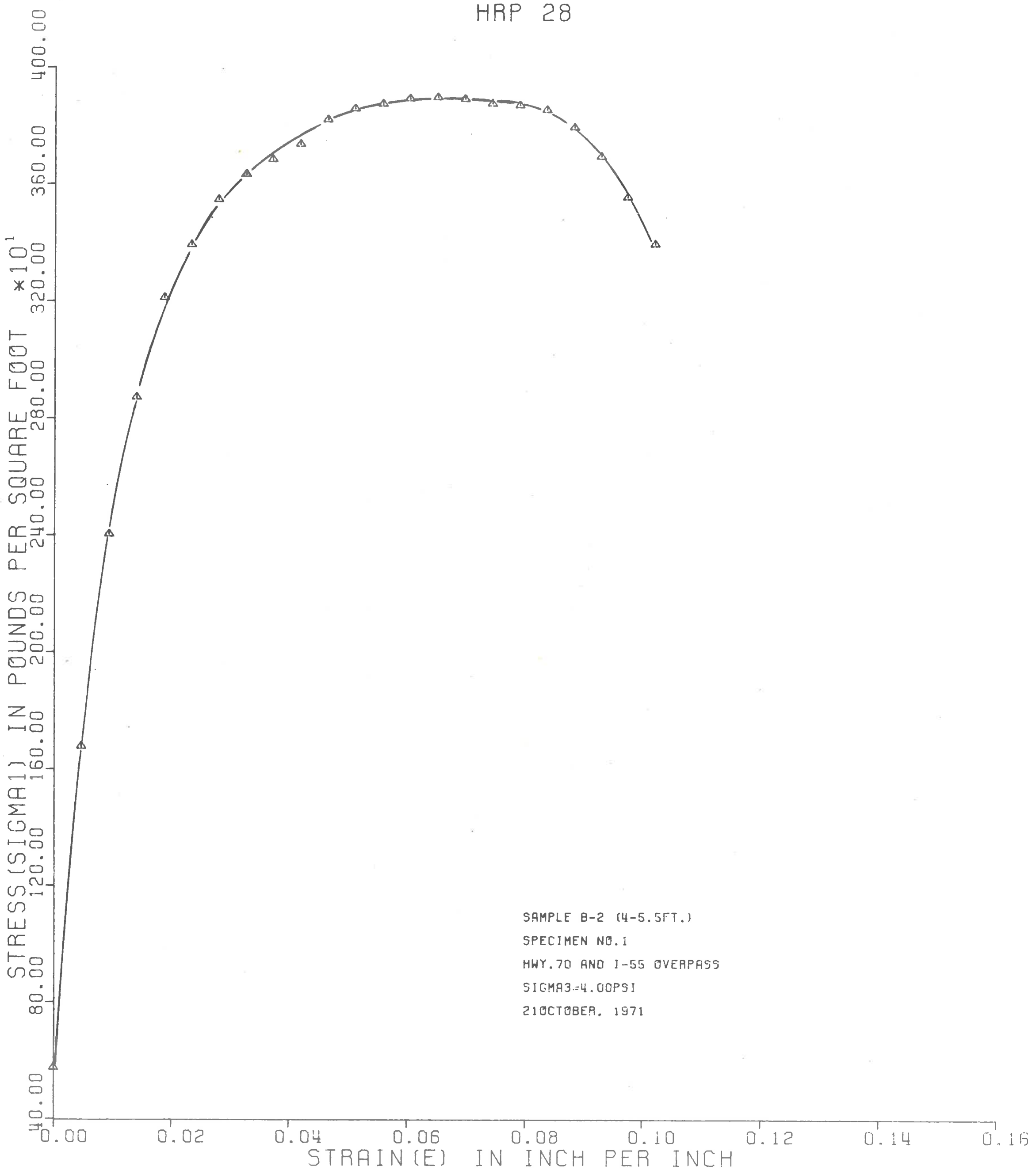
SAMPLE B-1 (2-3.5FT.)
SPECIMEN NO.2
HWY.70 AND I-55 OVERPASS
SIGMA3=10.00PSI
19OCTOBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



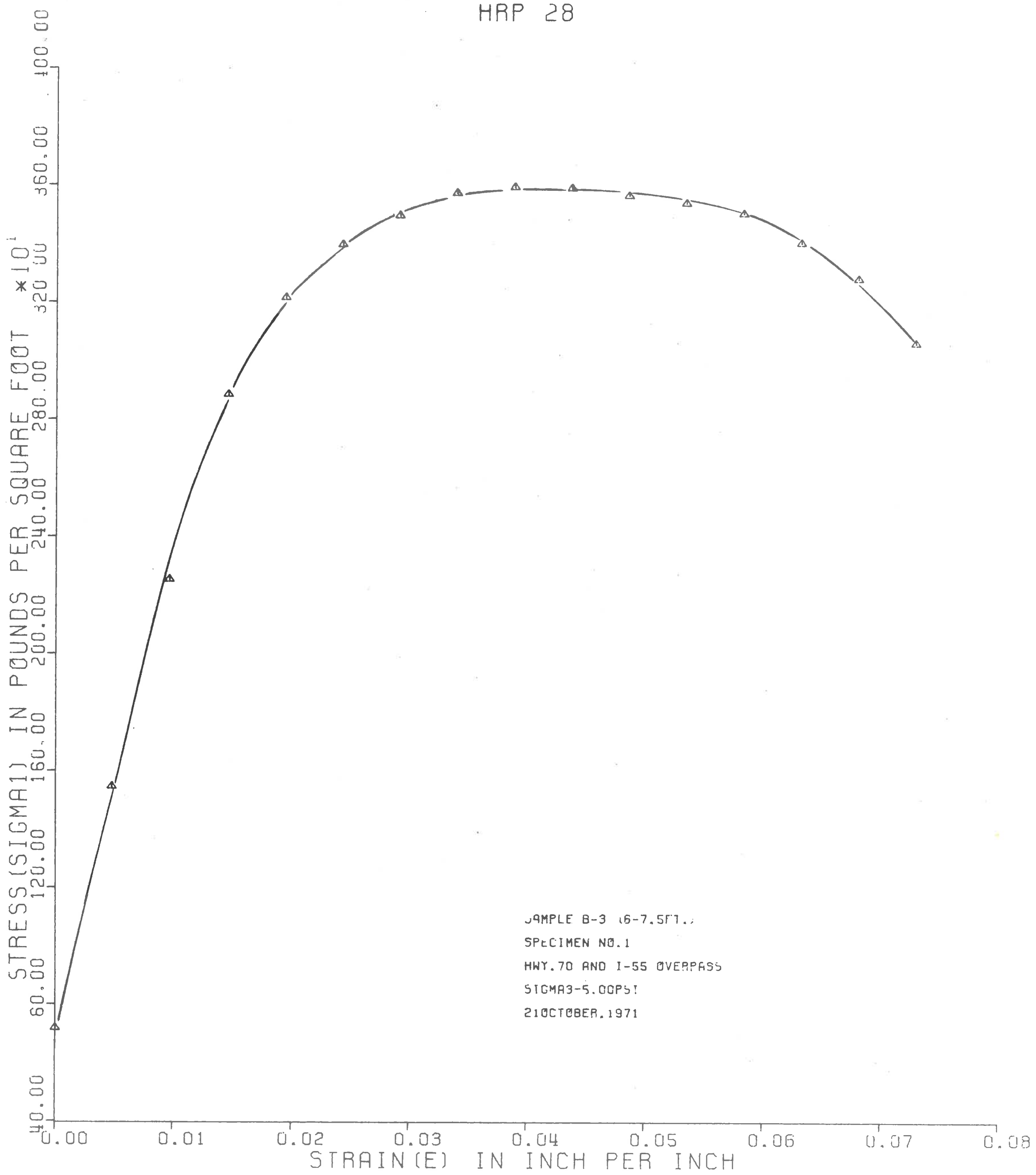
SAMPLE B-1 (2-3.5FT.)
SPECIMEN NO.3
HWY.70 AND I-55 OVERPASS
SIGMA3=15.00PSI
19OCTOBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



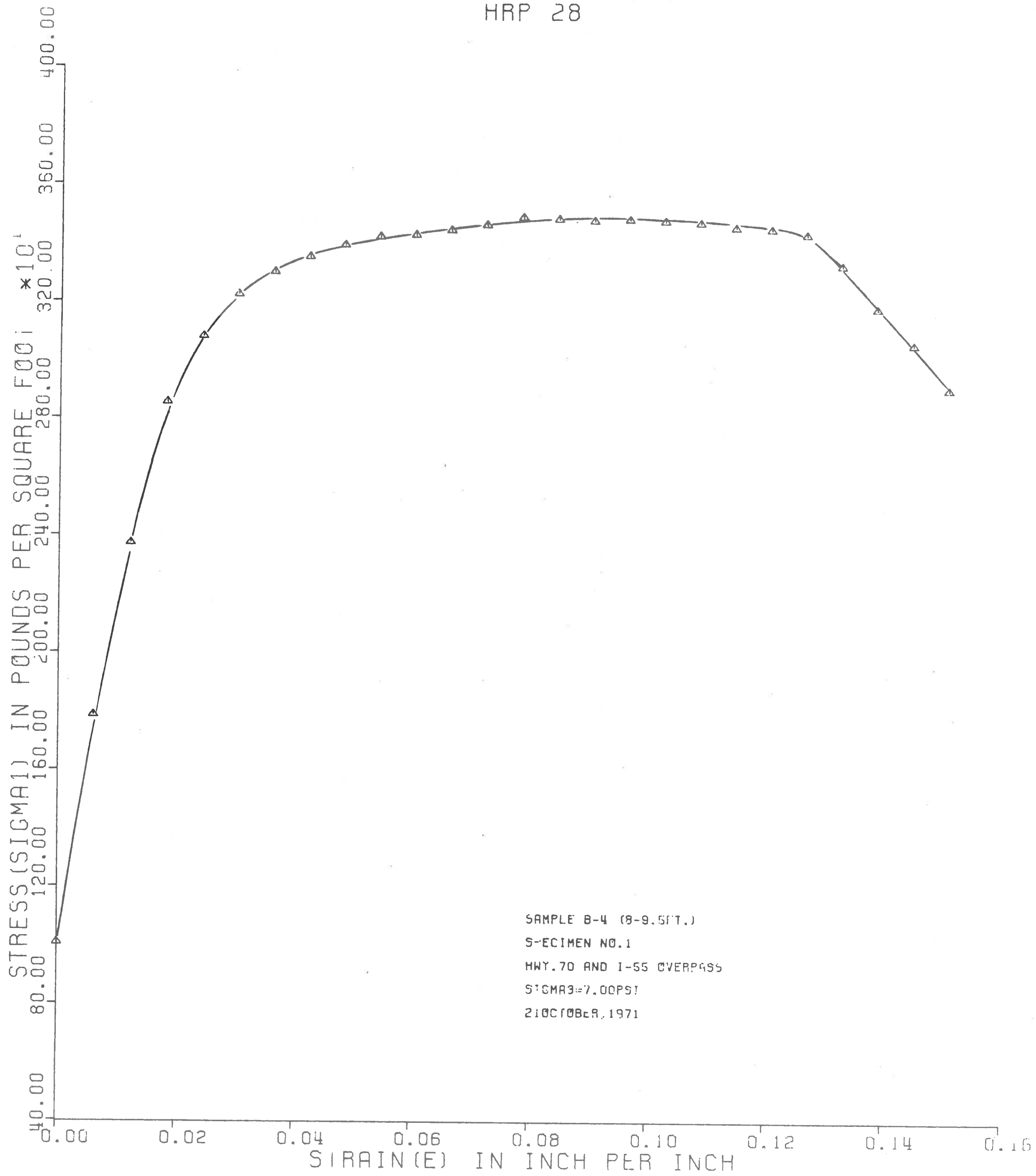
SAMPLE B-2 (4-5.5FT.)
SPECIMEN NO.1
HWY.70 AND I-55 OVERPASS
SIGMA3=4.00PSI
21OCTOBER, 1971

MAJOR PRINCIPAL STRESS VS VERTICAL STRAIN
COHESIVE SOIL
HRP 28

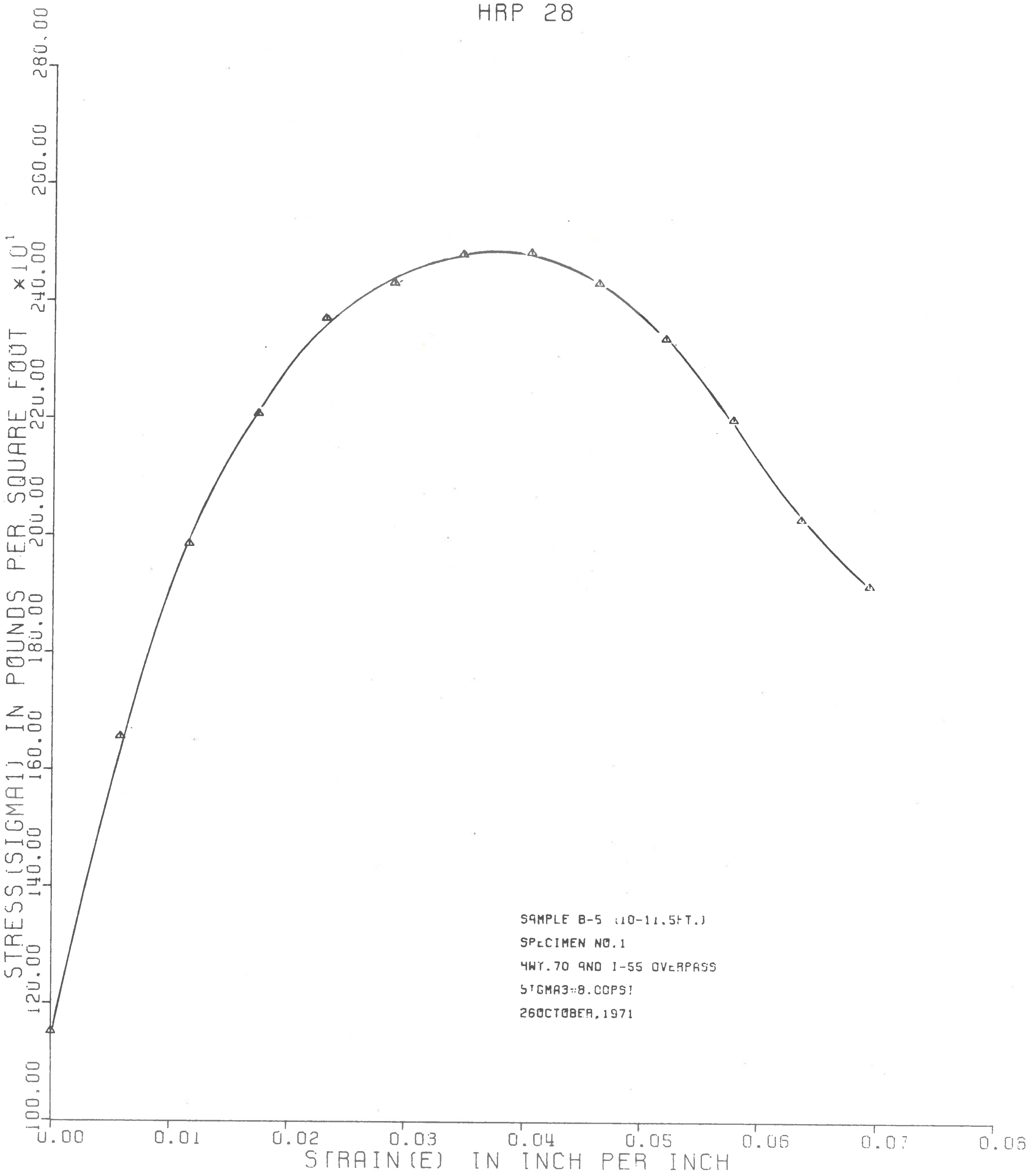


SAMPLE B-3 (6-7.5FT.)
SPECIMEN NO.1
HWY.70 AND I-55 OVERPASS
SIGMA3-5.00PSI
21OCTOBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

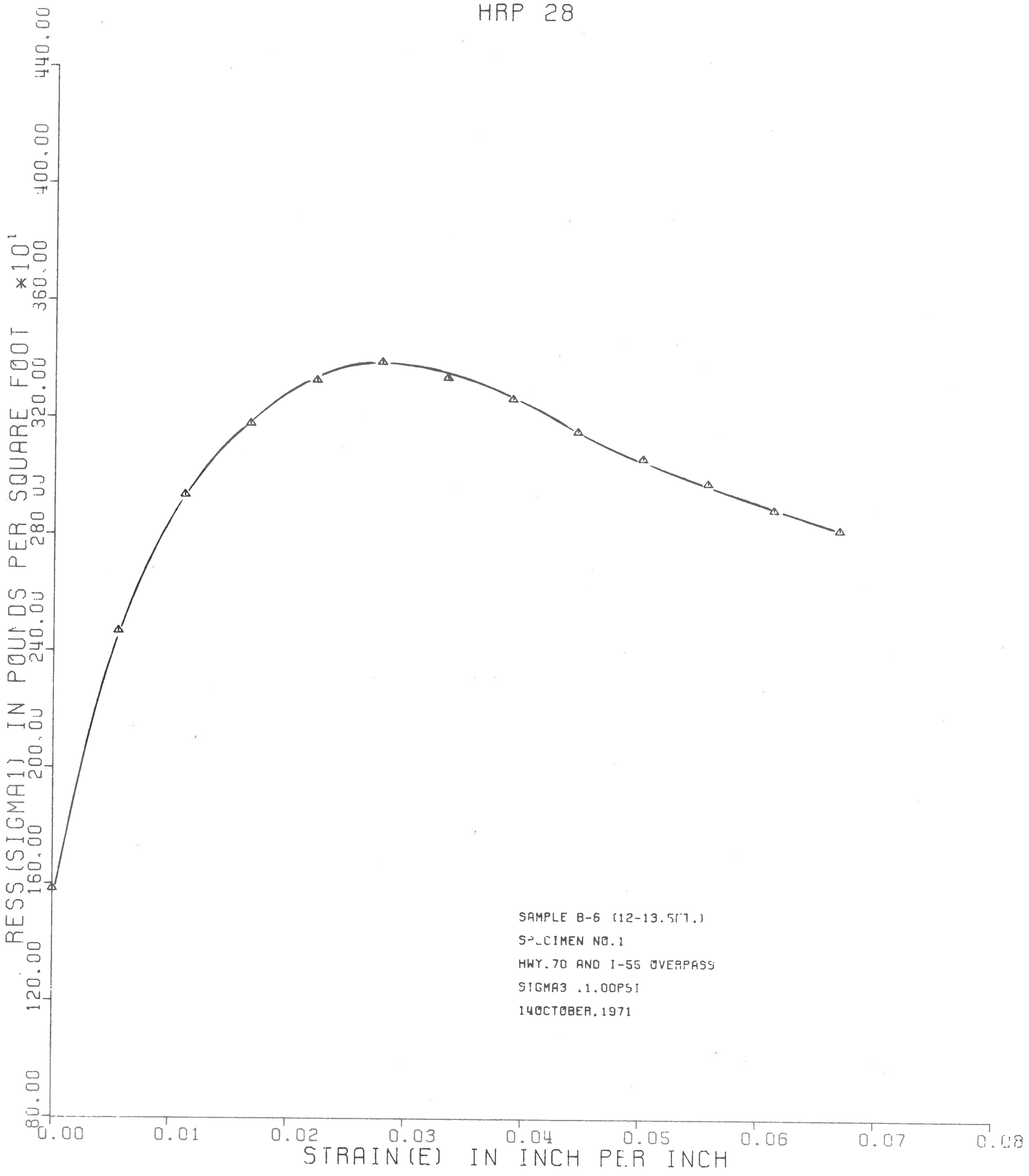


MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

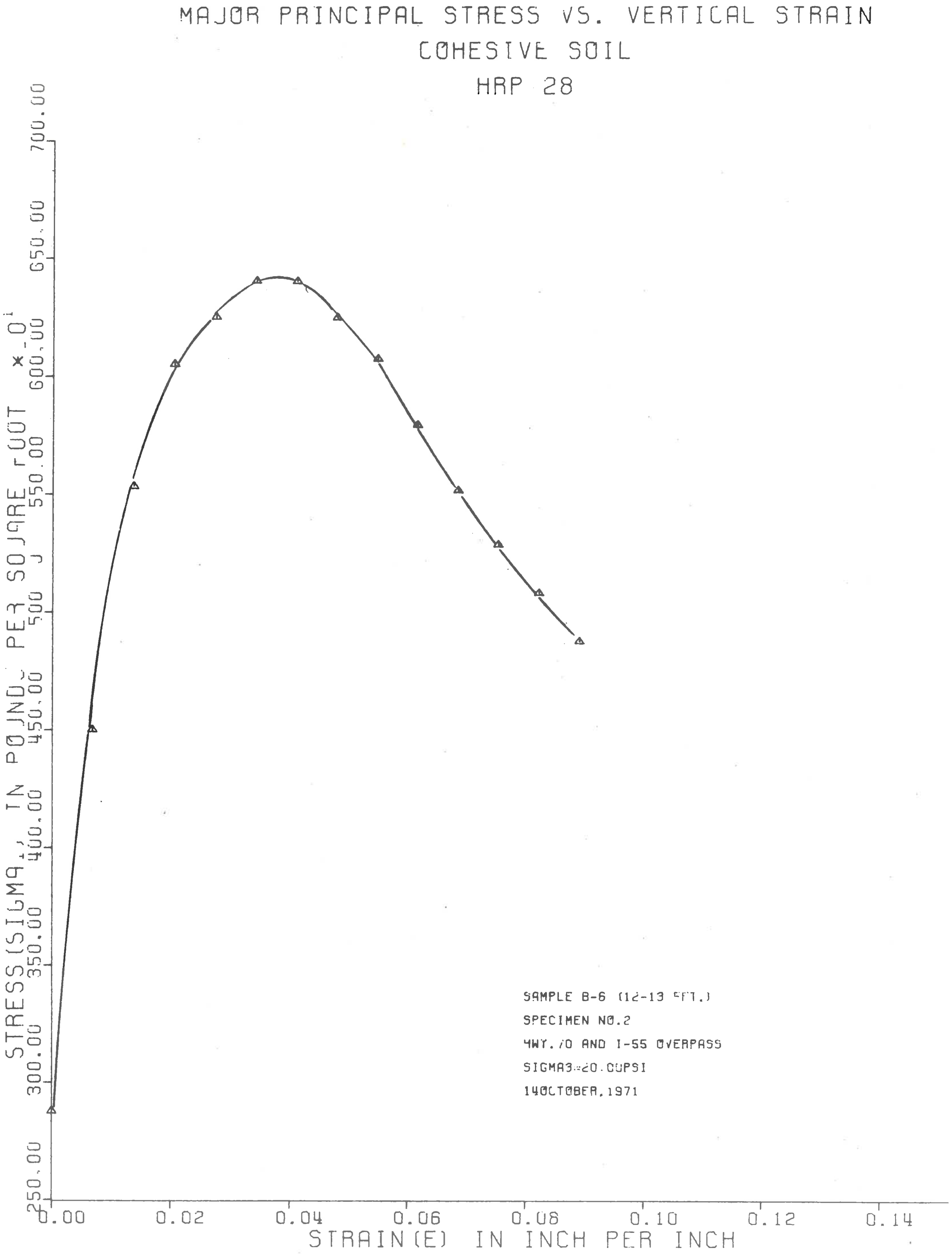


SAMPLE B-5 (10-11.5FT.)
SPECIMEN NO.1
HWY.70 AND I-55 OVERPASS
SIGMA3=8.00PSI
26OCTOBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

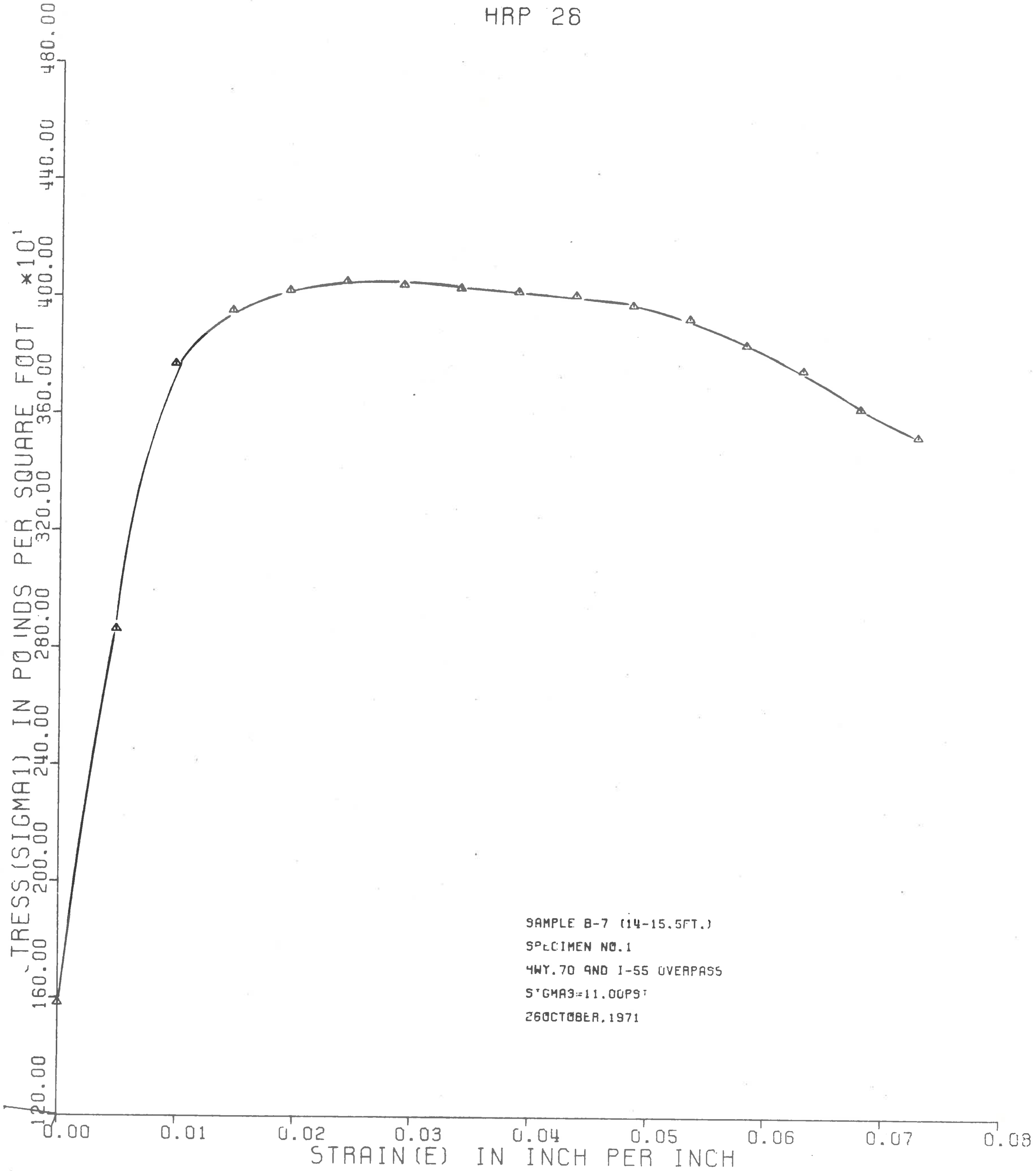


SAMPLE B-6 (12-13.5FT.)
SPECIMEN NO.1
HWY.70 AND I-55 OVERPASS
SIGMA3 =1.00PSI
14OCTOBER,1971



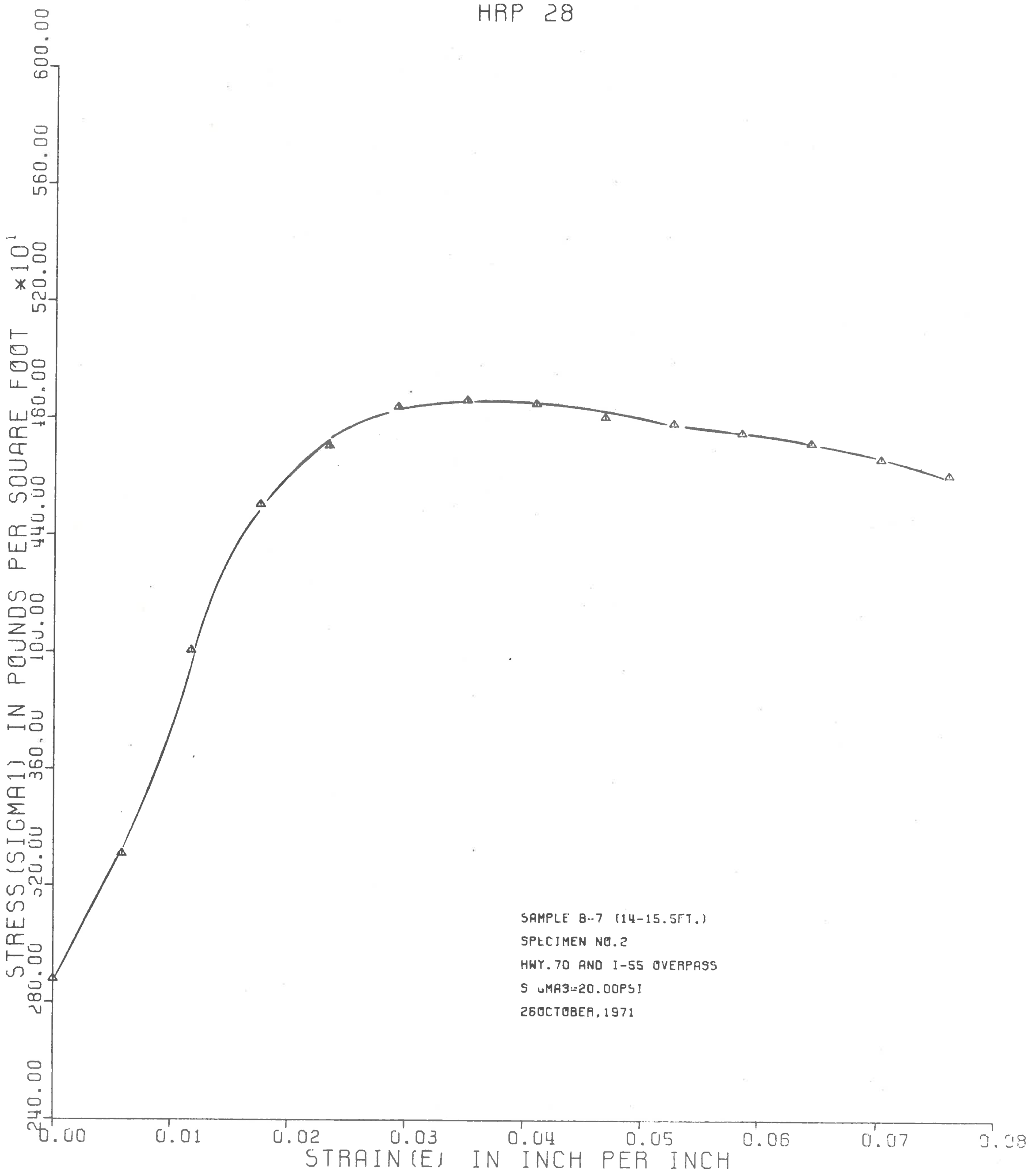
MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



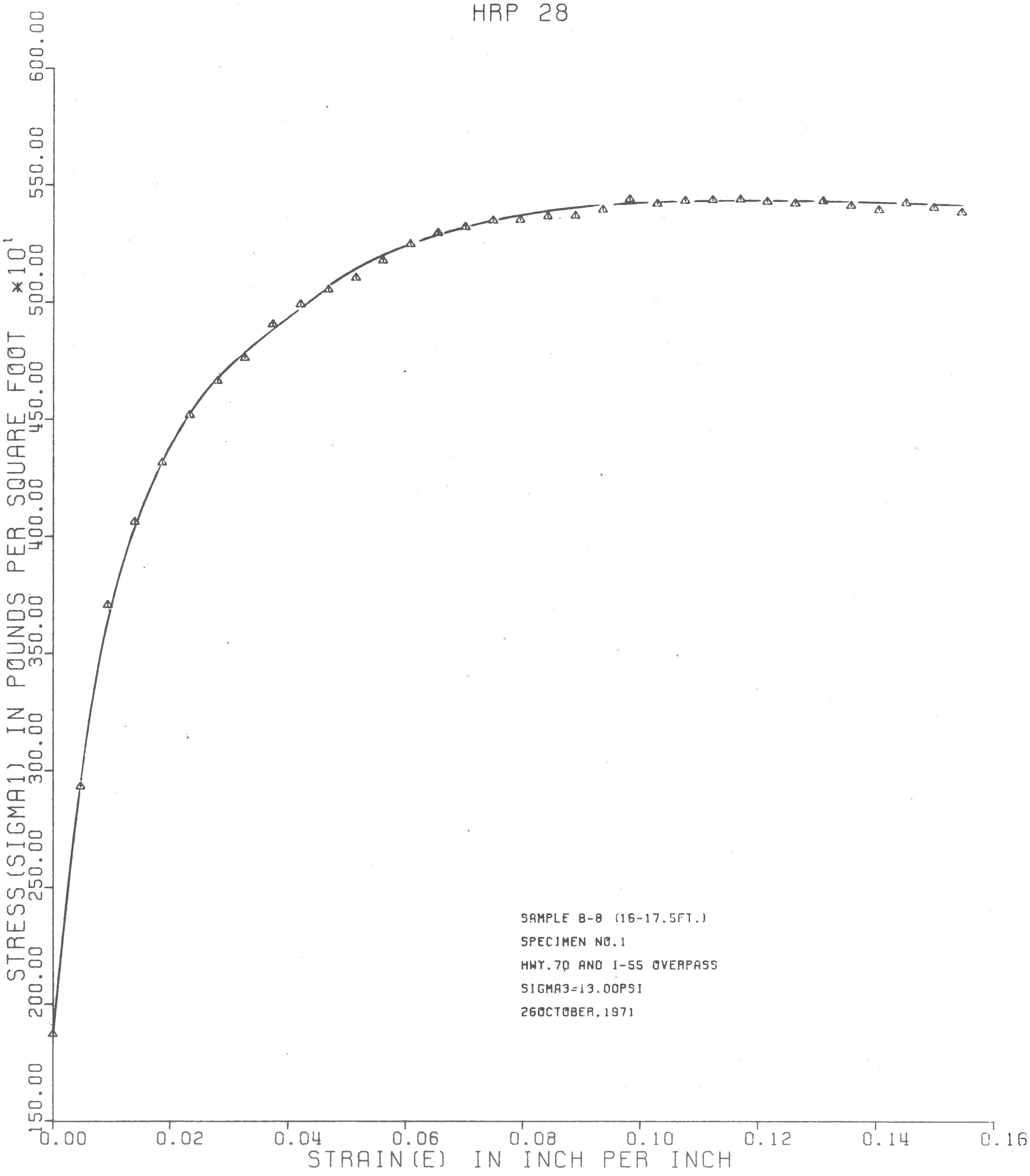
SAMPLE B-7 (14-15.5FT.)
SPECIMEN NO.1
HWY.70 AND I-55 OVERPASS
SIGMA3=11.00PSI
26OCTOBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



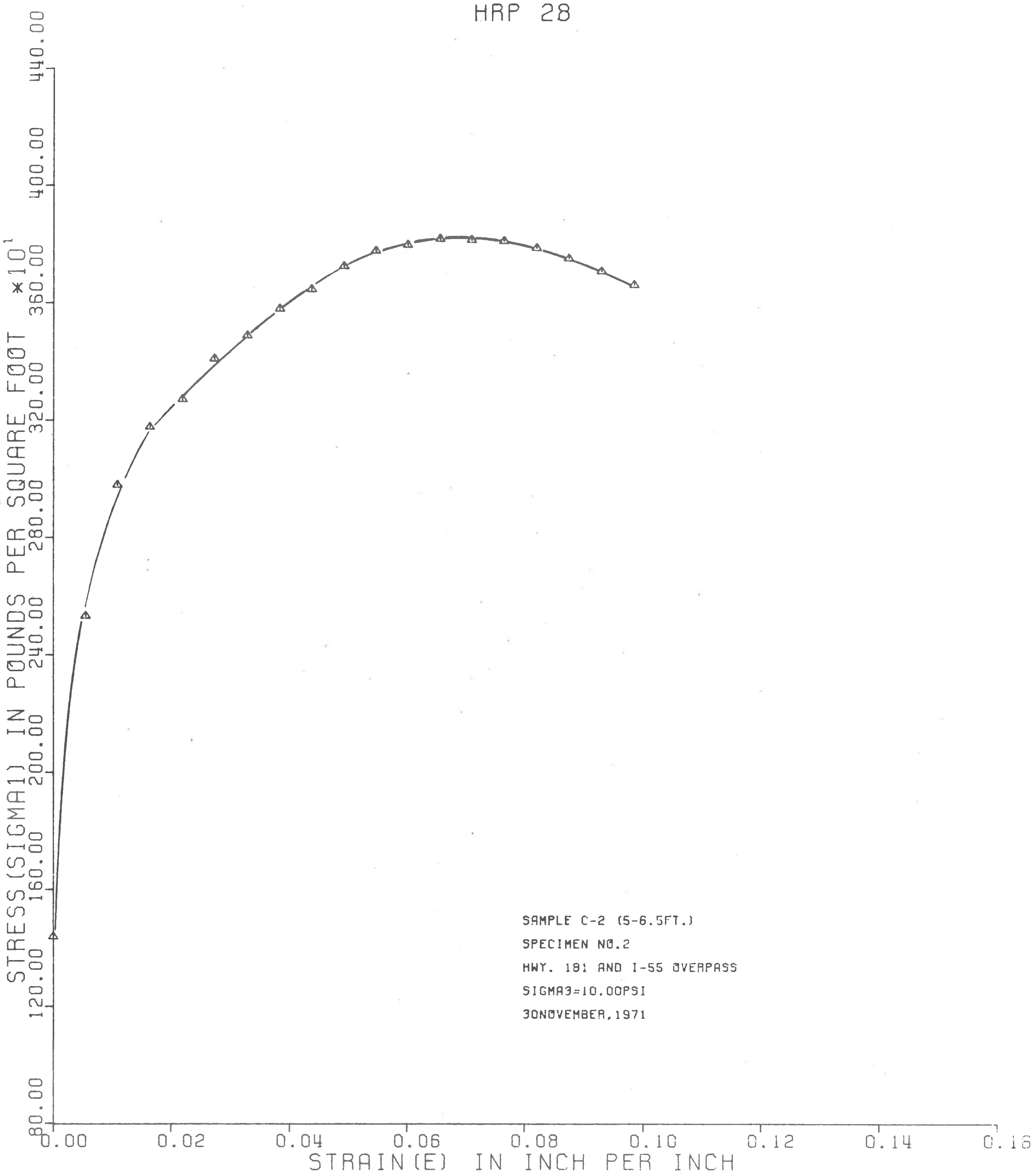
SAMPLE B-7 (14-15.5FT.)
SPECIMEN NO.2
HWY.70 AND I-55 OVERPASS
SIGMA3=20.00PSI
26OCTOBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



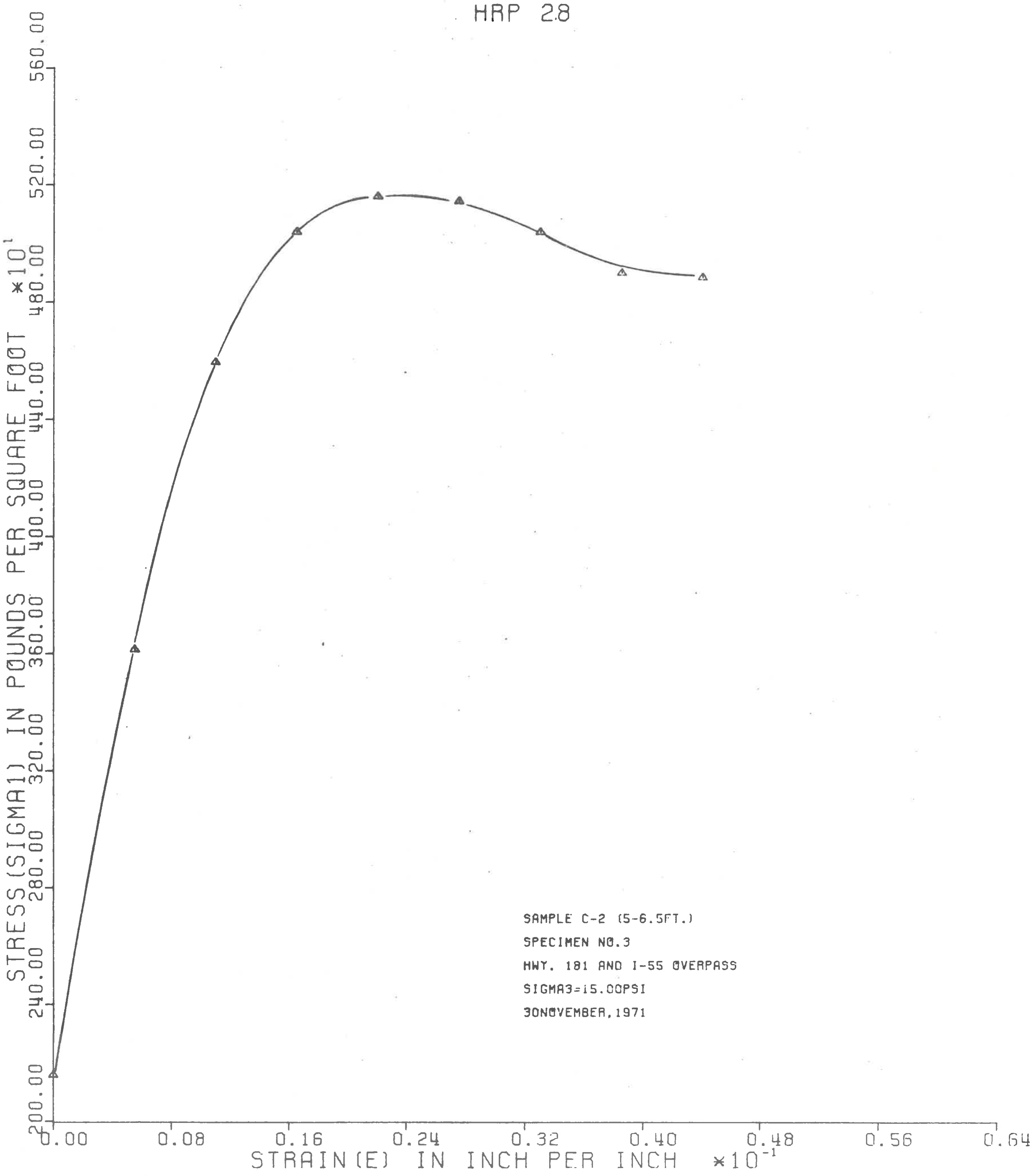
SAMPLE B-8 (16-17.5FT.)
SPECIMEN NO.1
HWY.70 AND I-55 OVERPASS
SIGMA3=13.00PSI
26OCTOBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



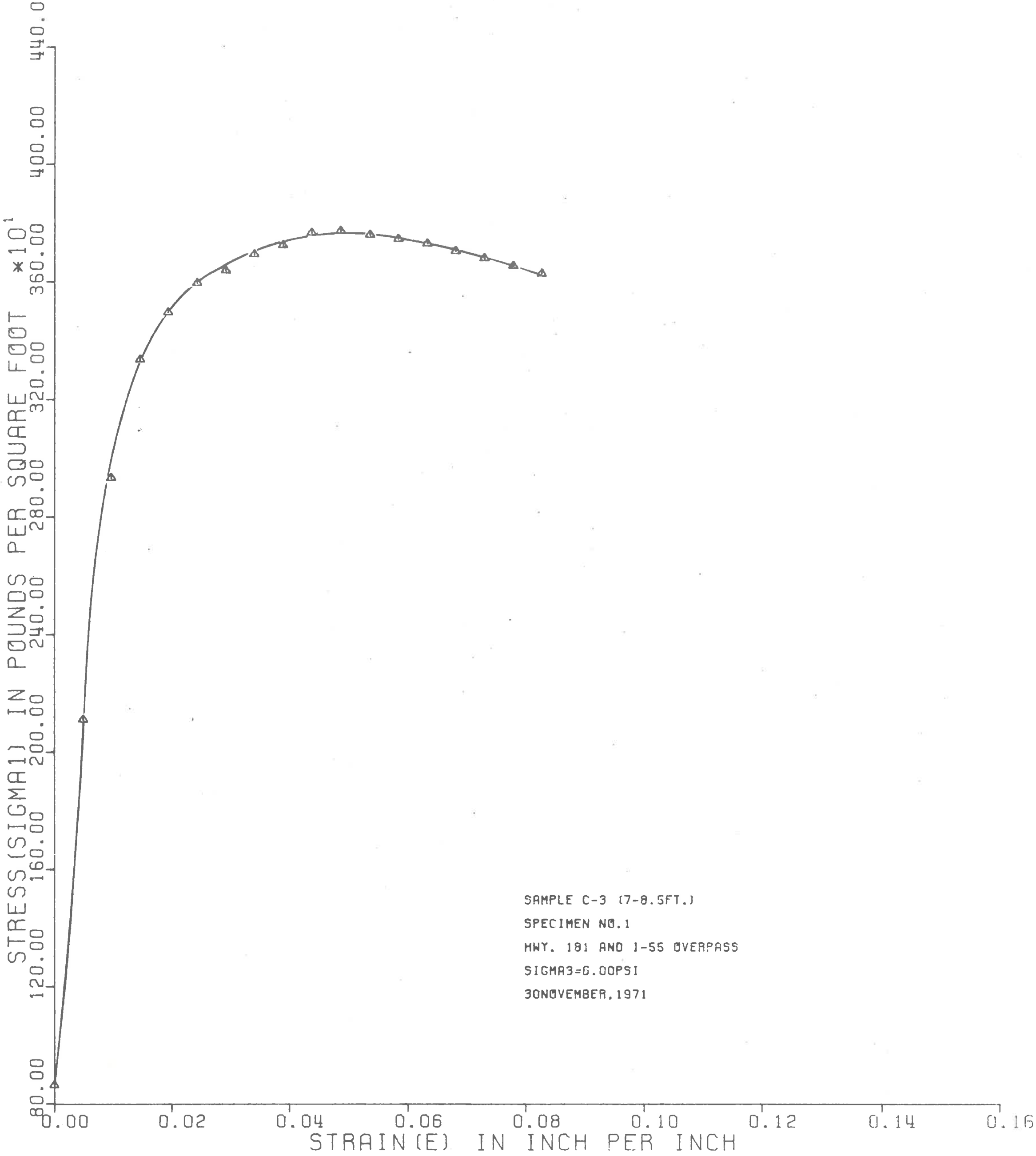
SAMPLE C-2 (5-6.5FT.)
SPECIMEN NO.2
HWY. 181 AND I-55 OVERPASS
SIGMA3=10.00PSI
30NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 2.8



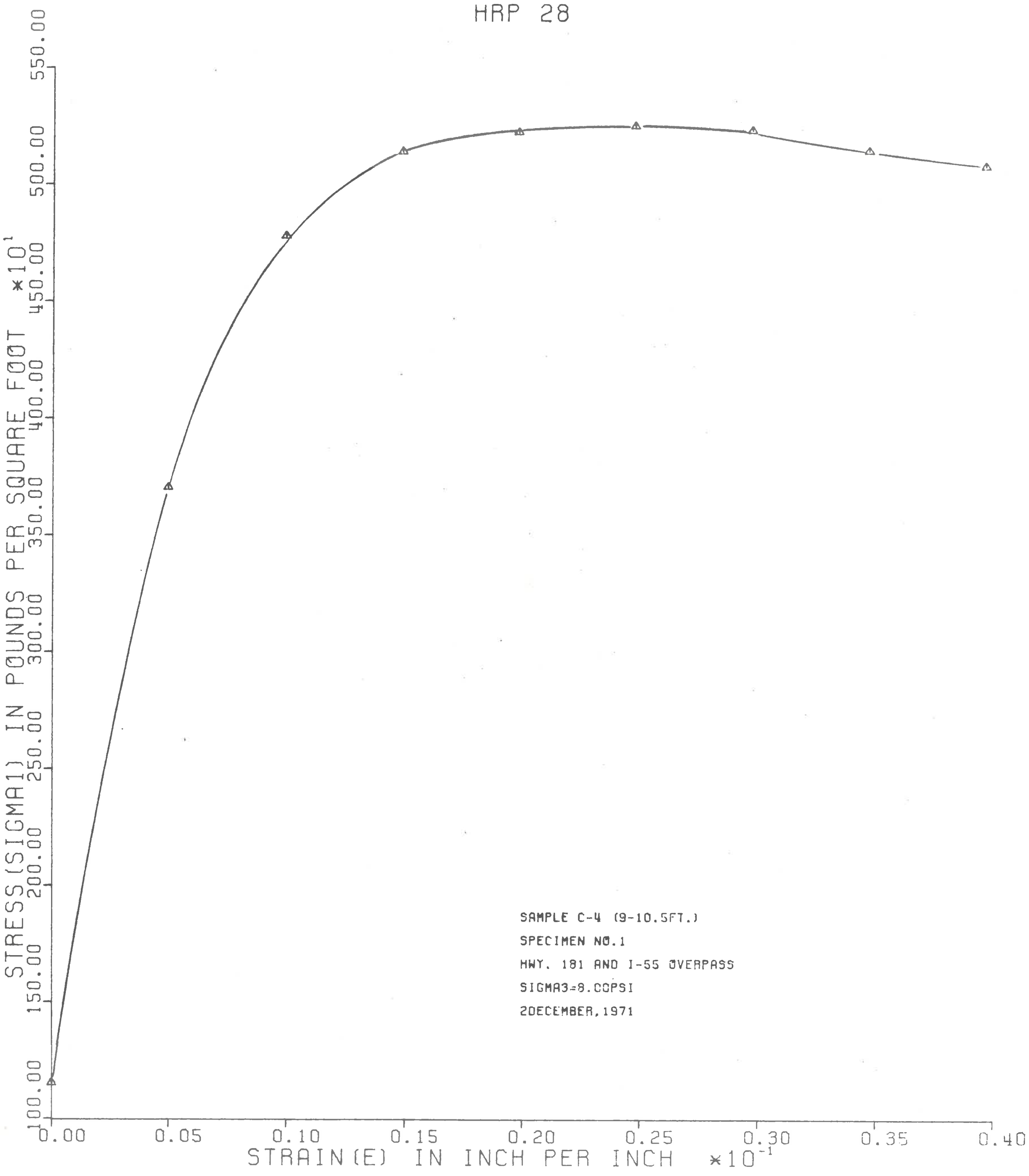
SAMPLE C-2 (5-6.5FT.)
SPECIMEN NO.3
HWY. 181 AND I-55 OVERPASS
SIGMA3=15.00PSI
30NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



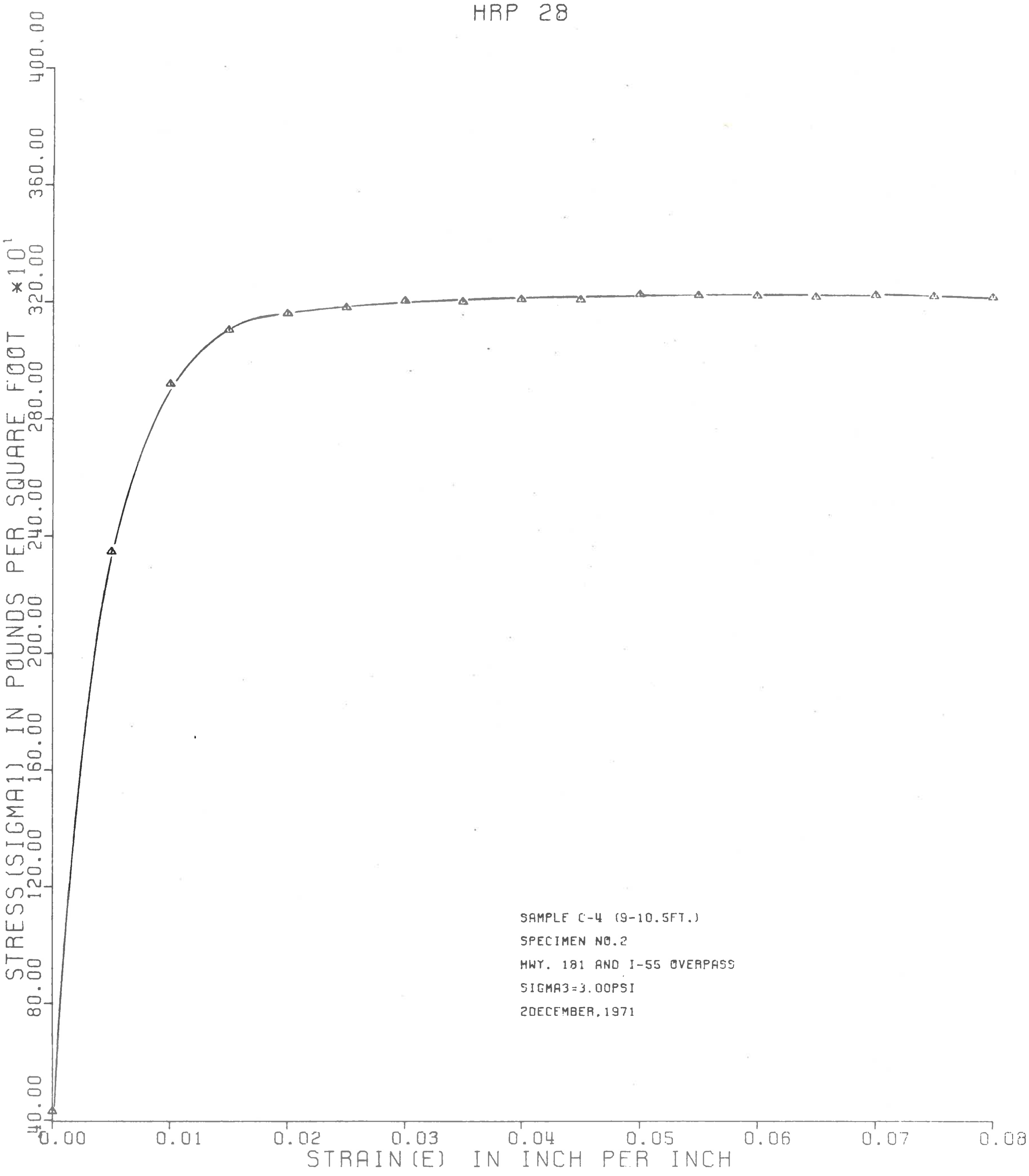
SAMPLE C-3 (7-8.5FT.)
SPECIMEN NO.1
HWY. 181 AND I-55 OVERPASS
SIGMA3=6.00PSI
30NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



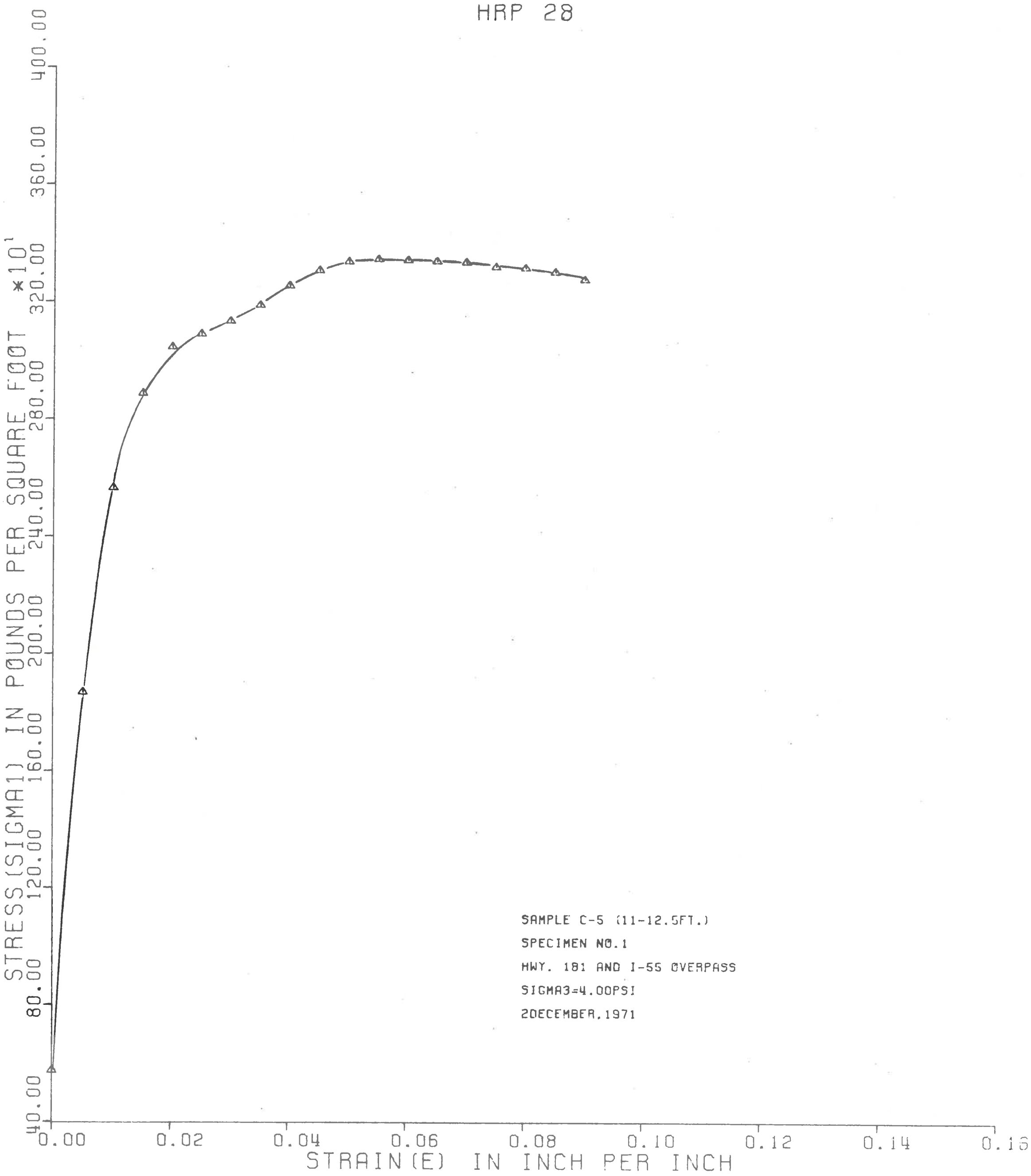
SAMPLE C-4 (9-10.5FT.)
SPECIMEN NO.1
HWY. 181 AND I-55 OVERPASS
SIGMA3=8.00PSI
20ECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



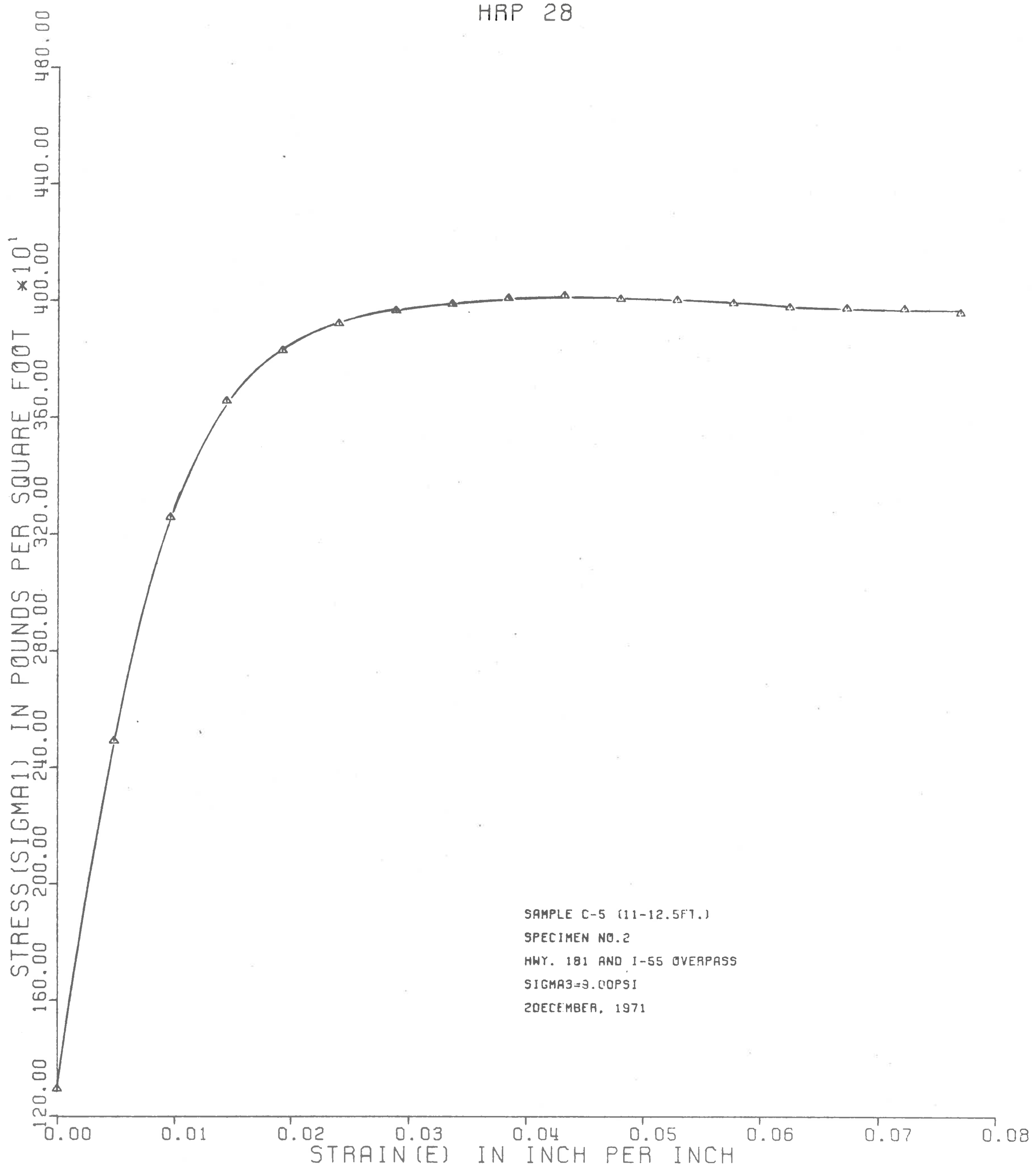
SAMPLE C-4 (9-10.5FT.)
SPECIMEN NO.2
HWY. 181 AND I-55 OVERPASS
SIGMA3=3.00PSI
2DECEMBER,1971

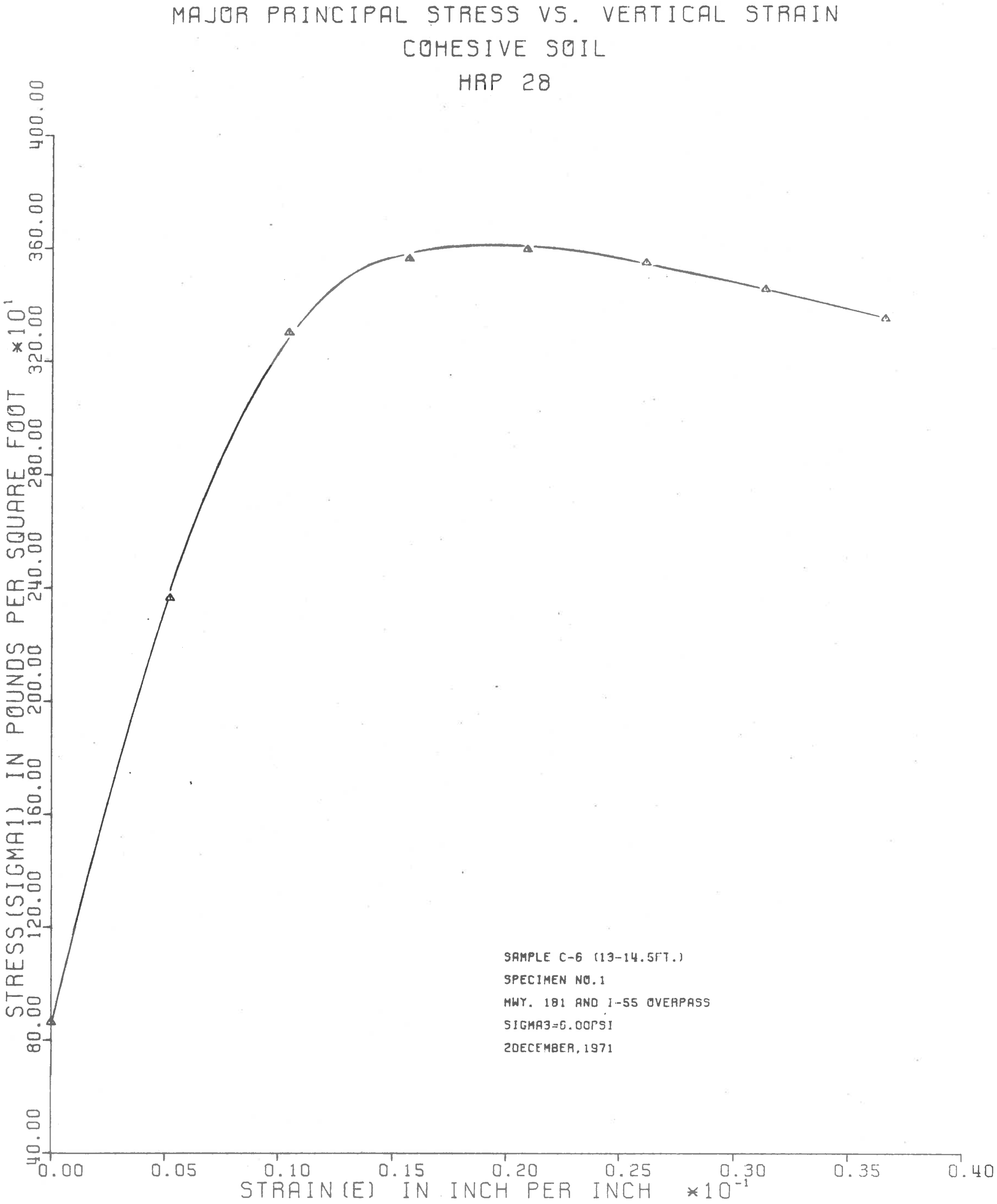
MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



SAMPLE C-5 (11-12.5FT.)
SPECIMEN NO.1
HWY. 181 AND I-55 OVERPASS
SIGMA3=4.00PSI
2DECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

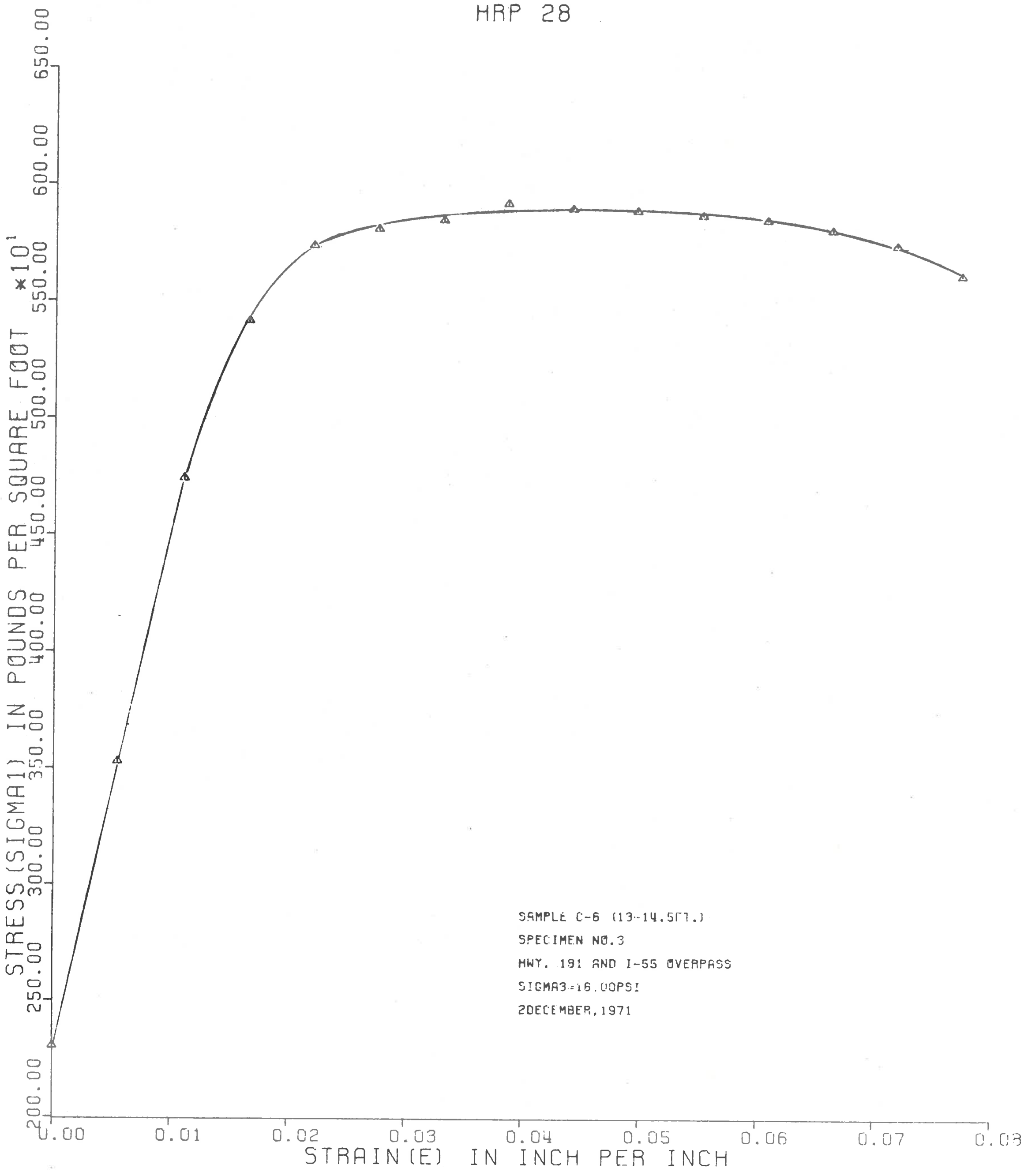




MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

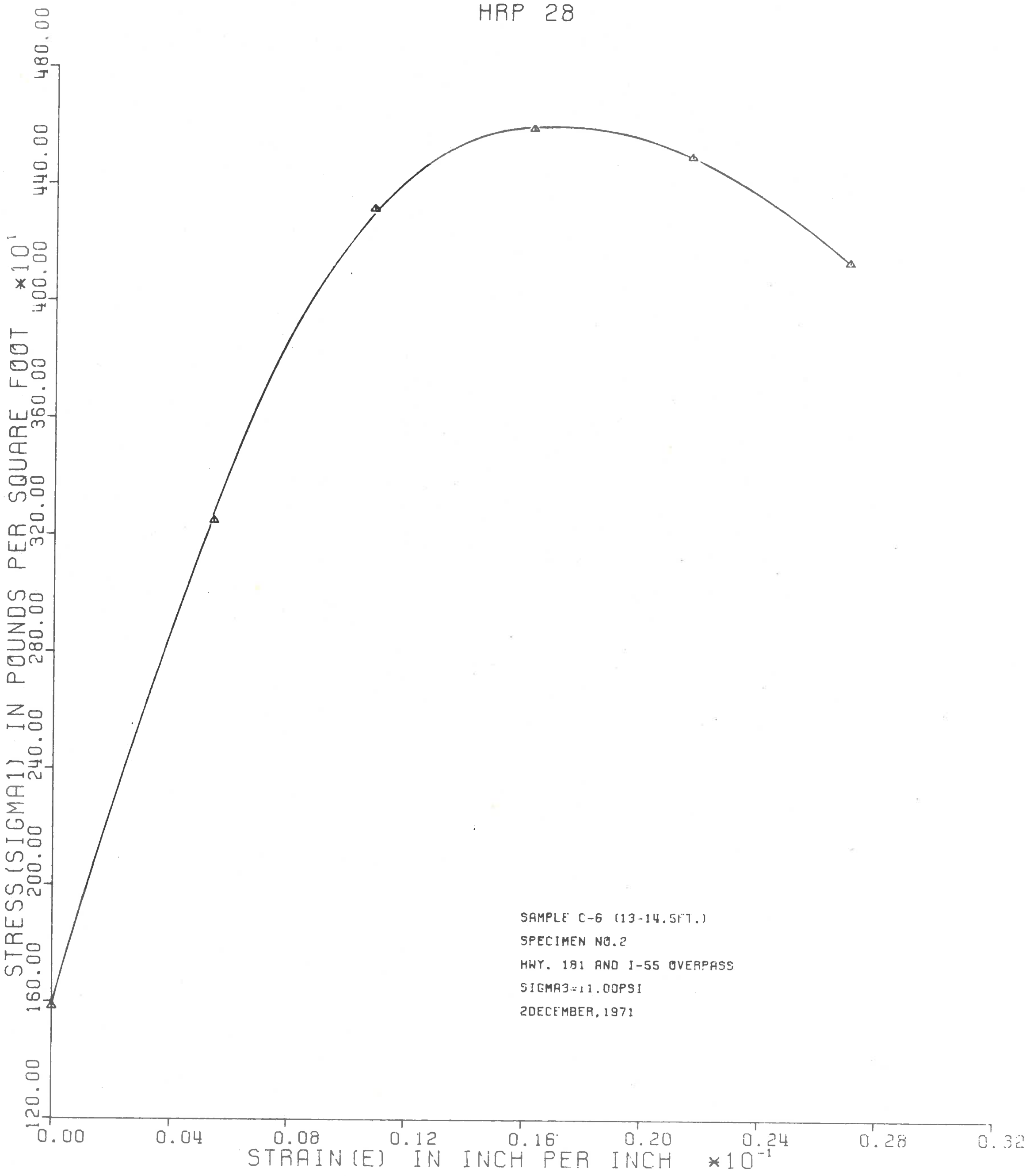
SAMPLE C-6 (13-14.5FT.)
SPECIMEN NO.1
HWY. 181 AND I-55 OVERPASS
SIGMA3=6.00PSI
2DECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



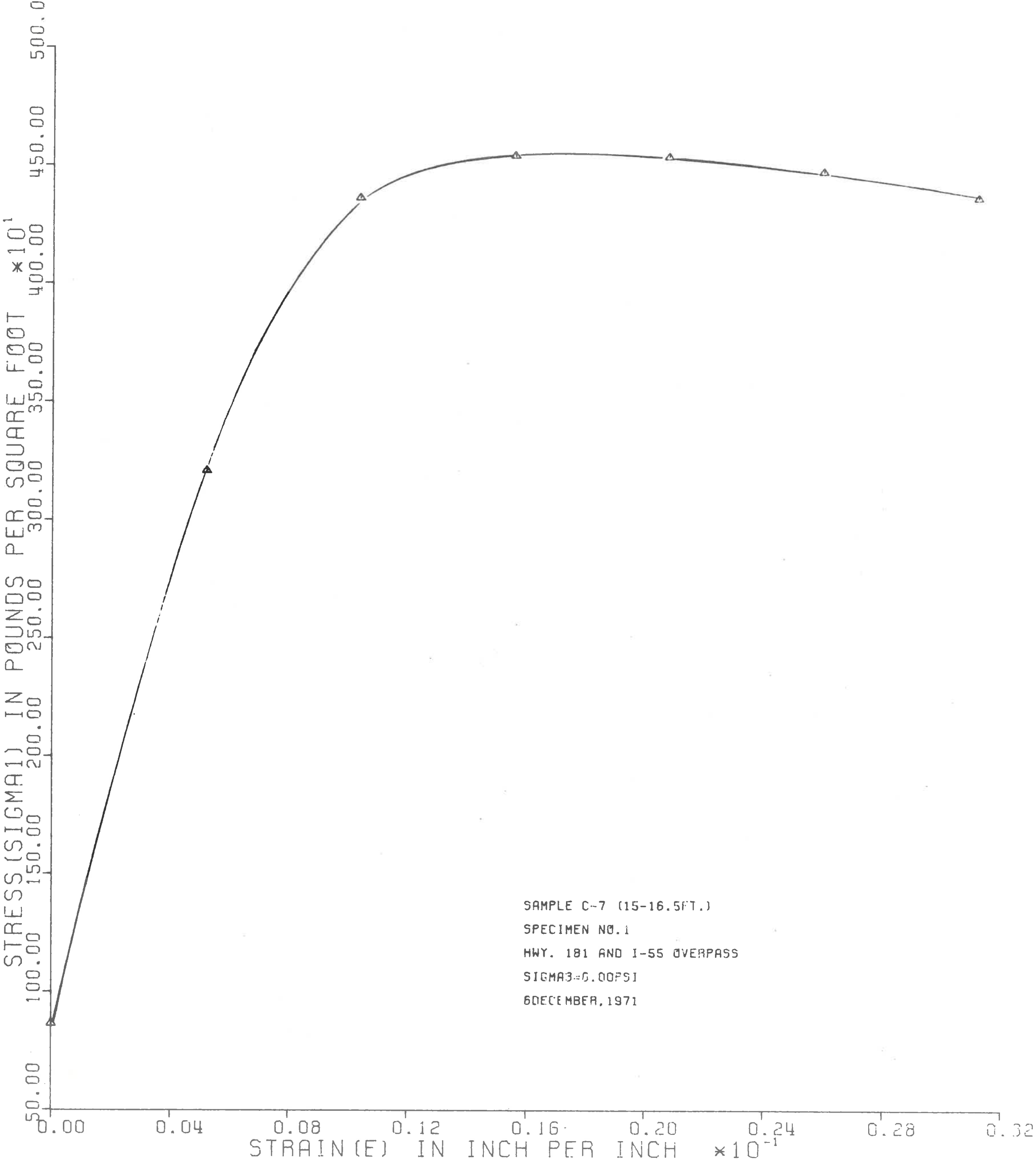
SAMPLE C-6 (13-14.5FT.)
SPECIMEN NO.3
HWY. 191 AND I-55 OVERPASS
SIGMA3=16.00PSI
2DECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



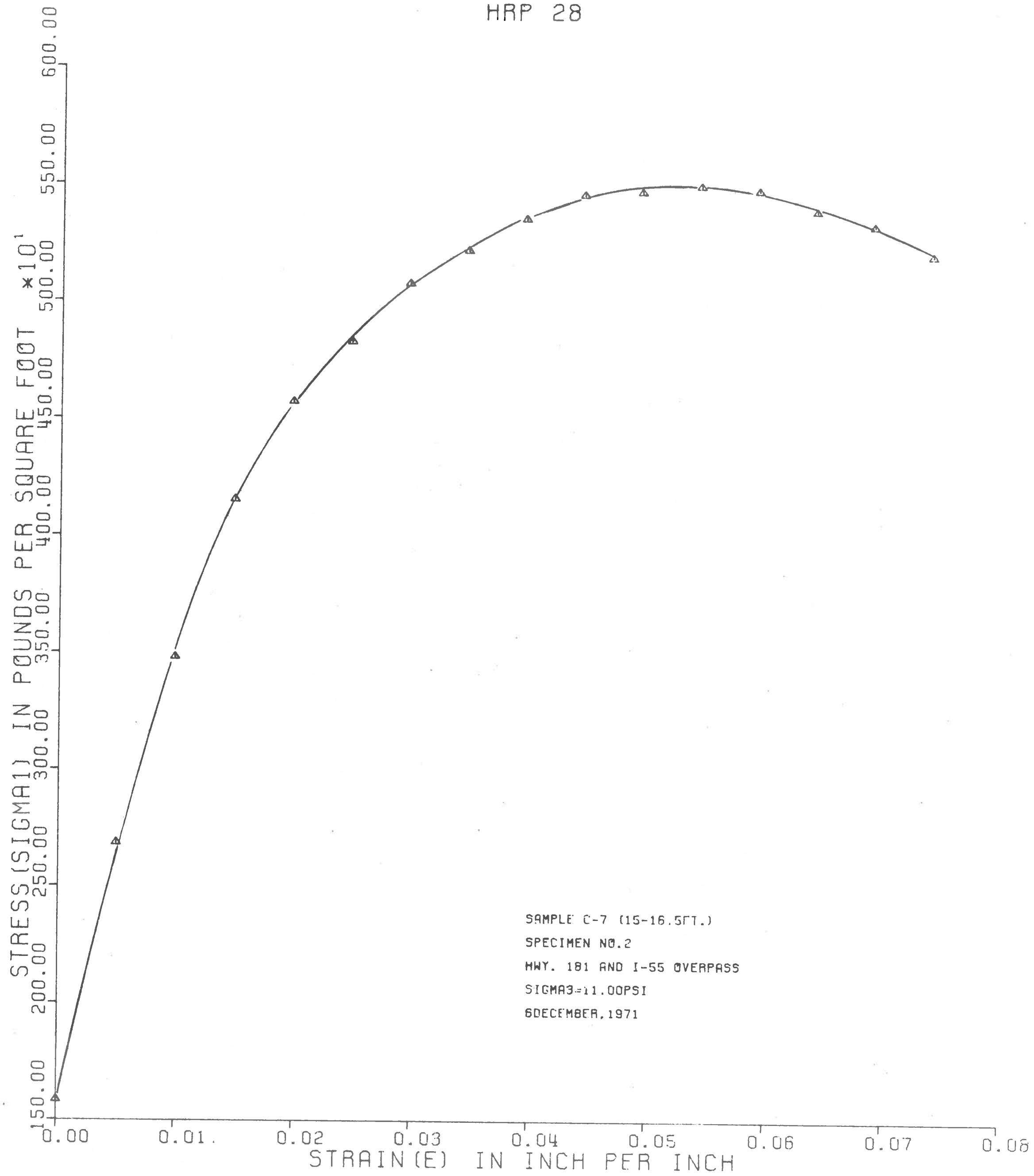
SAMPLE C-6 (13-14.5FT.)
SPECIMEN NO.2
HWY. 181 AND I-55 OVERPASS
SIGMA3=11.00PSI
2DECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

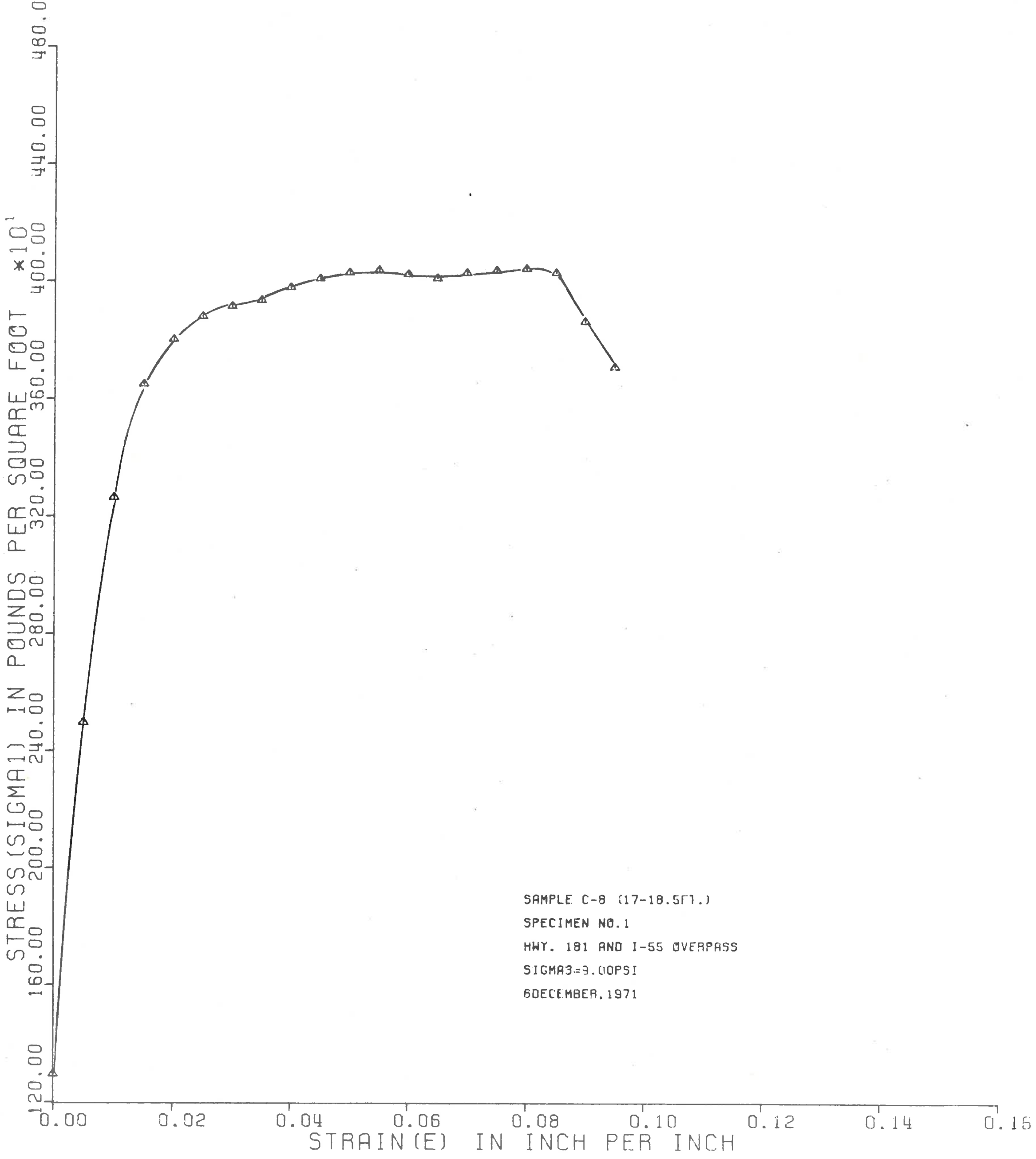


SAMPLE C-7 (15-16.5FT.)
SPECIMEN NO.1
HWY. 181 AND I-55 OVERPASS
SIGMA3=0.00PSI
6DECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

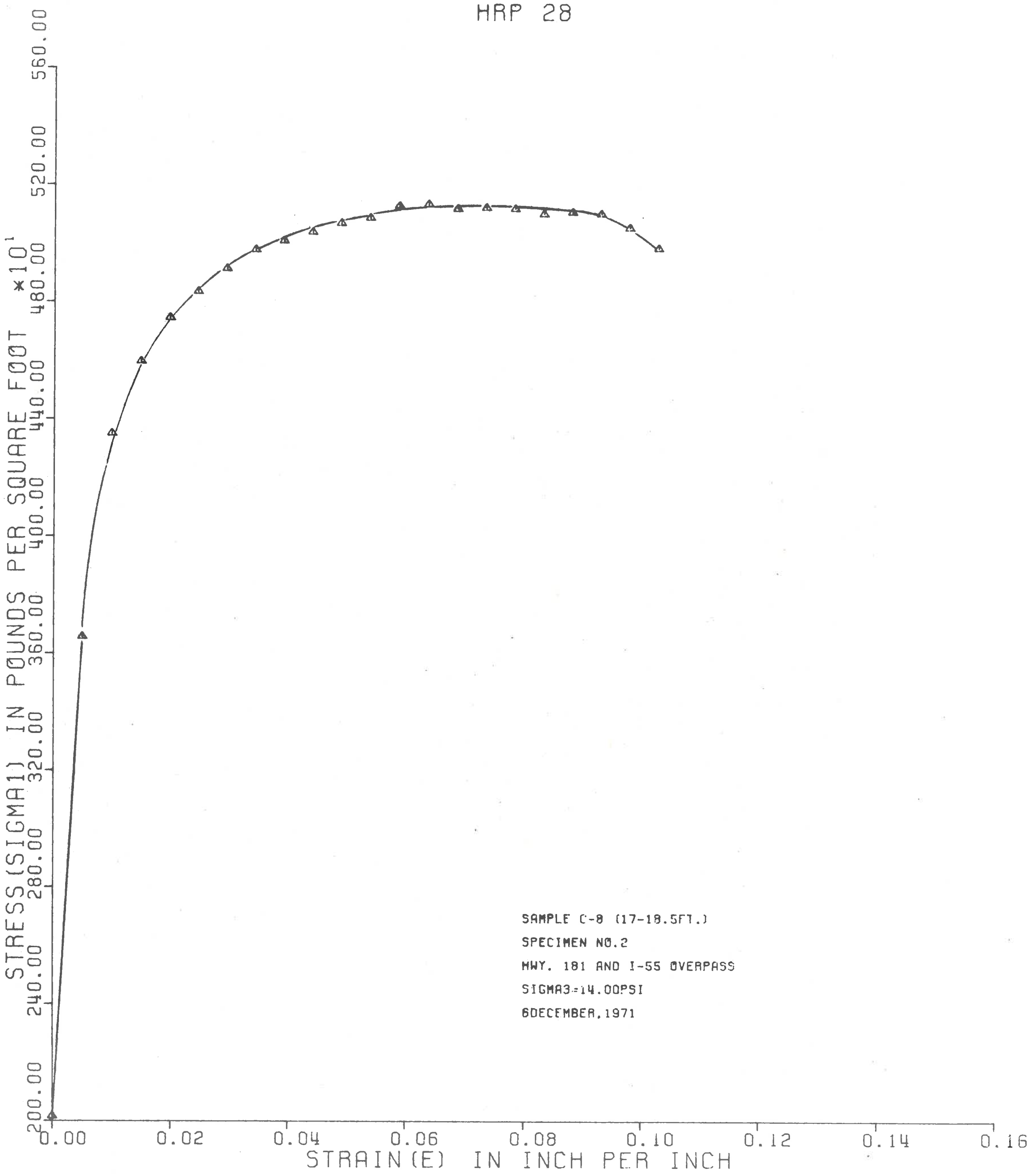


MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



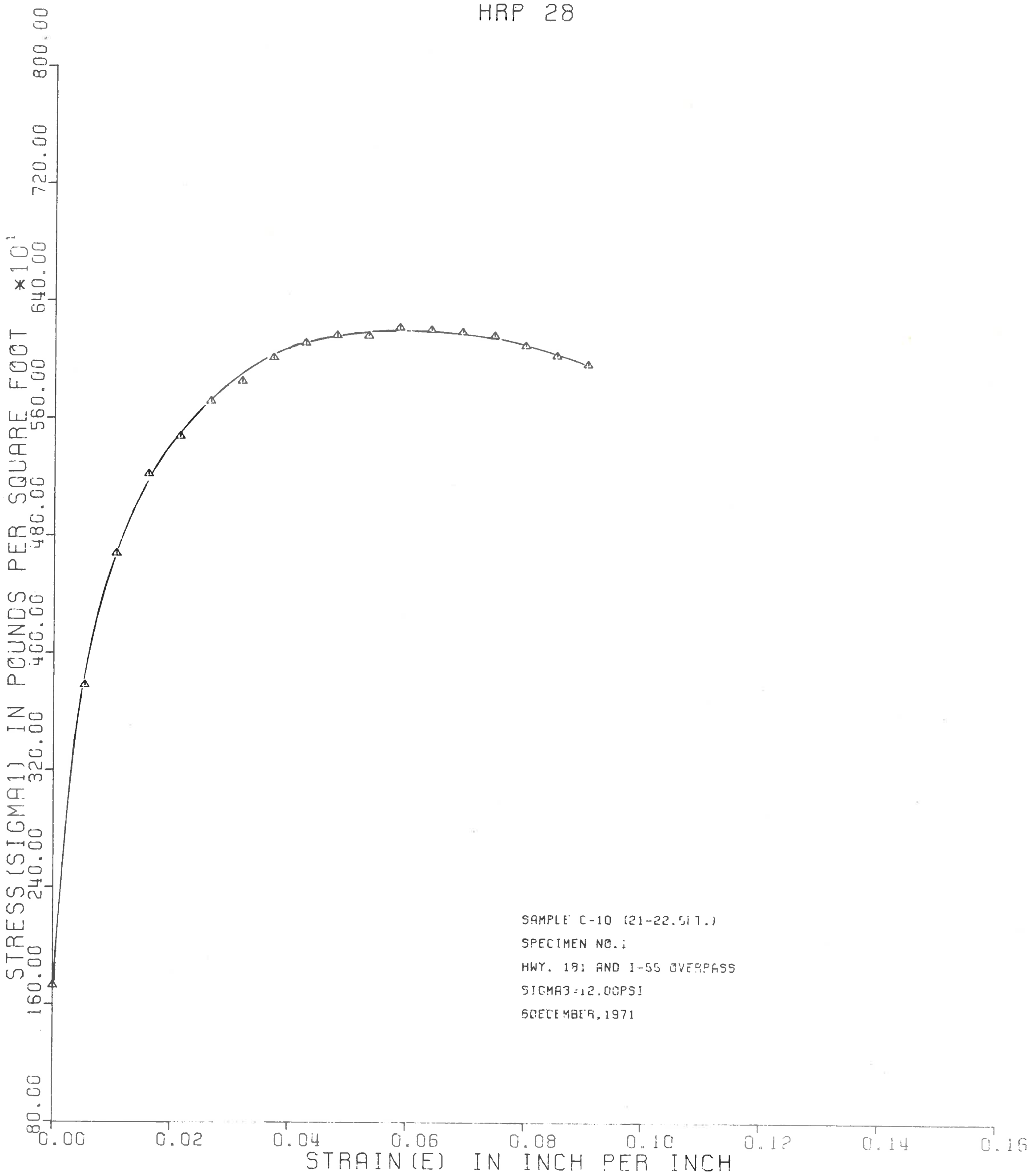
SAMPLE C-8 (17-18.5FT.)
SPECIMEN NO.1
HWY. 181 AND I-55 OVERPASS
SIGMA3=9.00PSI
6DECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



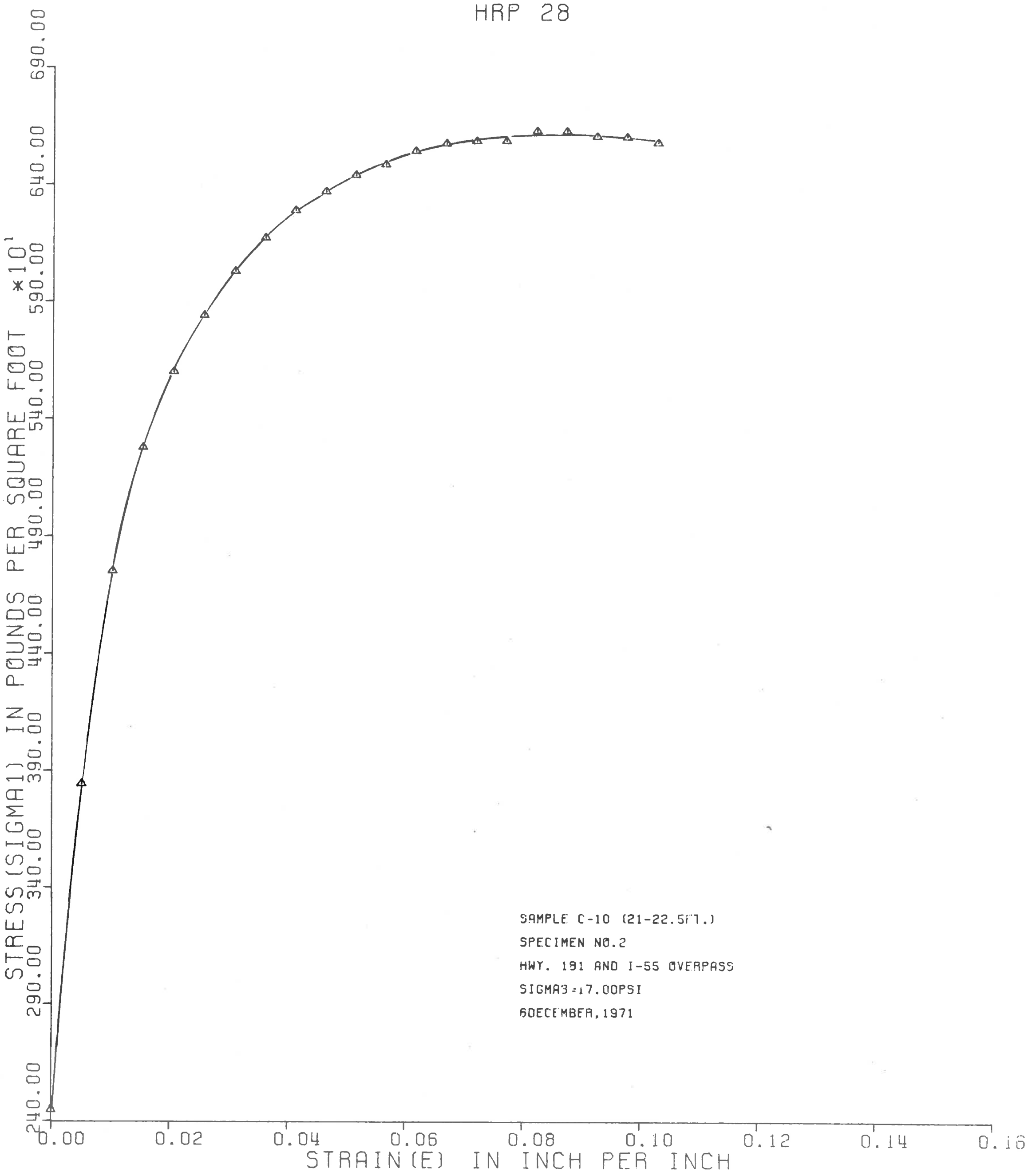
SAMPLE C-8 (17-18.5FT.)
SPECIMEN NO.2
HWY. 181 AND I-55 OVERPASS
SIGMA3=14.00PSI
6DECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



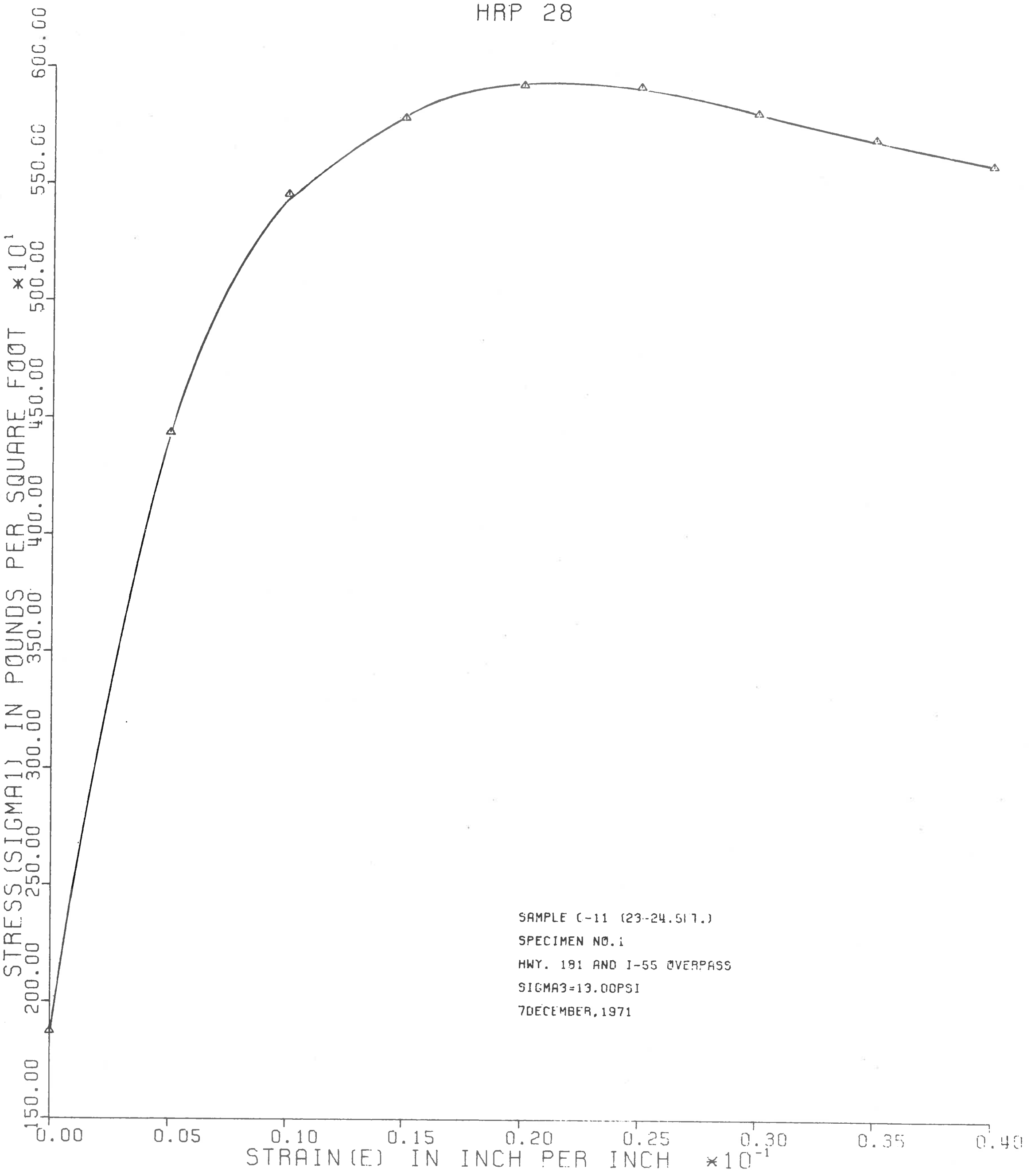
SAMPLE C-10 (21-22.5FT.)
SPECIMEN NO.1
HWY. 191 AND I-55 OVERPASS
SIGMA3=12.00PSI
6DECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



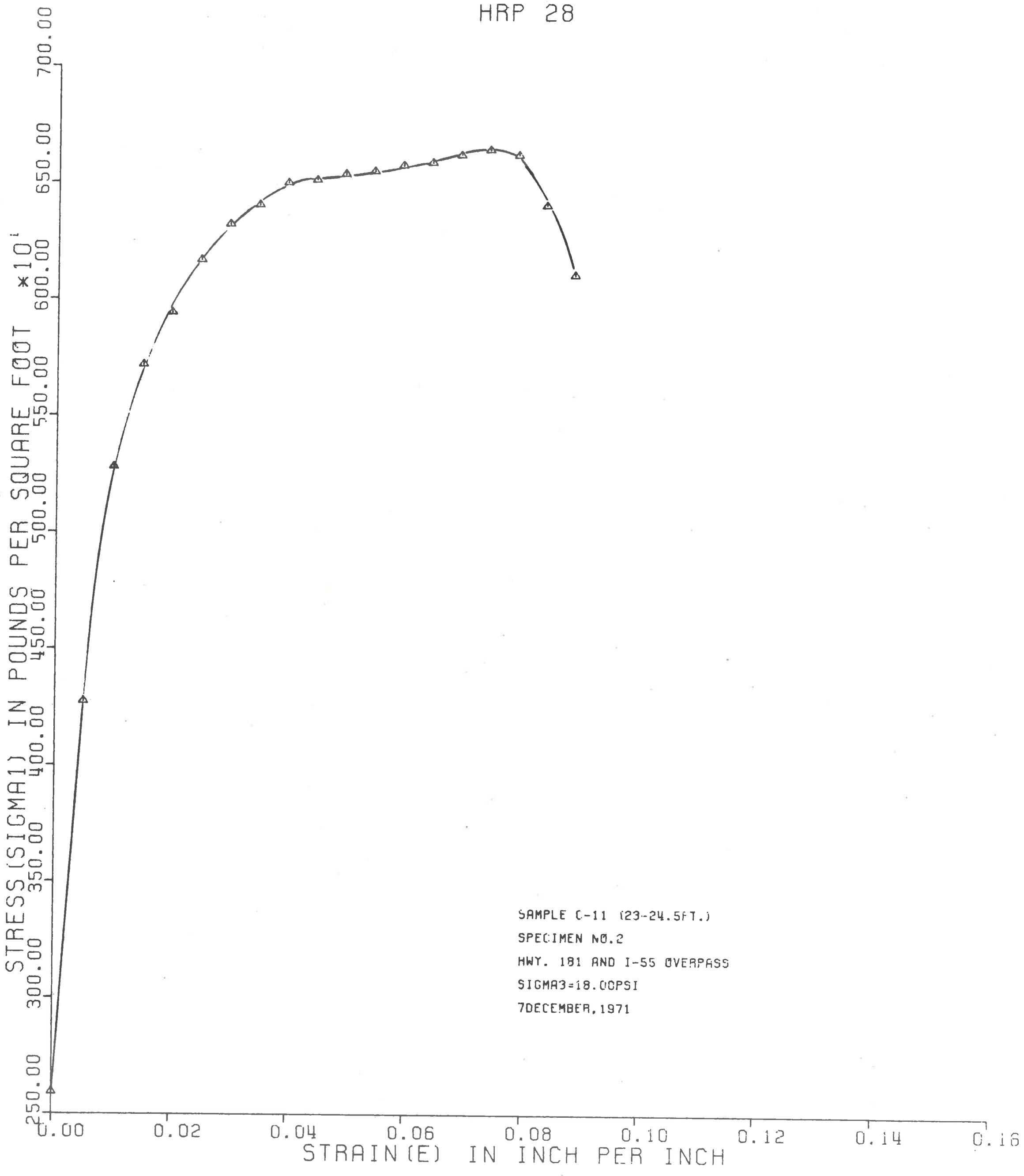
SAMPLE C-10 (21-22.5FT.)
SPECIMEN NO.2
HWY. 191 AND I-55 OVERPASS
SIGMA3=17.00PSI
6DECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

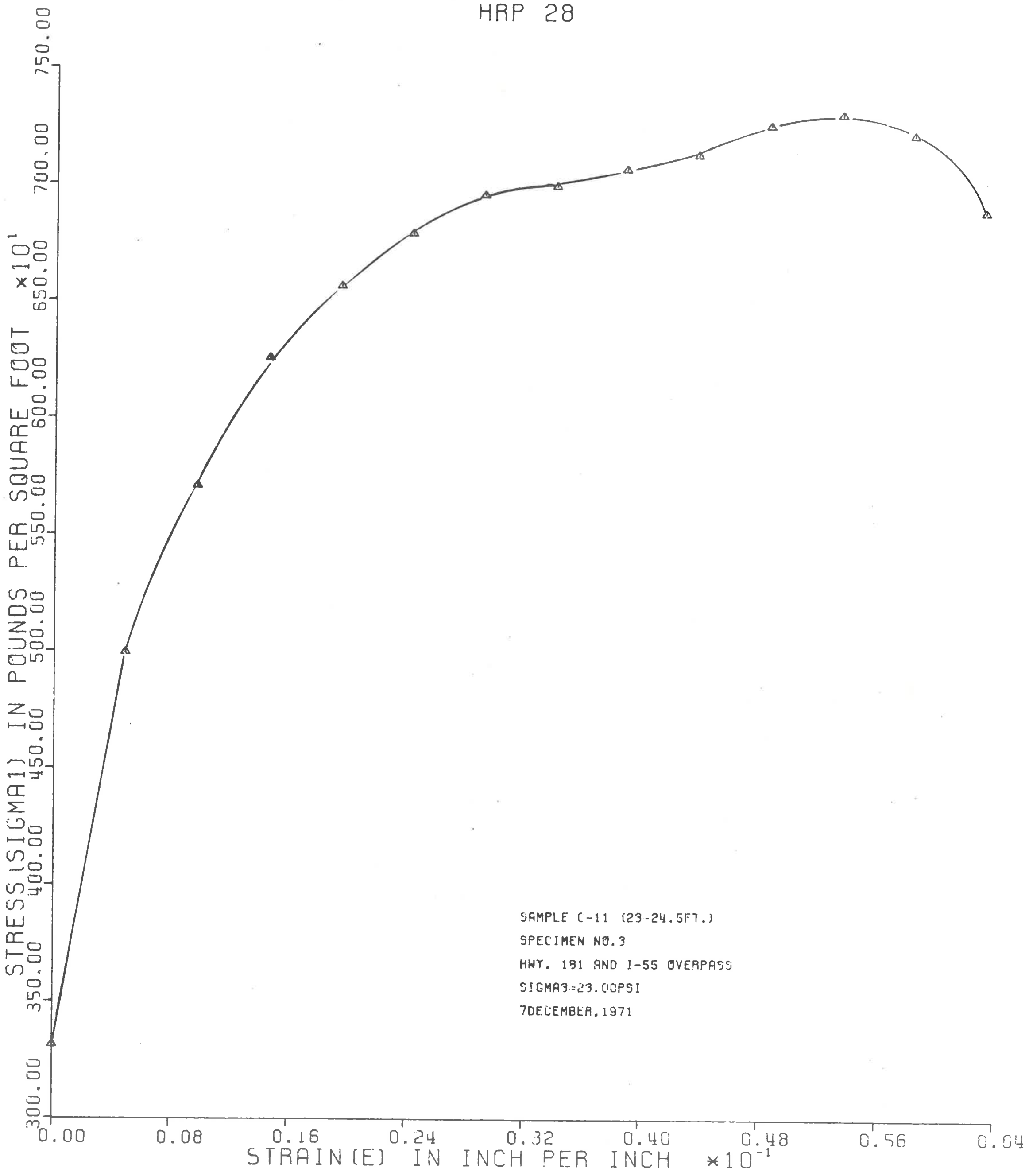


SAMPLE C-11 (23-24.5FT.)
SPECIMEN NO.1
HWY. 191 AND I-55 OVERPASS
SIGMA3=13.00PSI
7DECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

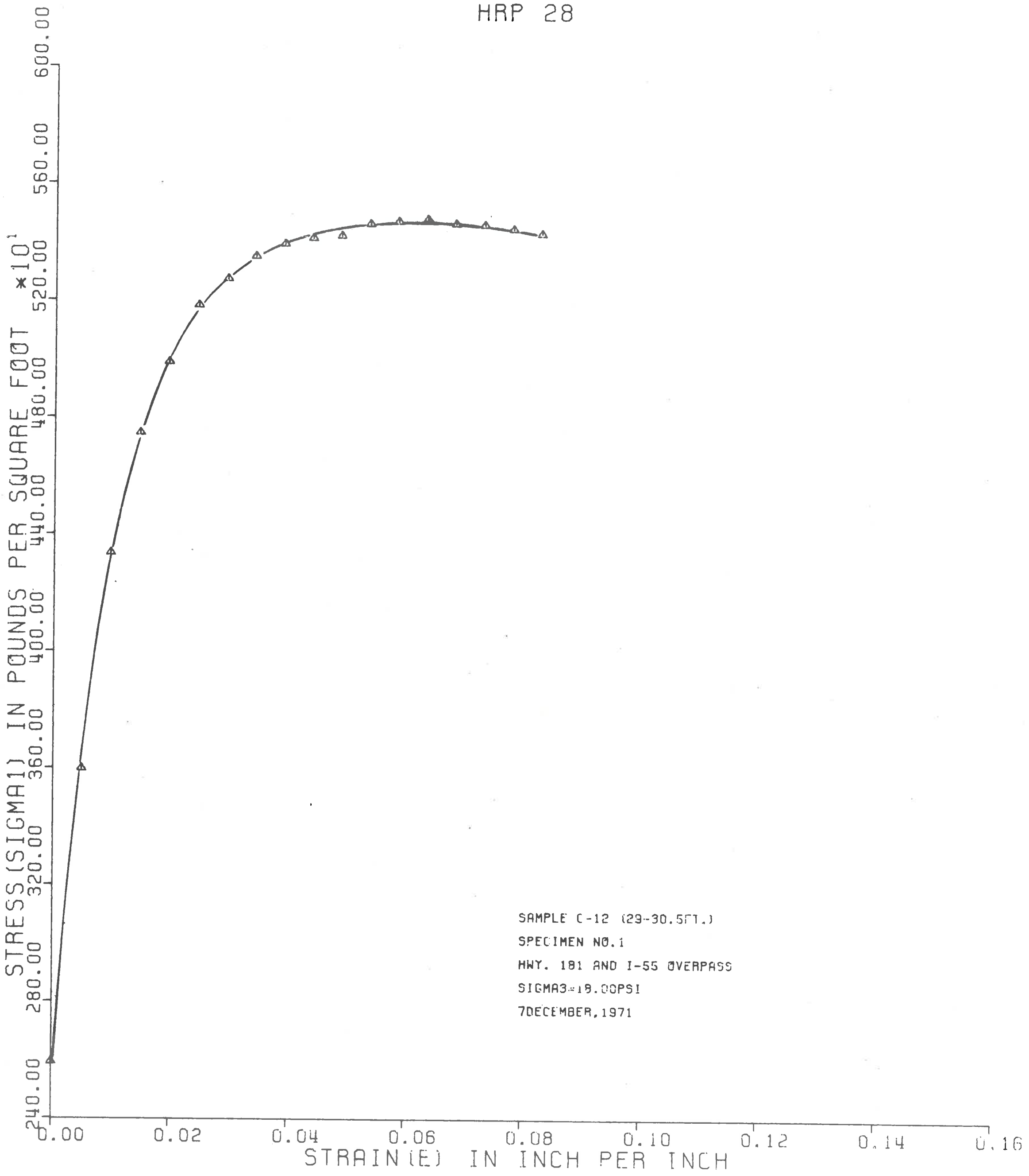


MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



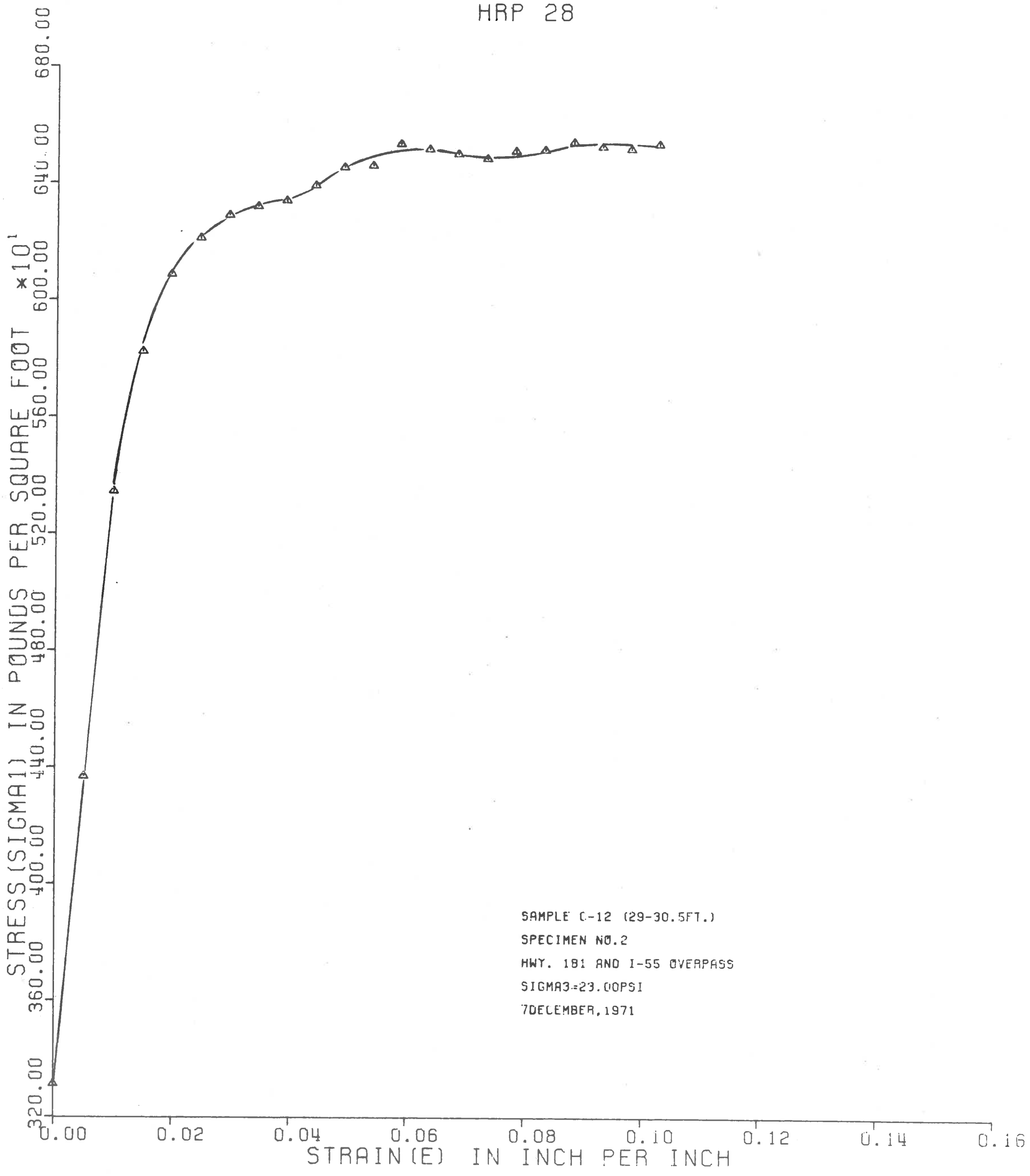
SAMPLE C-11 (23-24.5FT.)
SPECIMEN NO.3
HWY. 181 AND I-55 OVERPASS
SIGMA3=23.00PSI
7DECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



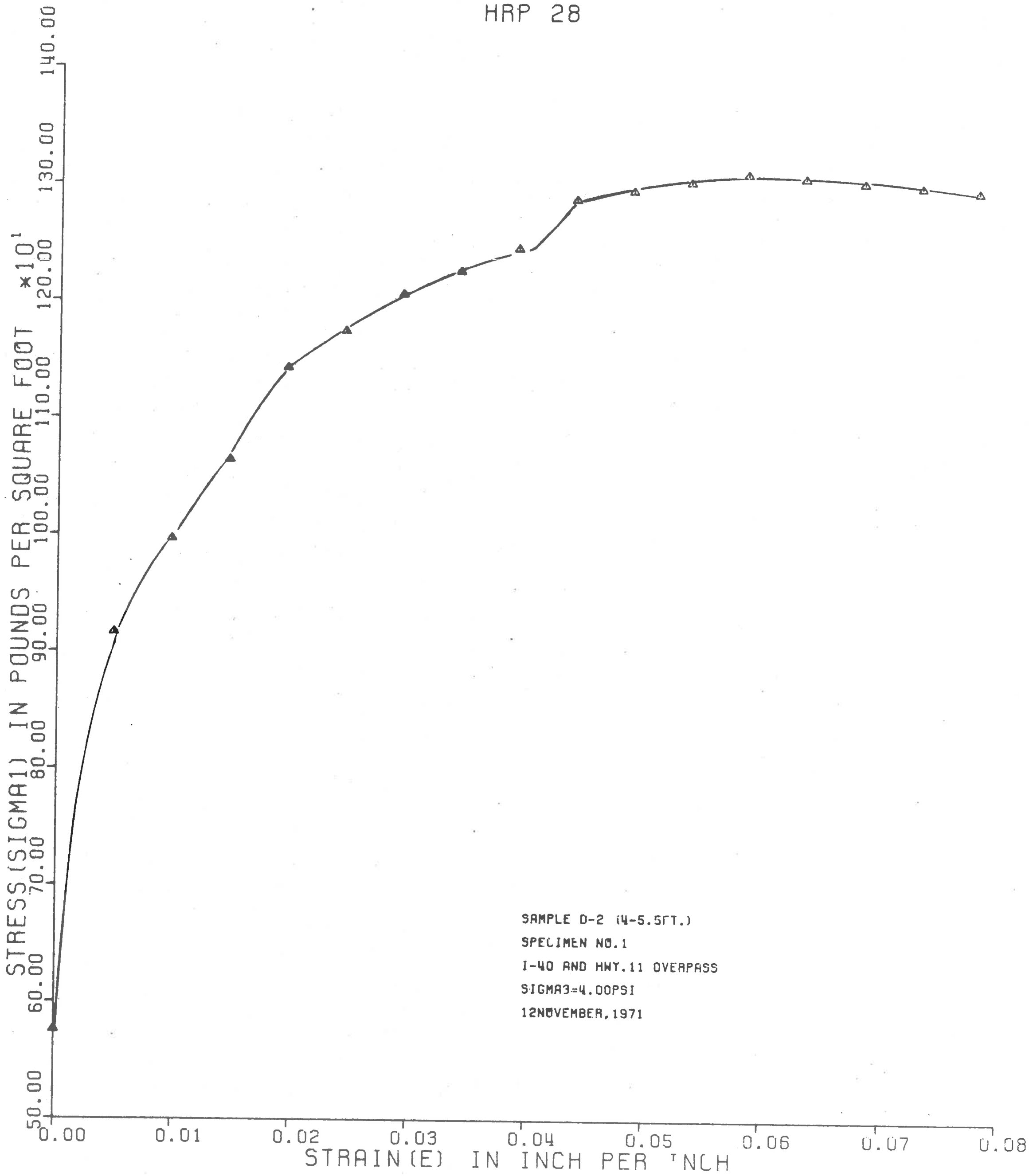
SAMPLE C-12 (29-30.5FT.)
SPECIMEN NO.1
HWY. 181 AND I-55 OVERPASS
SIGMA3=19.00PSI
7DECEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

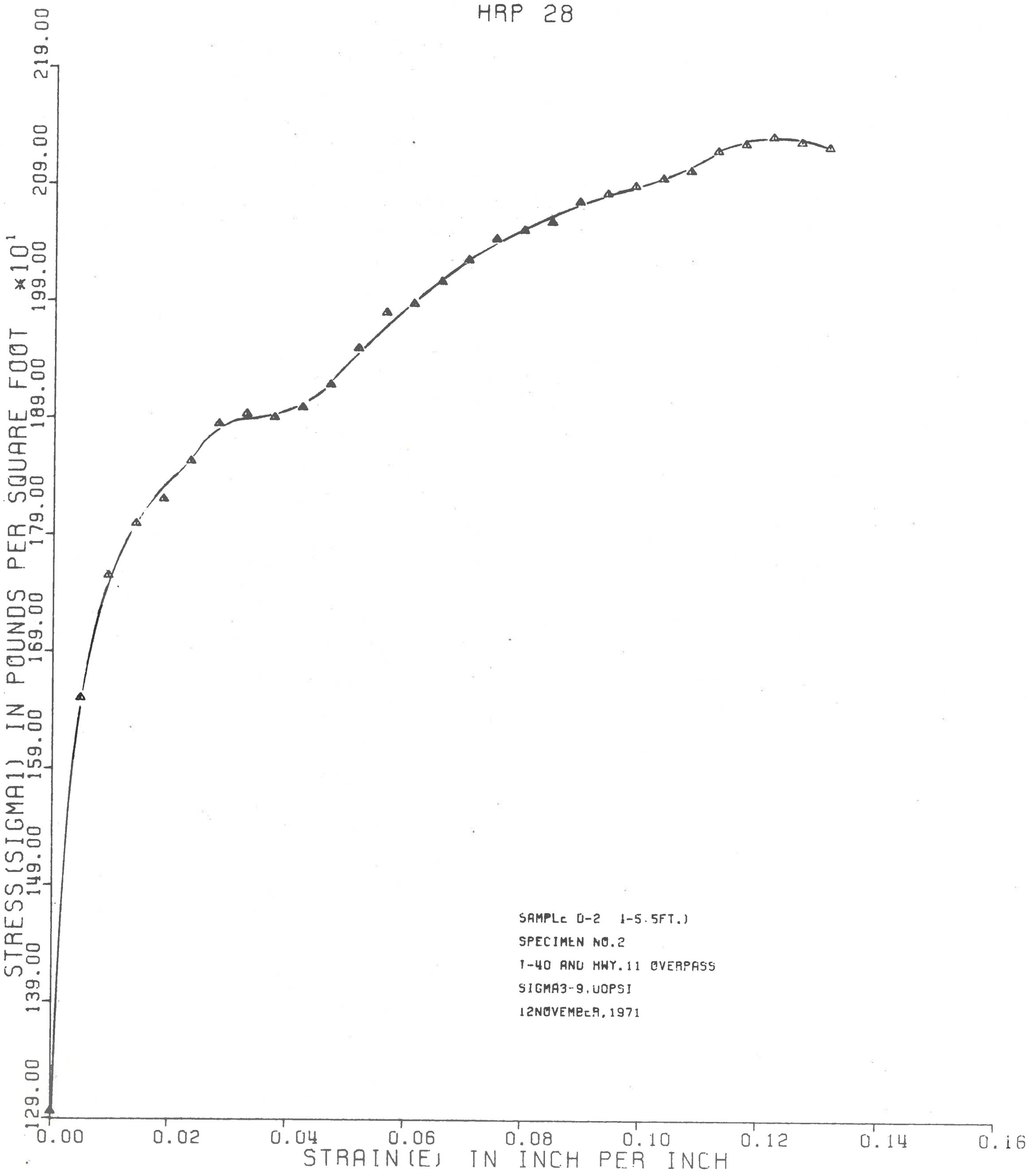


SAMPLE C-12 (29-30.5FT.)
SPECIMEN NO.2
HWY. 181 AND I-55 OVERPASS
SIGMA3=23.00PSI
7DECEMBER,1971

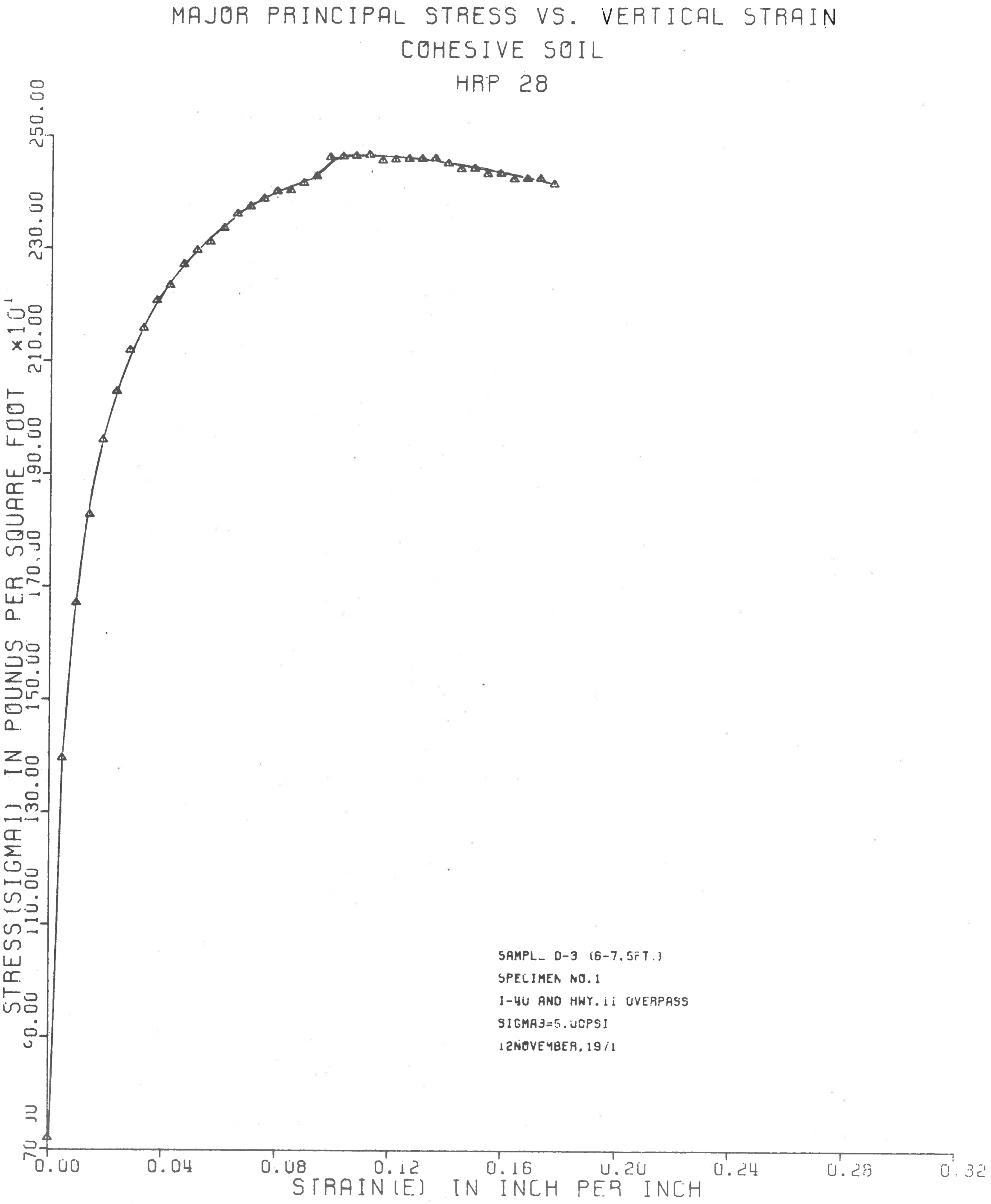
MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

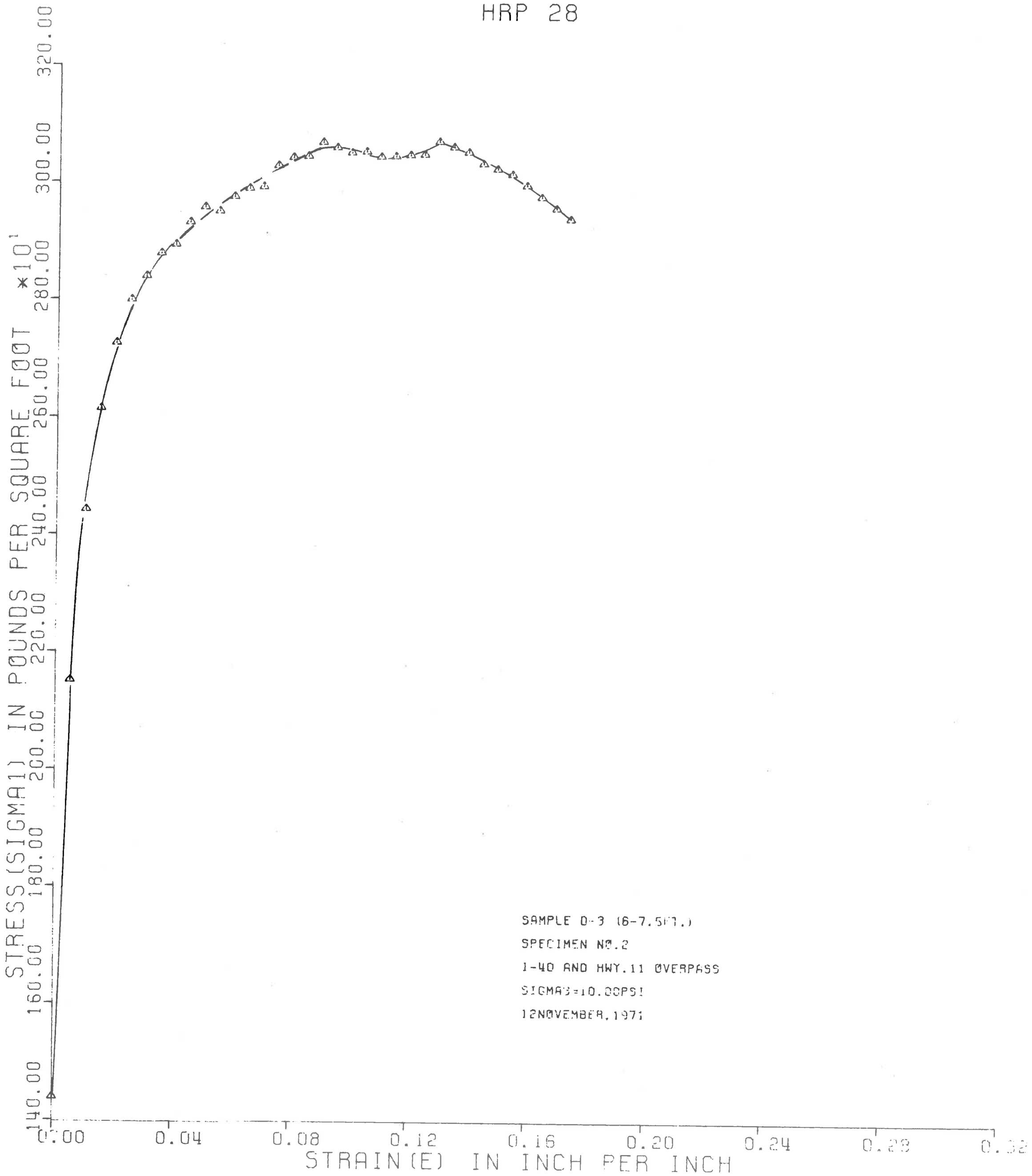


SAMPLE D-2 1-5.5FT.)
SPECIMEN NO.2
I-40 AND HWY.11 OVERPASS
SIGMA3-9.00PSI
12NOVEMBER,1971

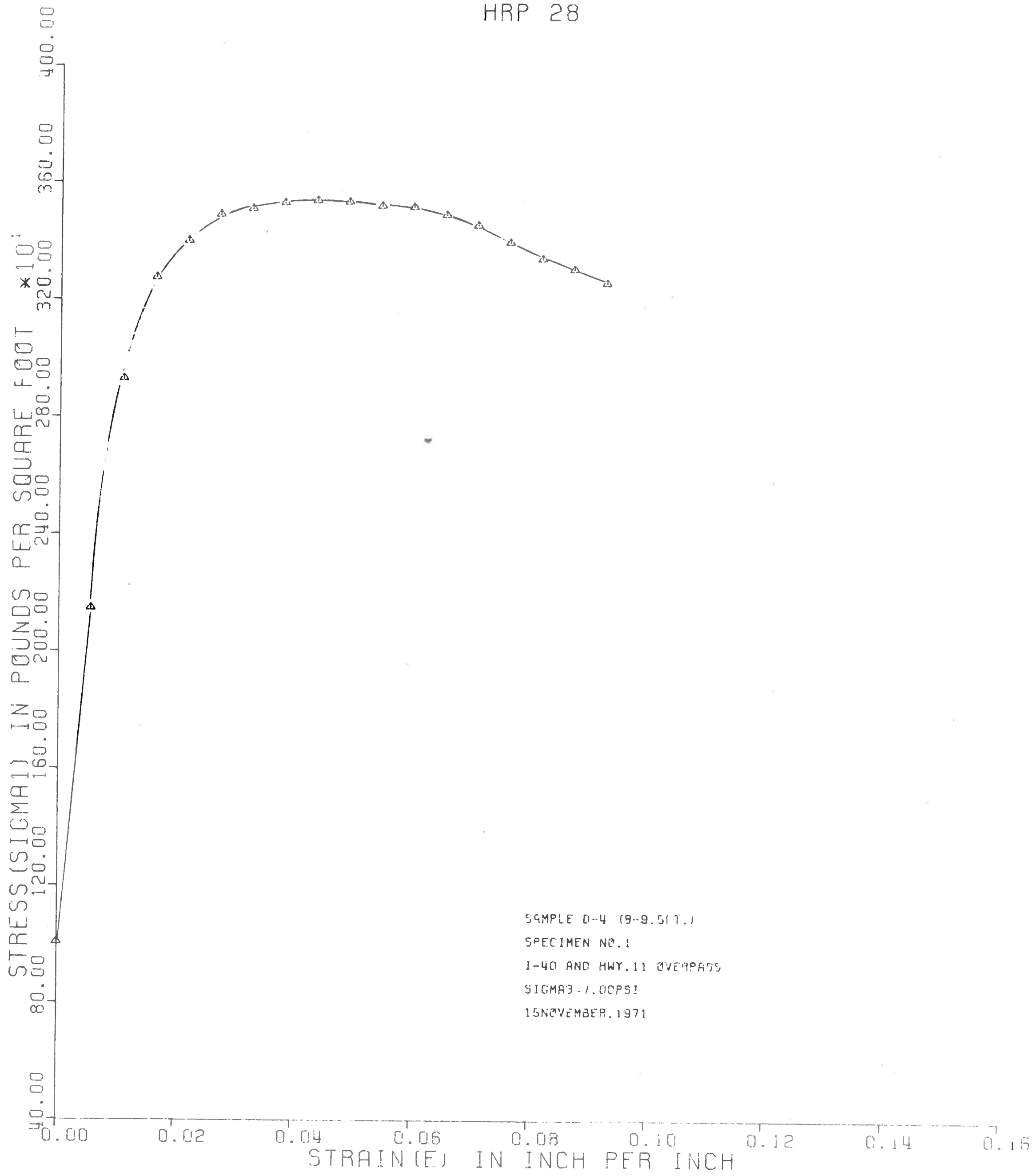


MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

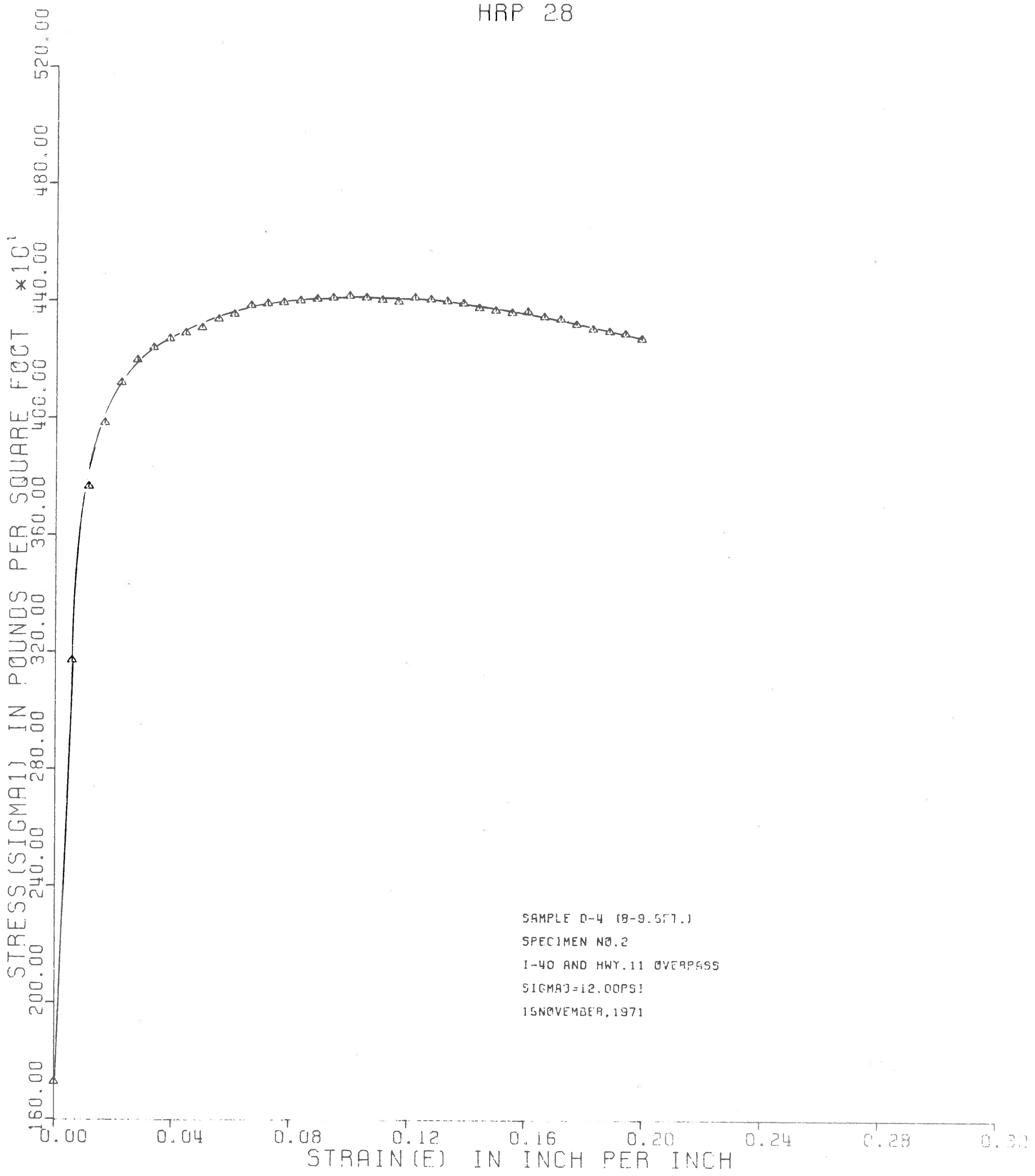
MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

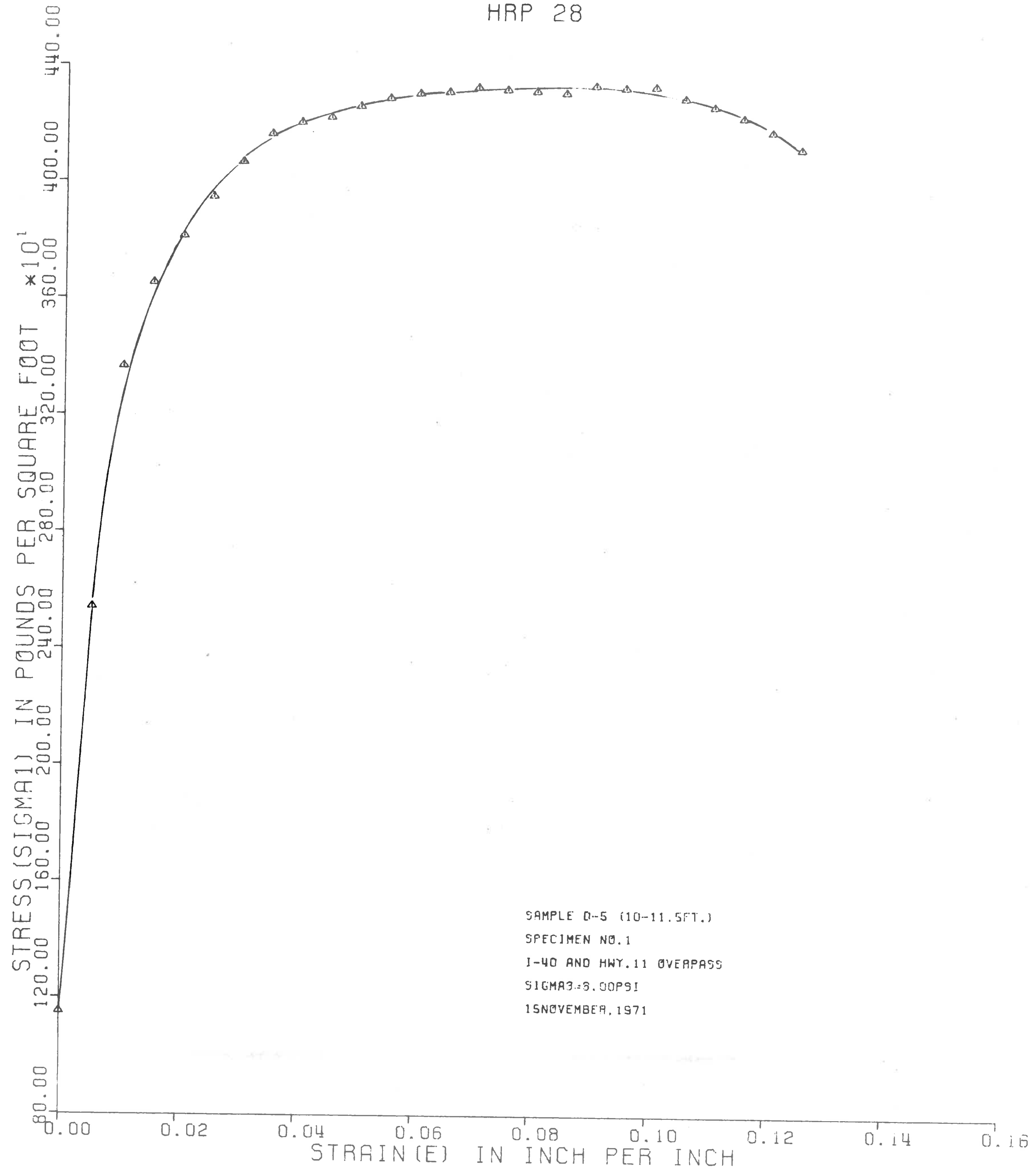


MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



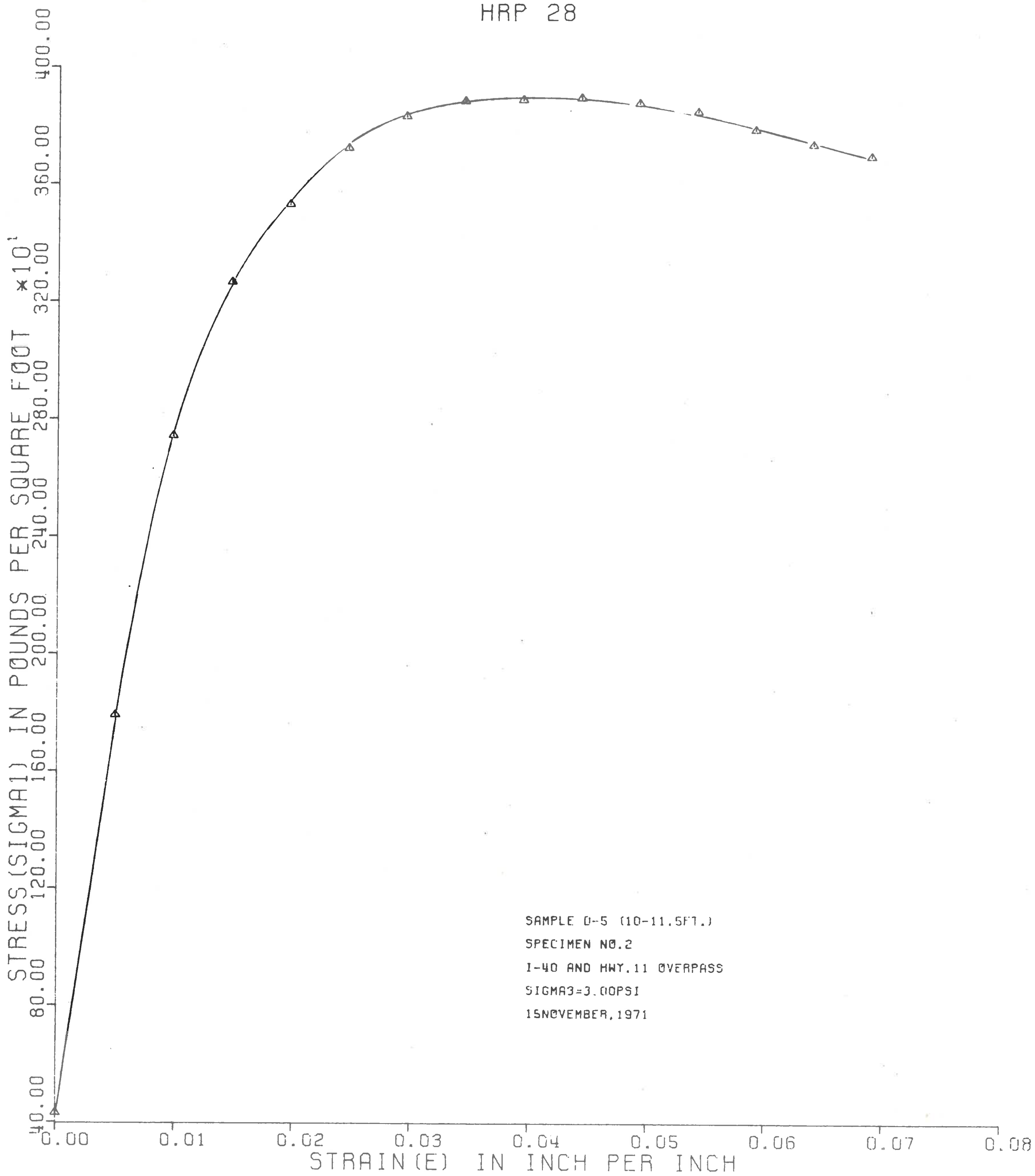
SAMPLE D-4 (8-9.5FT.)
SPECIMEN NO.2
I-40 AND HWY.11 OVERPASS
SIGMA3=12.00PSI
15NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

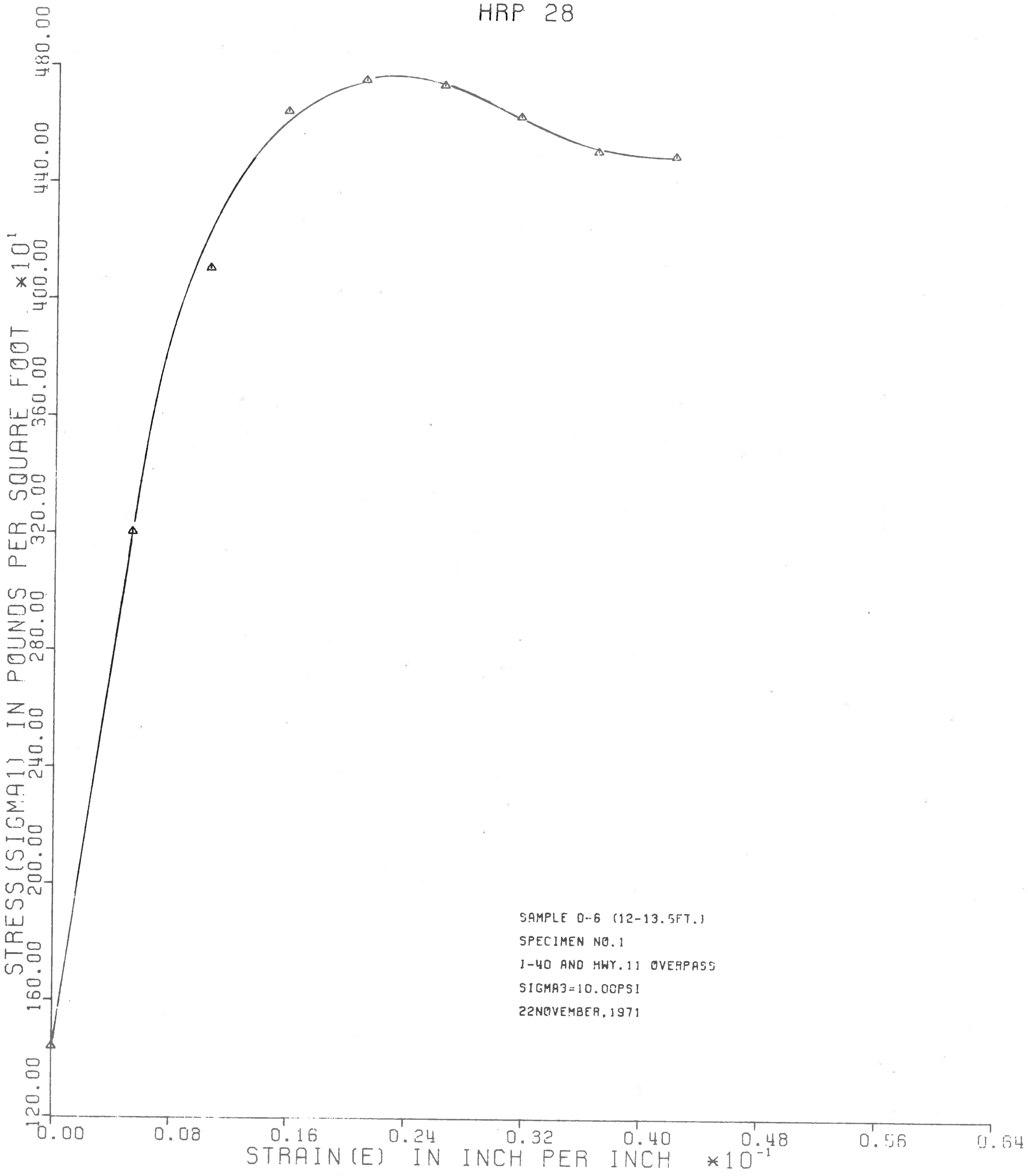


SAMPLE D-5 (10-11.5FT.)
SPECIMEN NO.1
I-40 AND HWY.11 OVERPASS
SIGMA3=6.00PSI
15NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

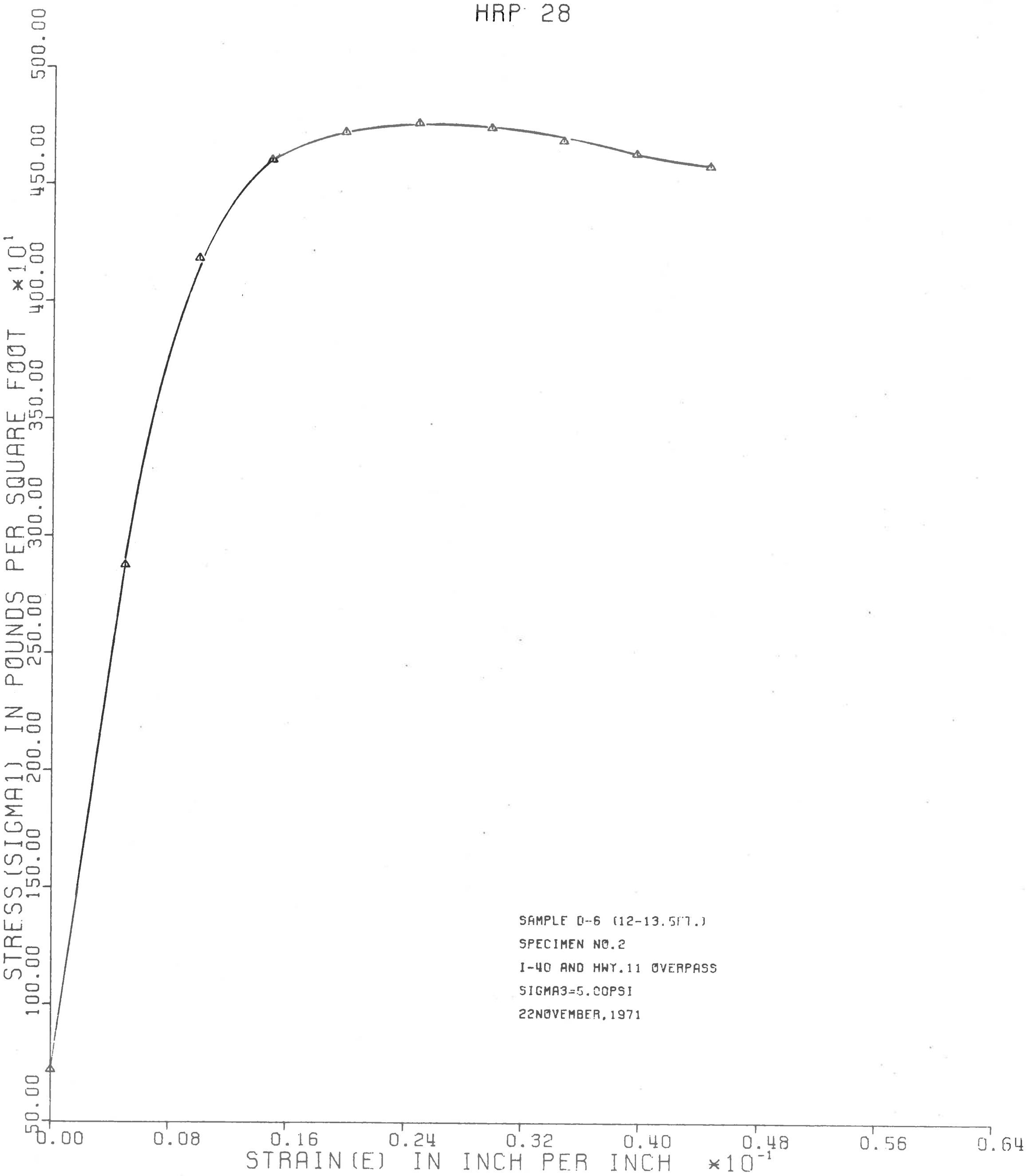


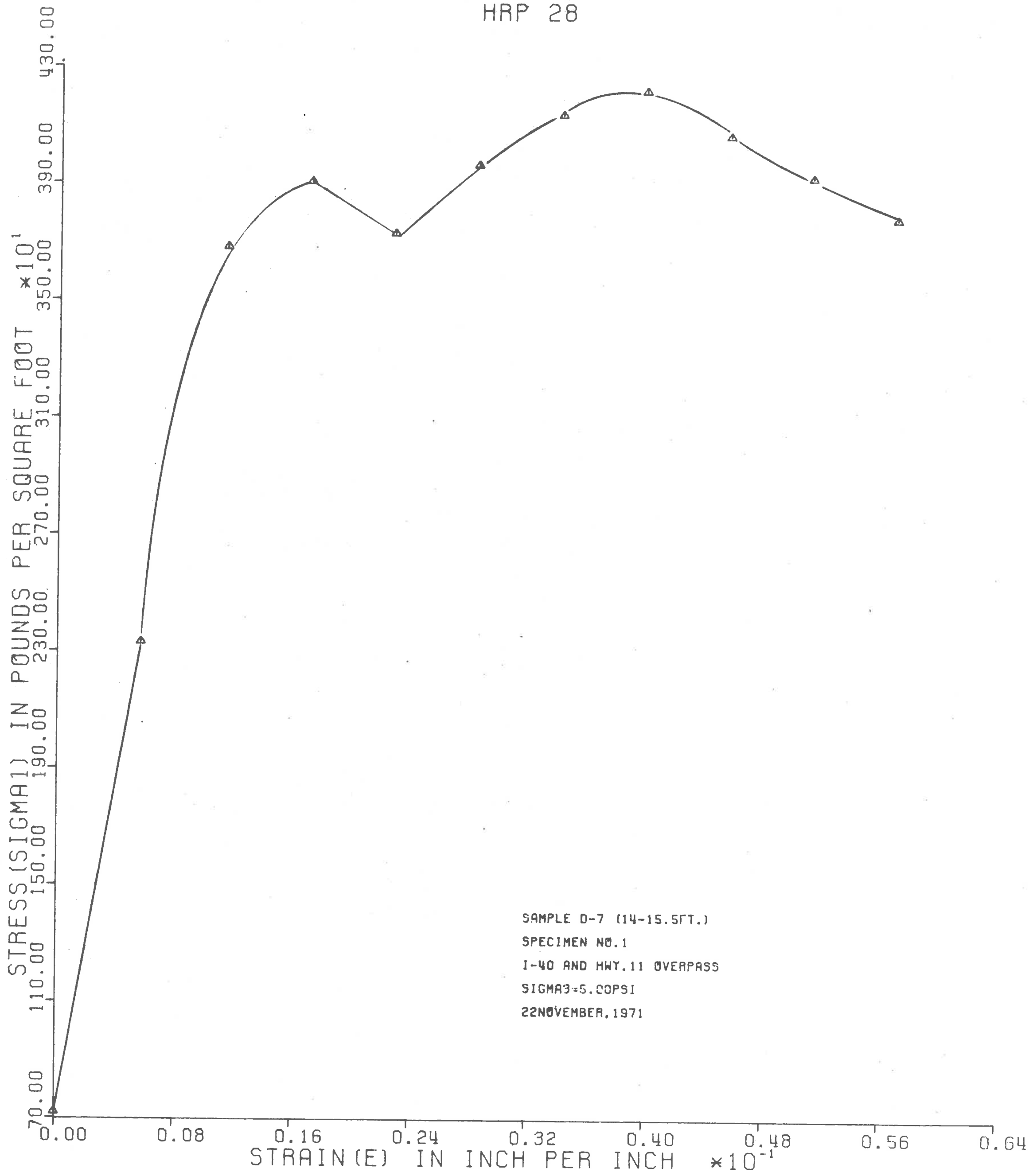
MAJØR PRINCIPAL STRESS VS. VERTICAL STRAIN
CØHESIVE SØIL
HRP 28



SAMPLE D-6 (12-13.5FT.)
SPECIMEN NØ.1
I-40 AND HWY.11 ØVERPASS
SIGMA3=10.00PSI
22NØVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

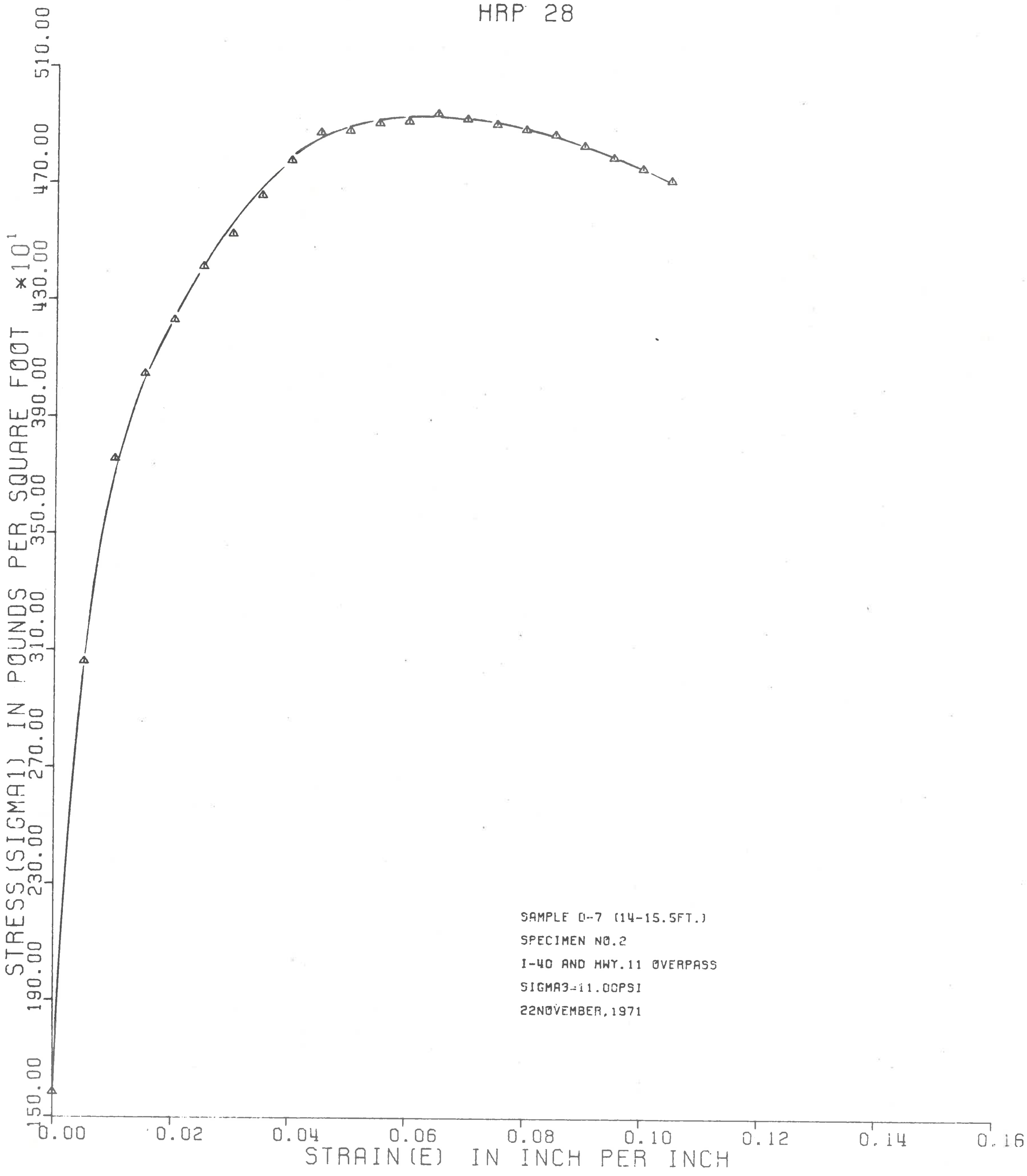




MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

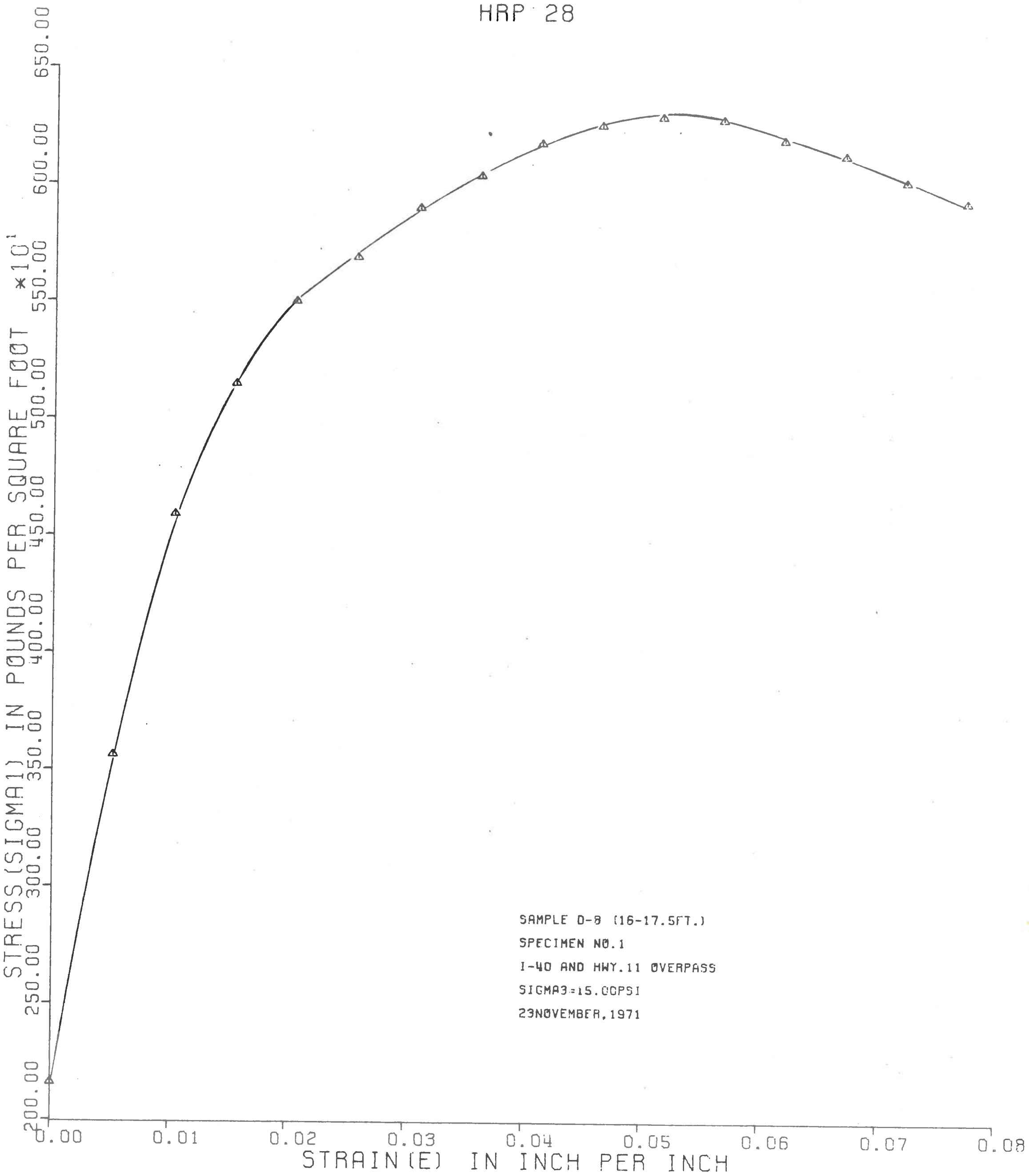
SAMPLE D-7 (14-15.5FT.)
SPECIMEN NO.1
I-40 AND HWY.11 OVERPASS
SIGMA3=5.00PSI
22NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



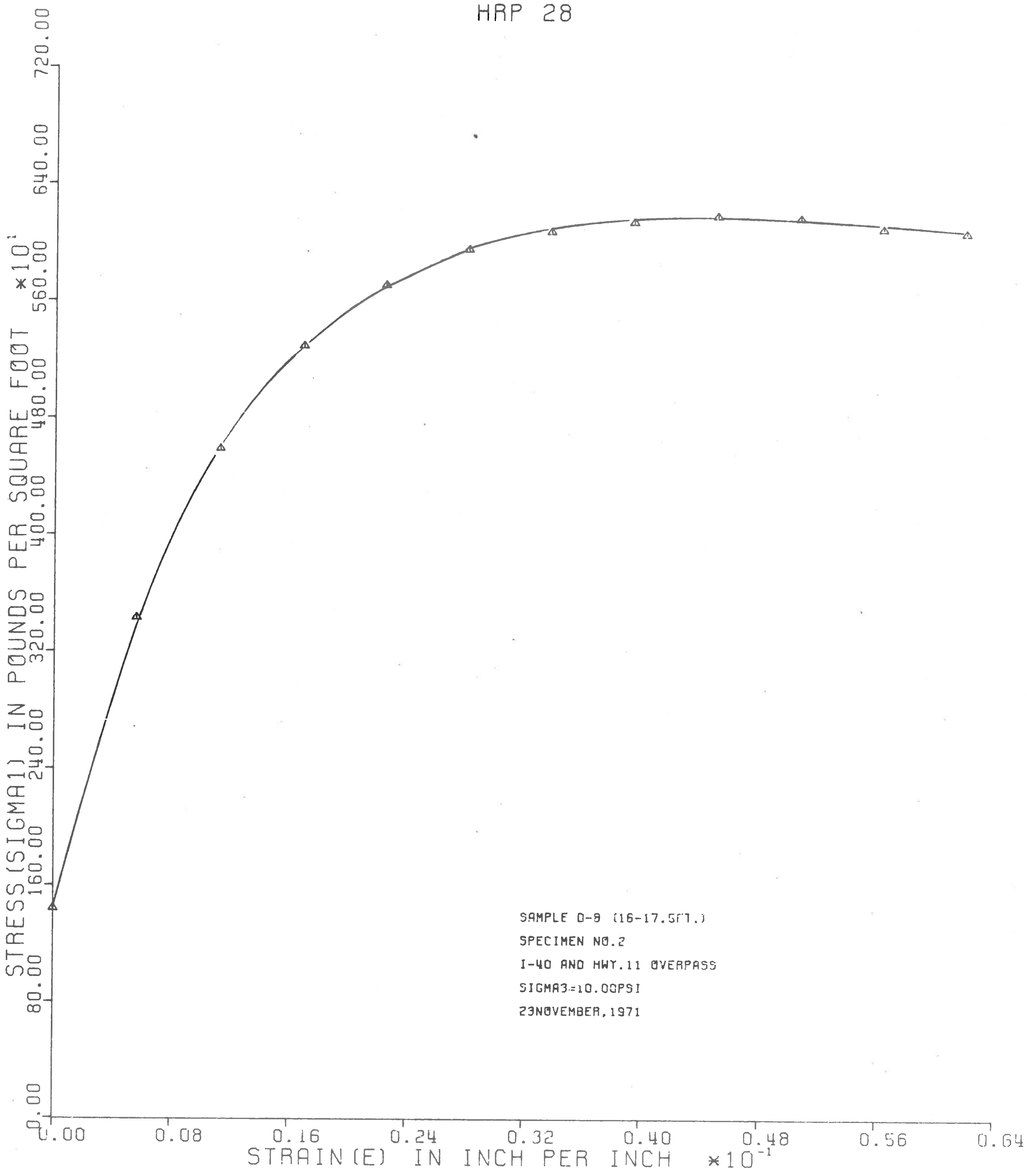
SAMPLE D-7 (14-15.5FT.)
SPECIMEN NO.2
I-40 AND HWY.11 OVERPASS
SIGMA3=11.00PSI
22NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

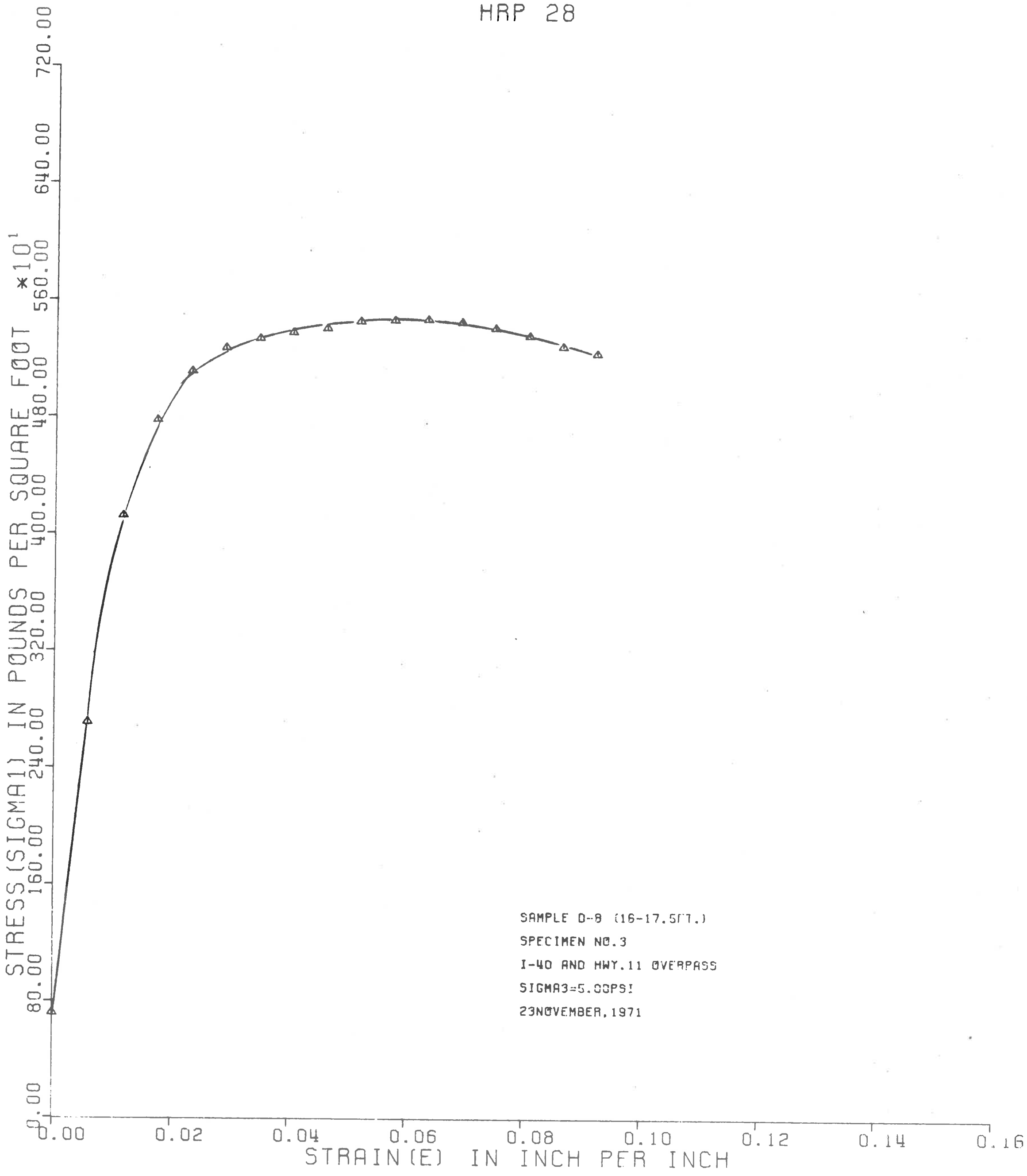


SAMPLE D-8 (16-17.5FT.)
SPECIMEN NO.1
I-40 AND HWY.11 OVERPASS
SIGMA3=15.00PSI
23NOVEMBER,1971

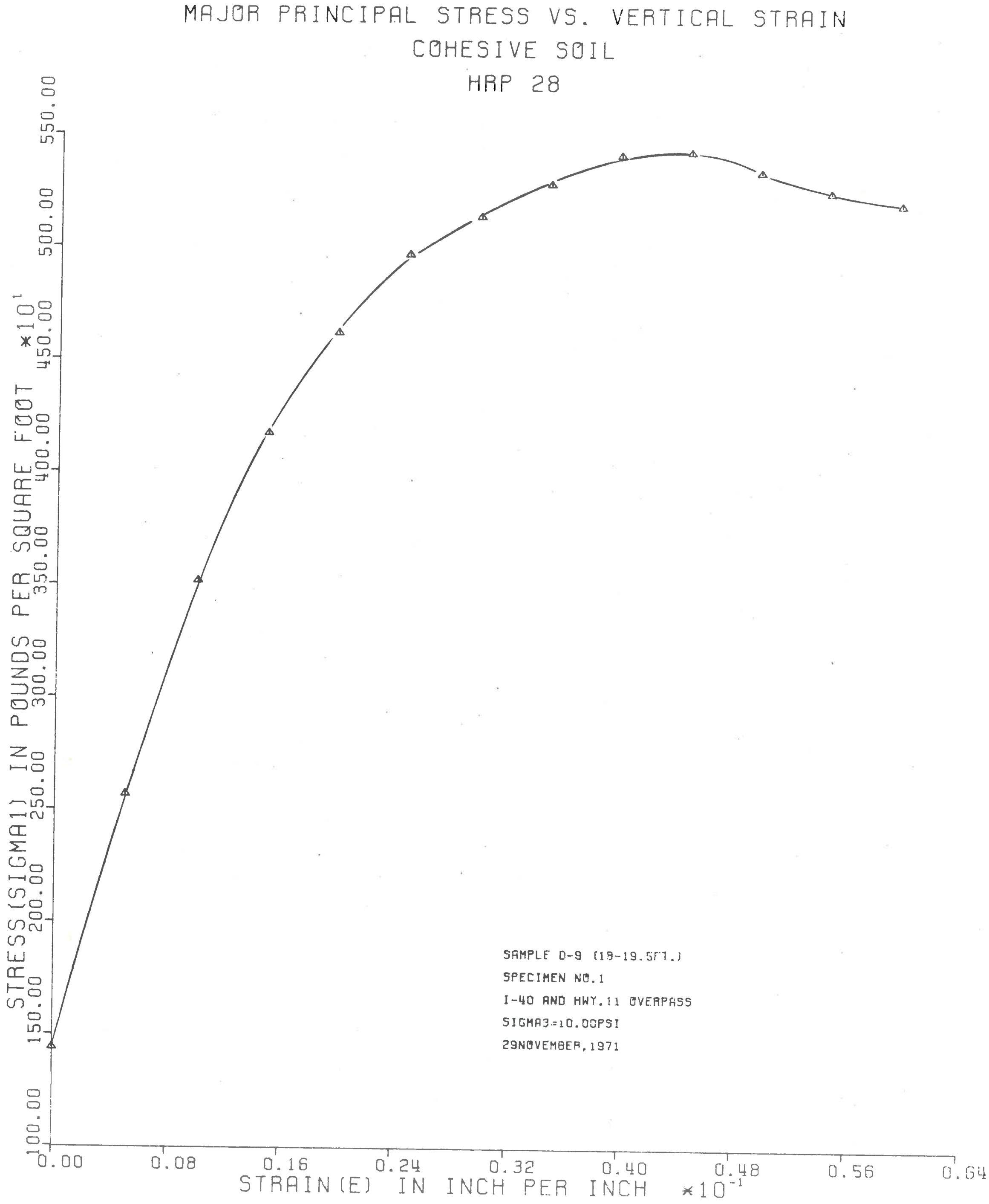
MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



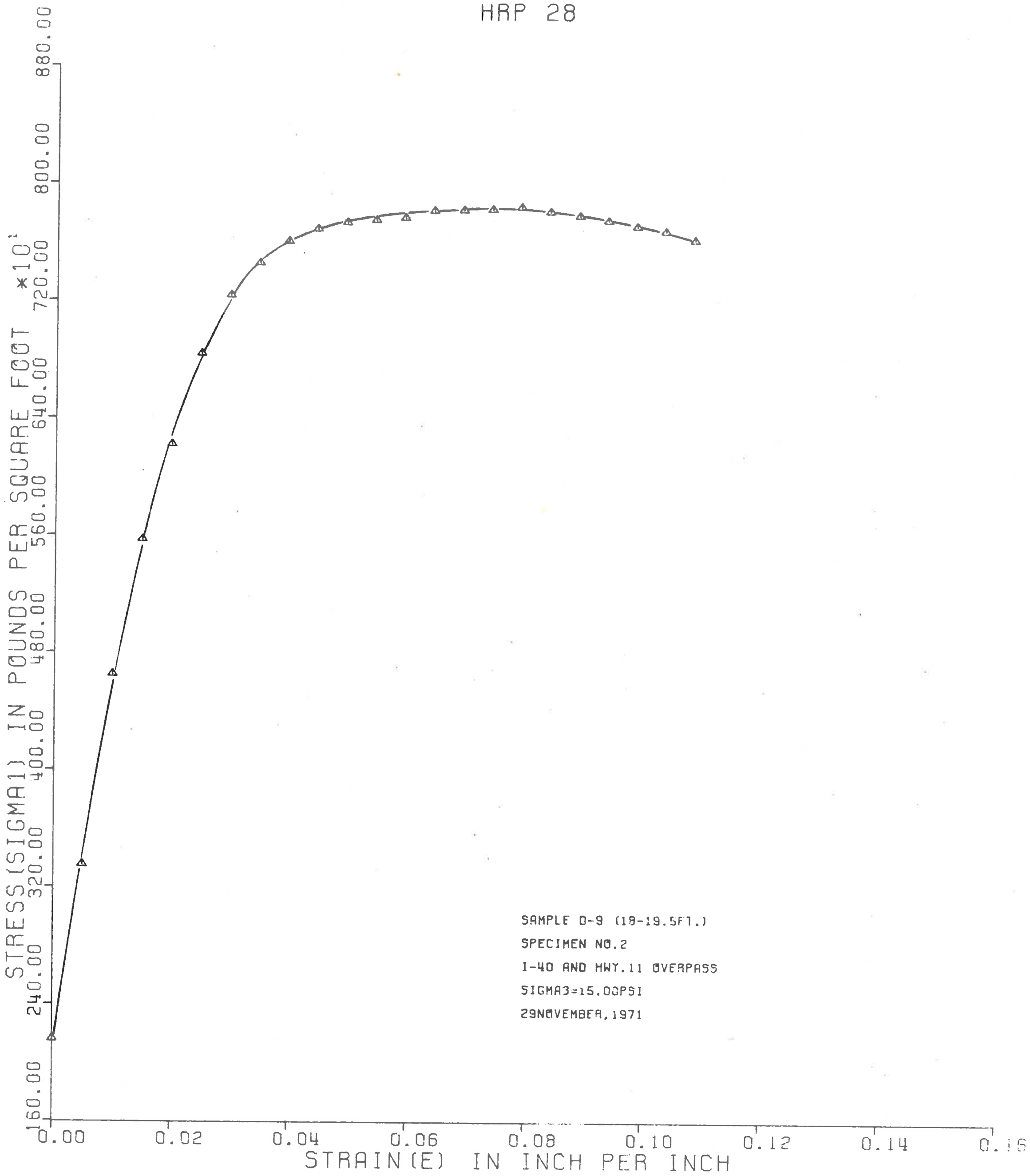
SAMPLE D-8 (16-17.5FT.)
SPECIMEN NO.3
I-40 AND HWY.11 OVERPASS
SIGMA3=5.00PSI
23NOVEMBER,1971



MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28

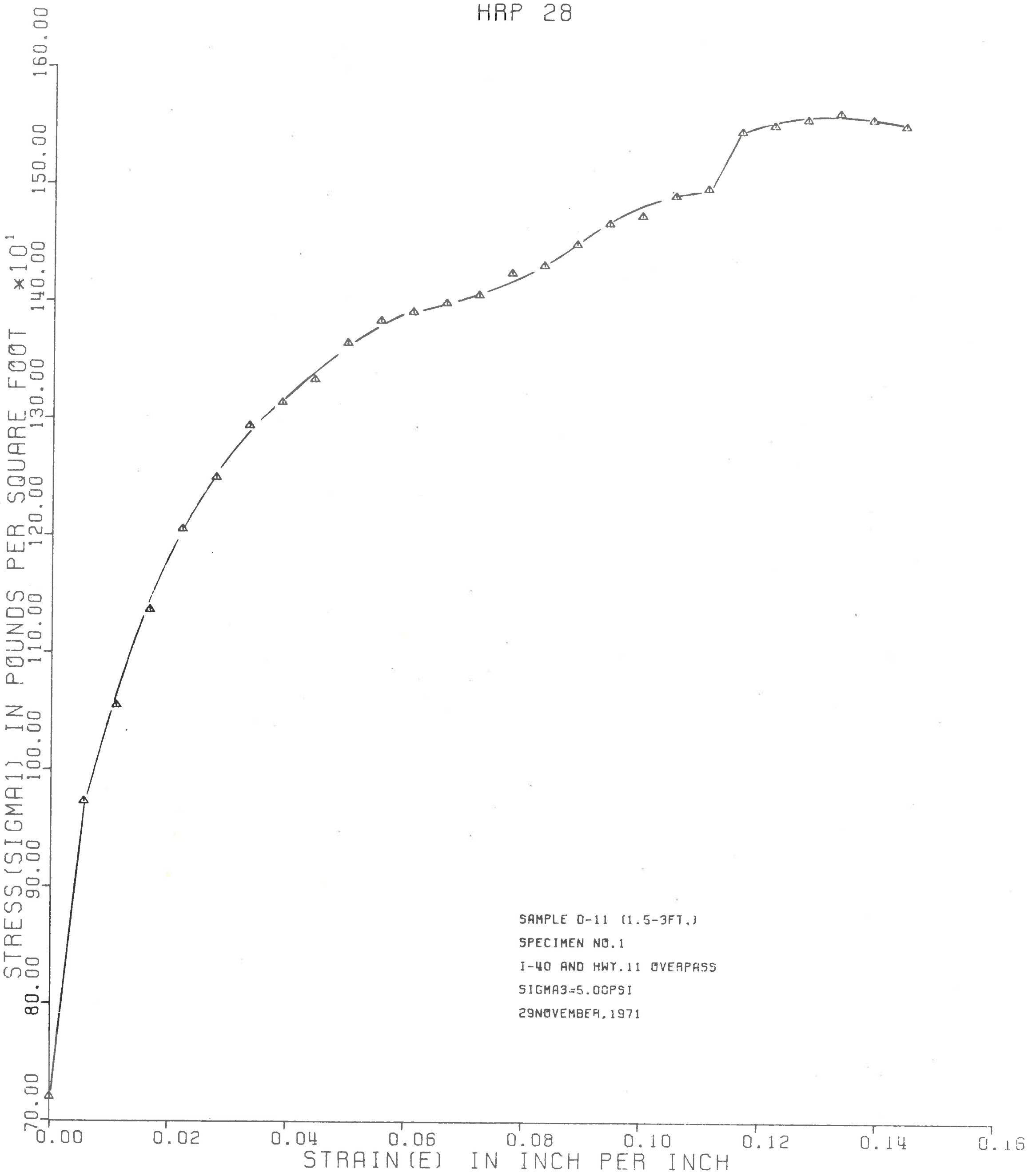
SAMPLE D-9 (19-19.5FT.)
SPECIMEN NO.1
I-40 AND HWY.11 OVERPASS
SIGMA3=10.00PSI
29NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



SAMPLE O-9 (18-19.5FT.)
SPECIMEN NO.2
I-40 AND HWY.11 OVERPASS
SIGMA3=15.00PSI
29NOVEMBER,1971

MAJOR PRINCIPAL STRESS VS. VERTICAL STRAIN
COHESIVE SOIL
HRP 28



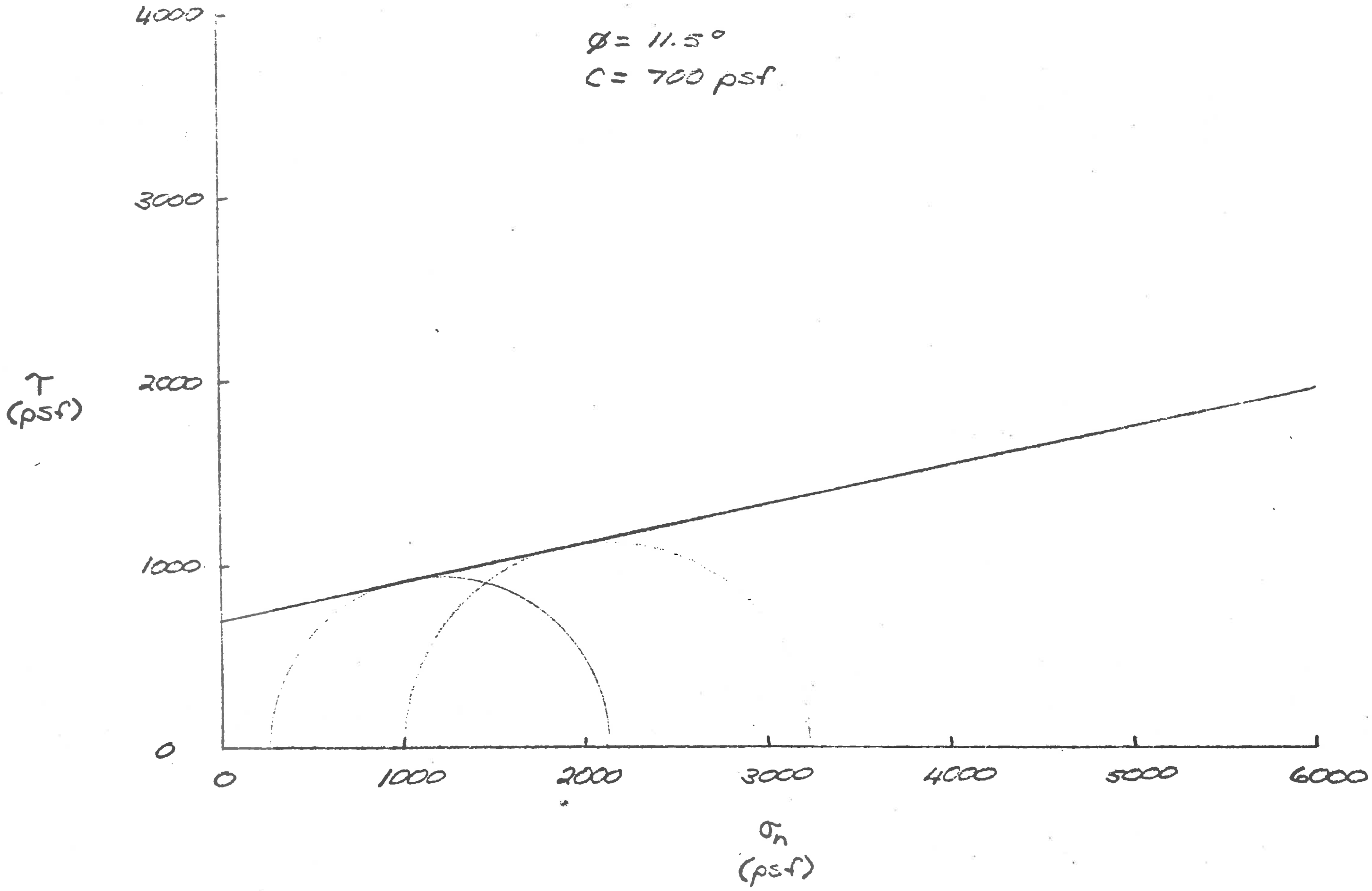
SAMPLE D-11 (1.5-3FT.)
SPECIMEN NO.1
I-40 AND HWY.11 OVERPASS
SIGMA3=5.00PSI
29NOVEMBER,1971

APPENDIX C

Mohr Rupture Envelopes

Sample A-1

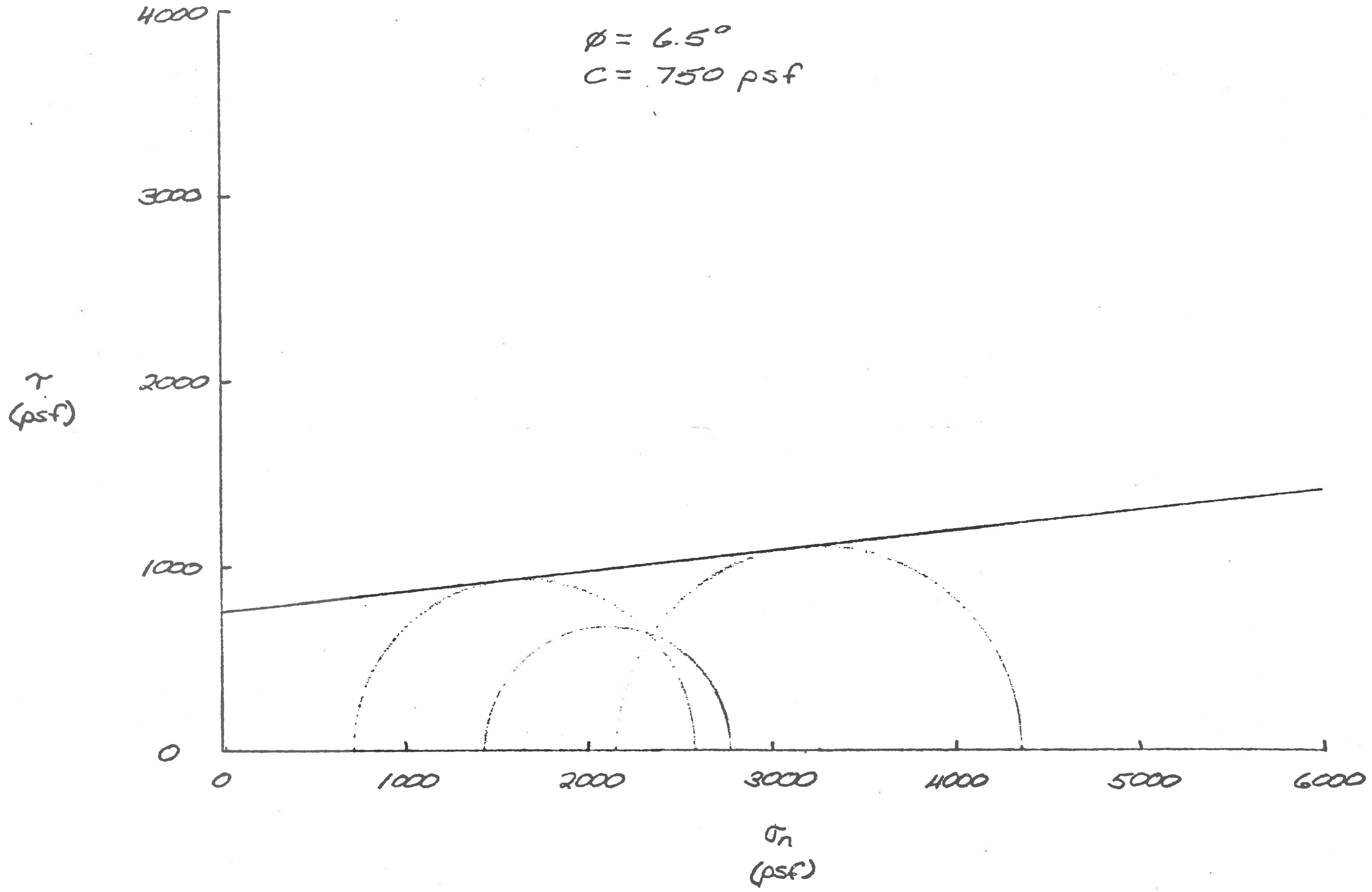
Brown-gray clay with spots of oxidized iron and traces of silt. Degree of saturation = 95 - 99 %.



$\phi = 11.5°$
$C = 700$ psf

Sample A-2

Gray clay . Degree of saturation = 91-98%.

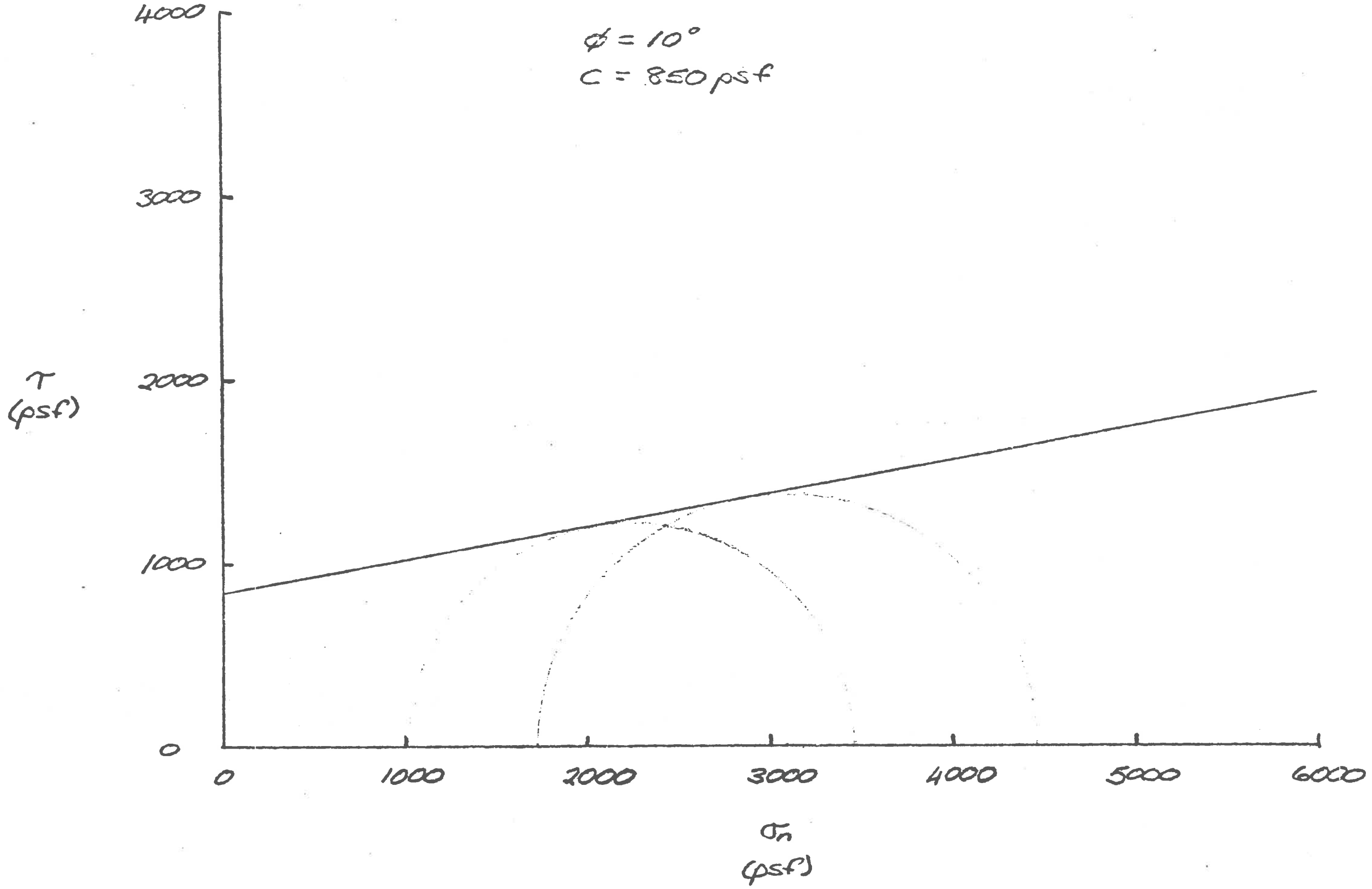


$\phi = 6.5°$

$C = 750$ psf

Sample A-3

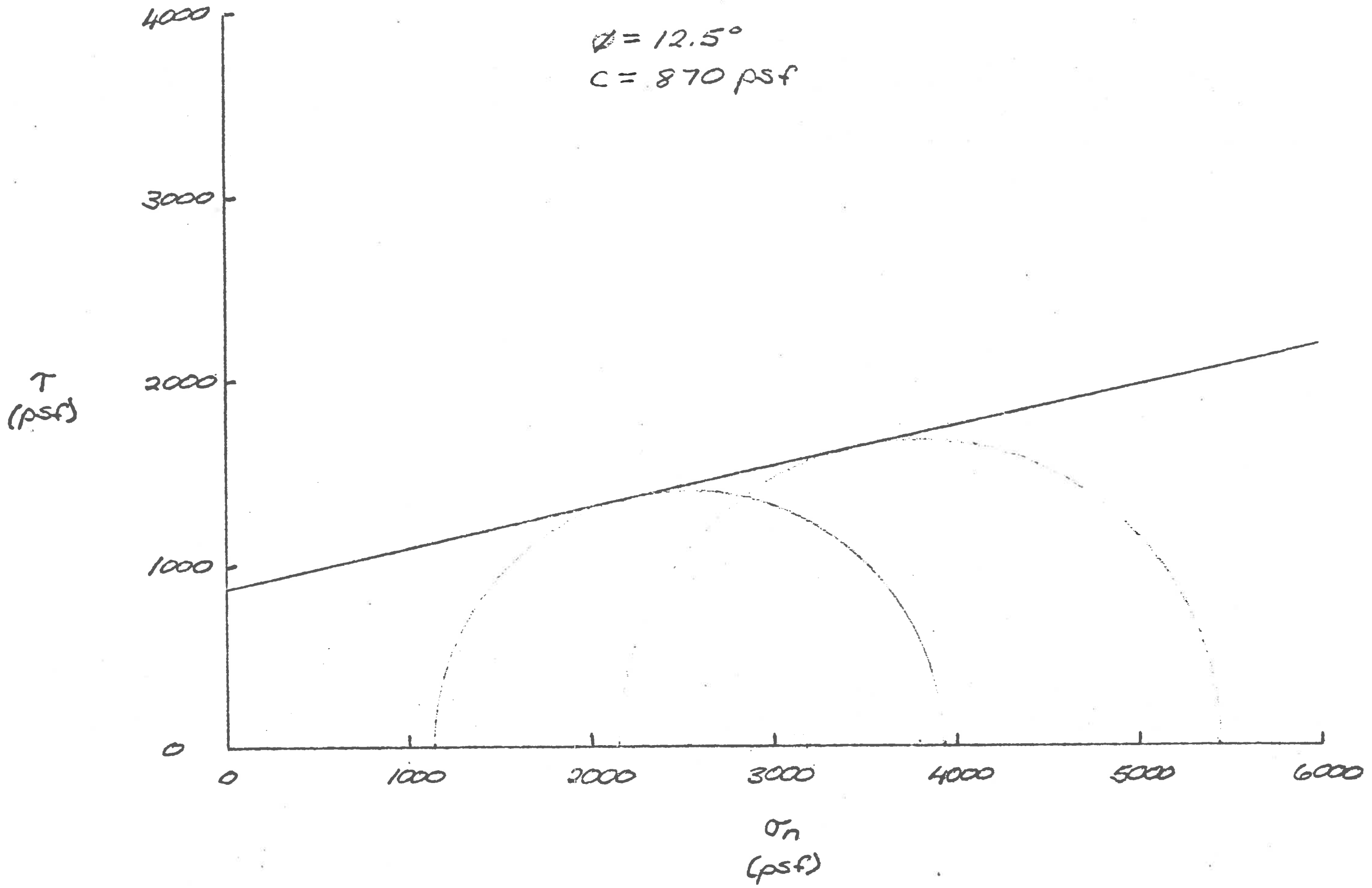
Brown-gray clay with iron oxidized spots. Degree of saturation = 98-100%.



$\phi = 10°$
$c = 850$ psf

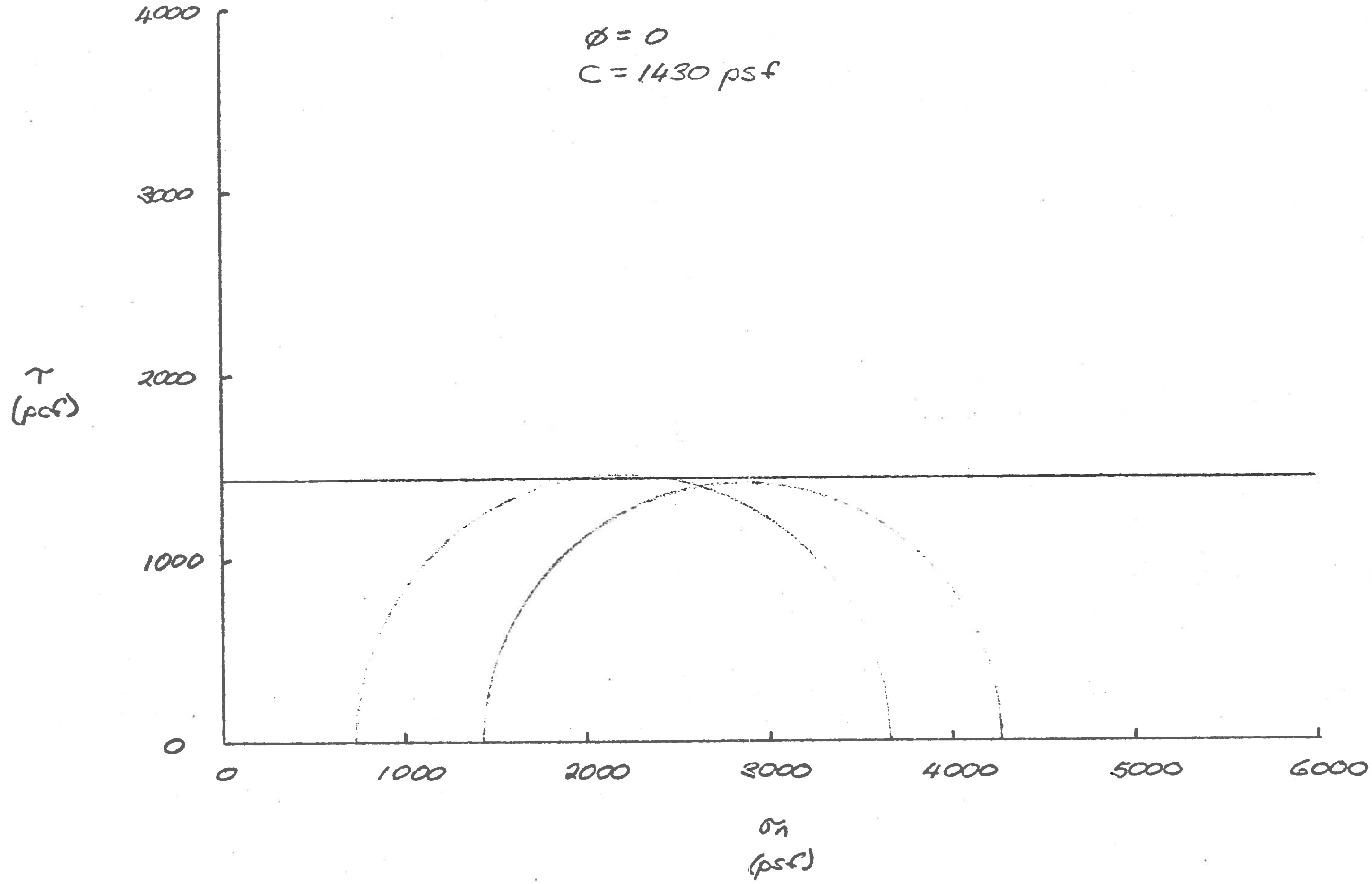
Sample A-4

Gray clay . Degree of saturation = 100% .



Sample A-5

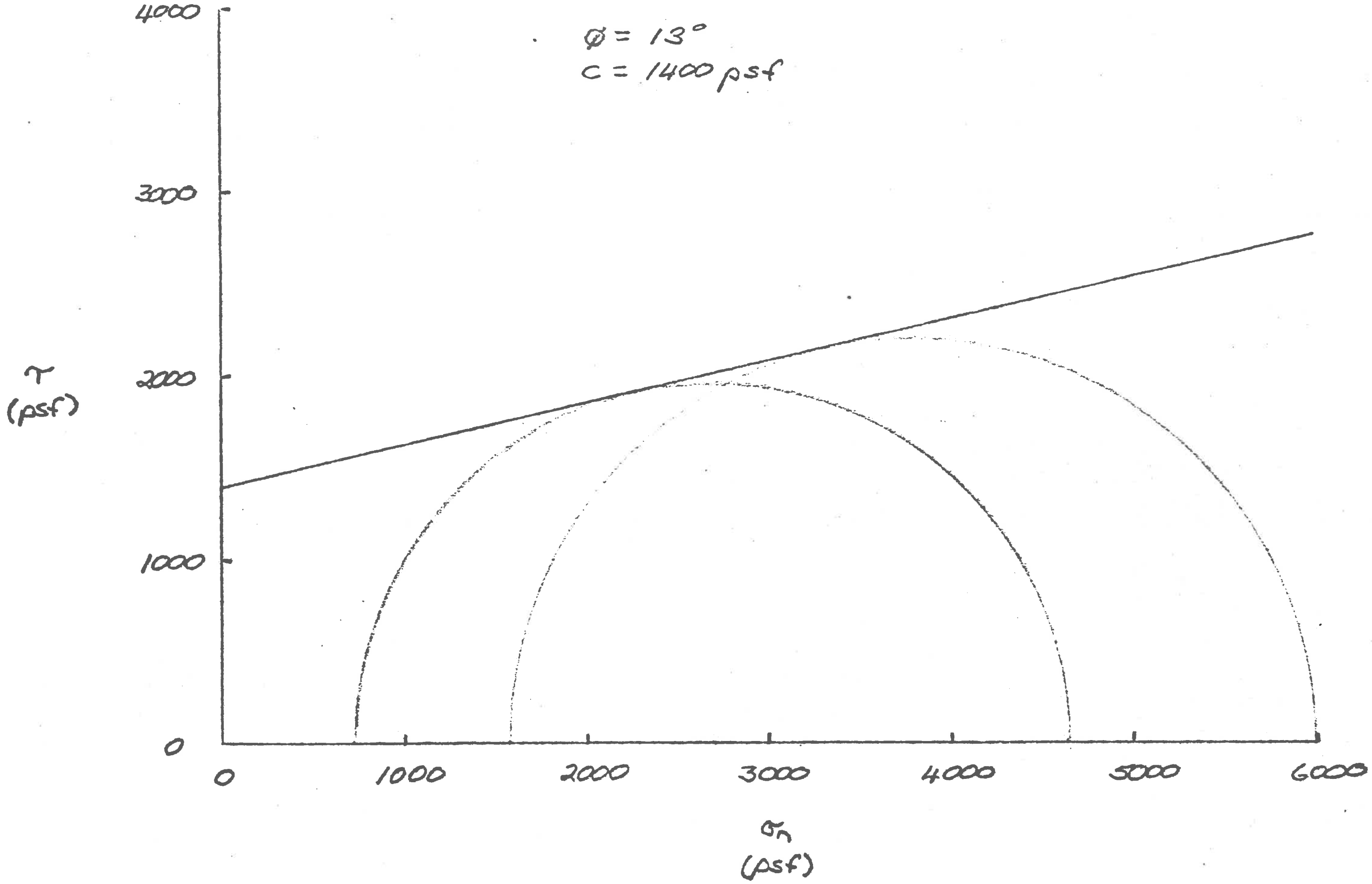
Brown-gray clay with roots. Deg. of sat. = 93-100%.



$\phi = 0$
C = 1430 psf

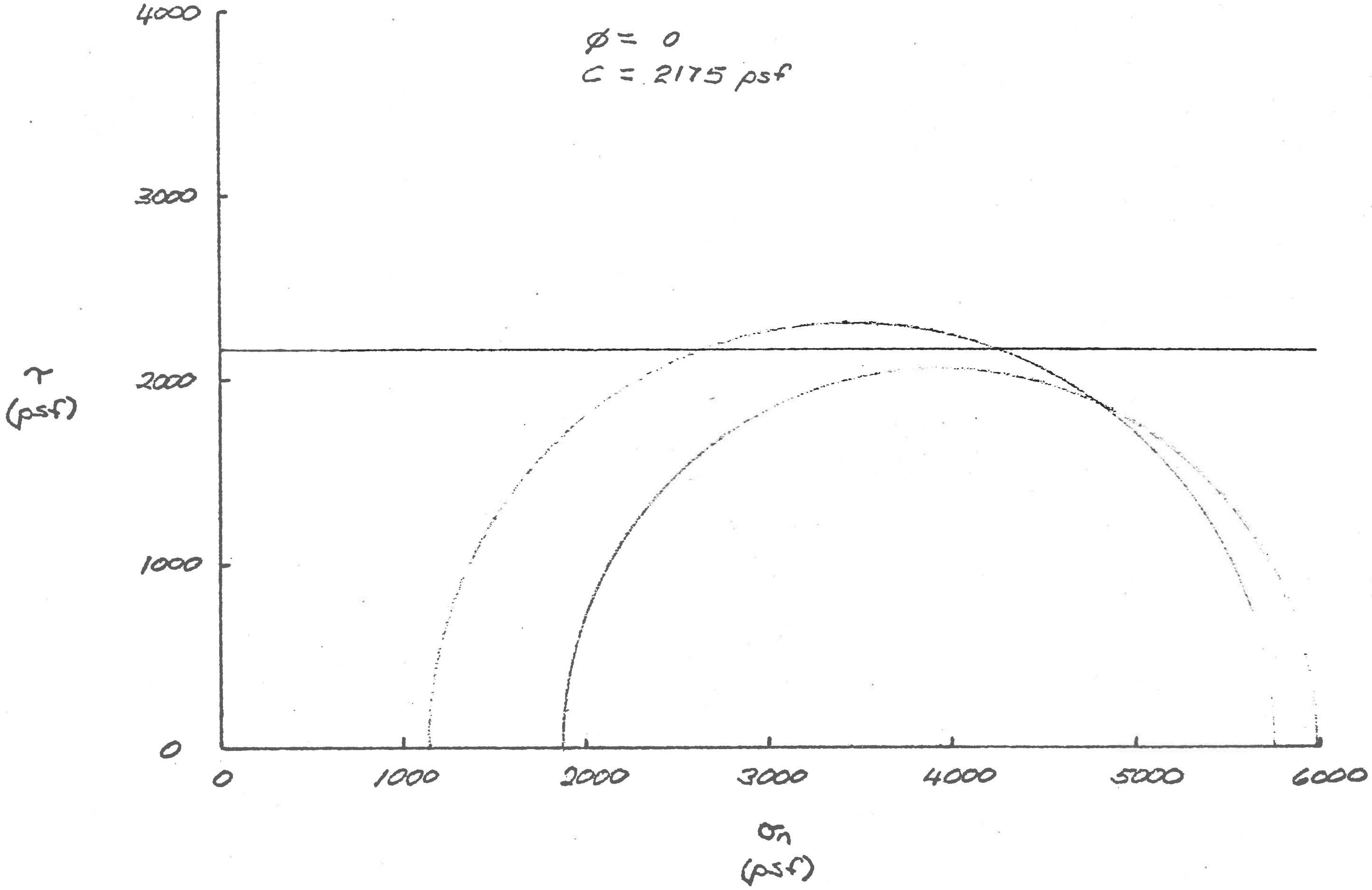
Sample A-6

Brown-gray clay. Deg. of sat. = 97-100%.



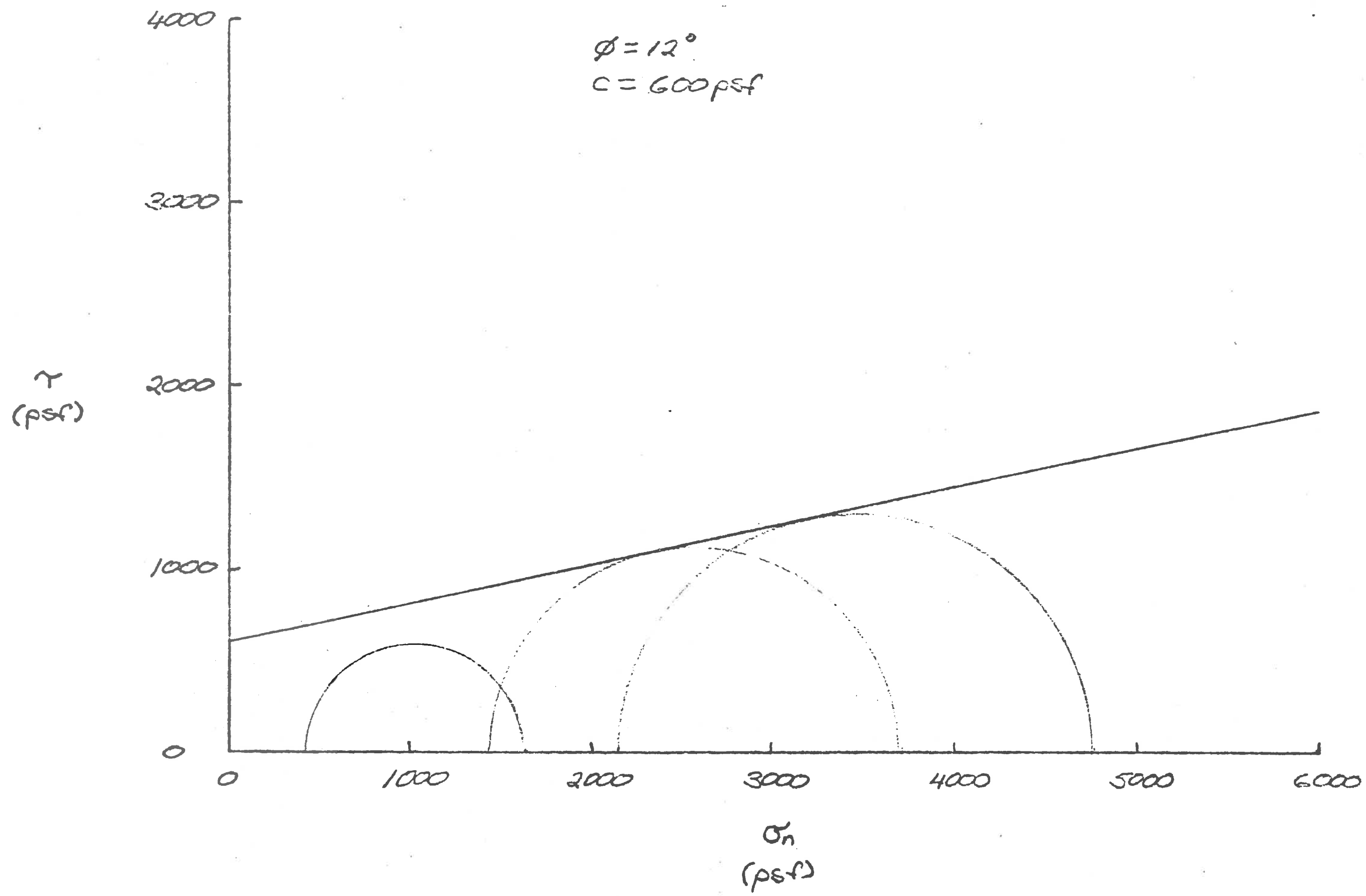
Sample A-7

Brown silty clay with roots. Deg. of
sat. = 91-98 %.



Sample B-1

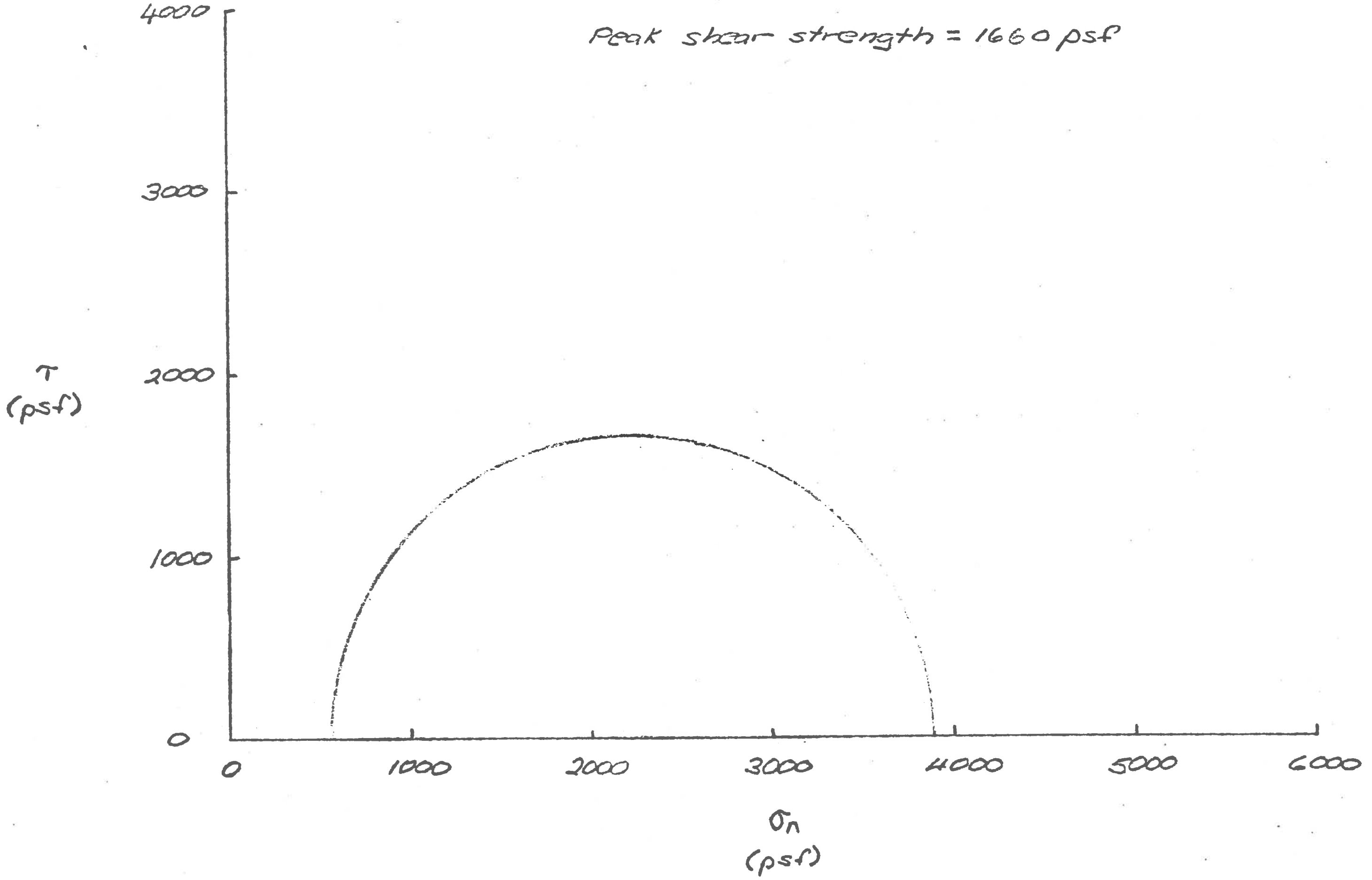
Light gray mottled brown clay with roots. Deg. of sat. = 91-96%.



$\phi = 12°$
$c = 600$ psf

Sample B-2

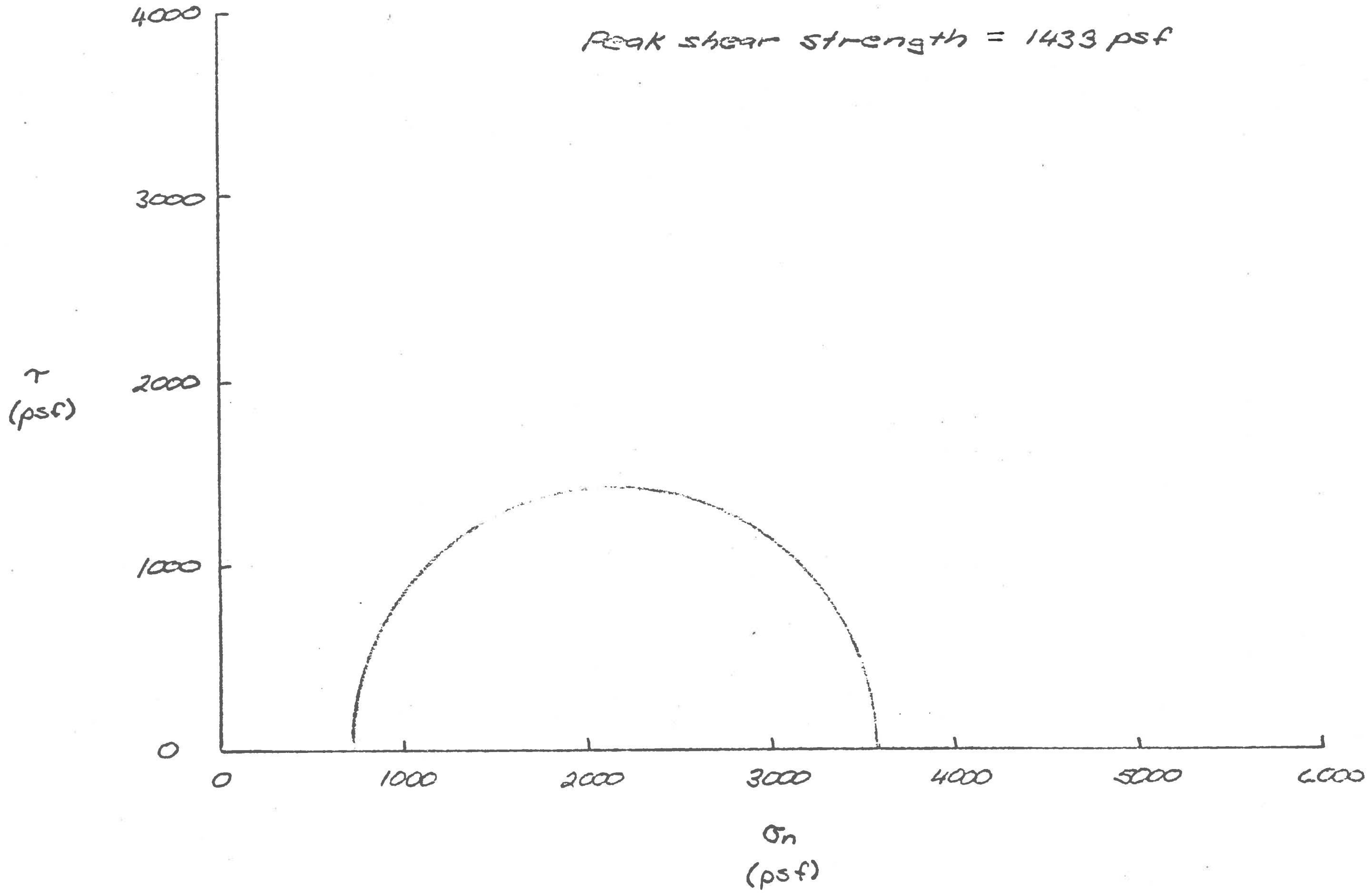
Brown silty clay with roots. Deg. of sat. = 83%



Peak shear strength = 1660 psf

Sample B-3

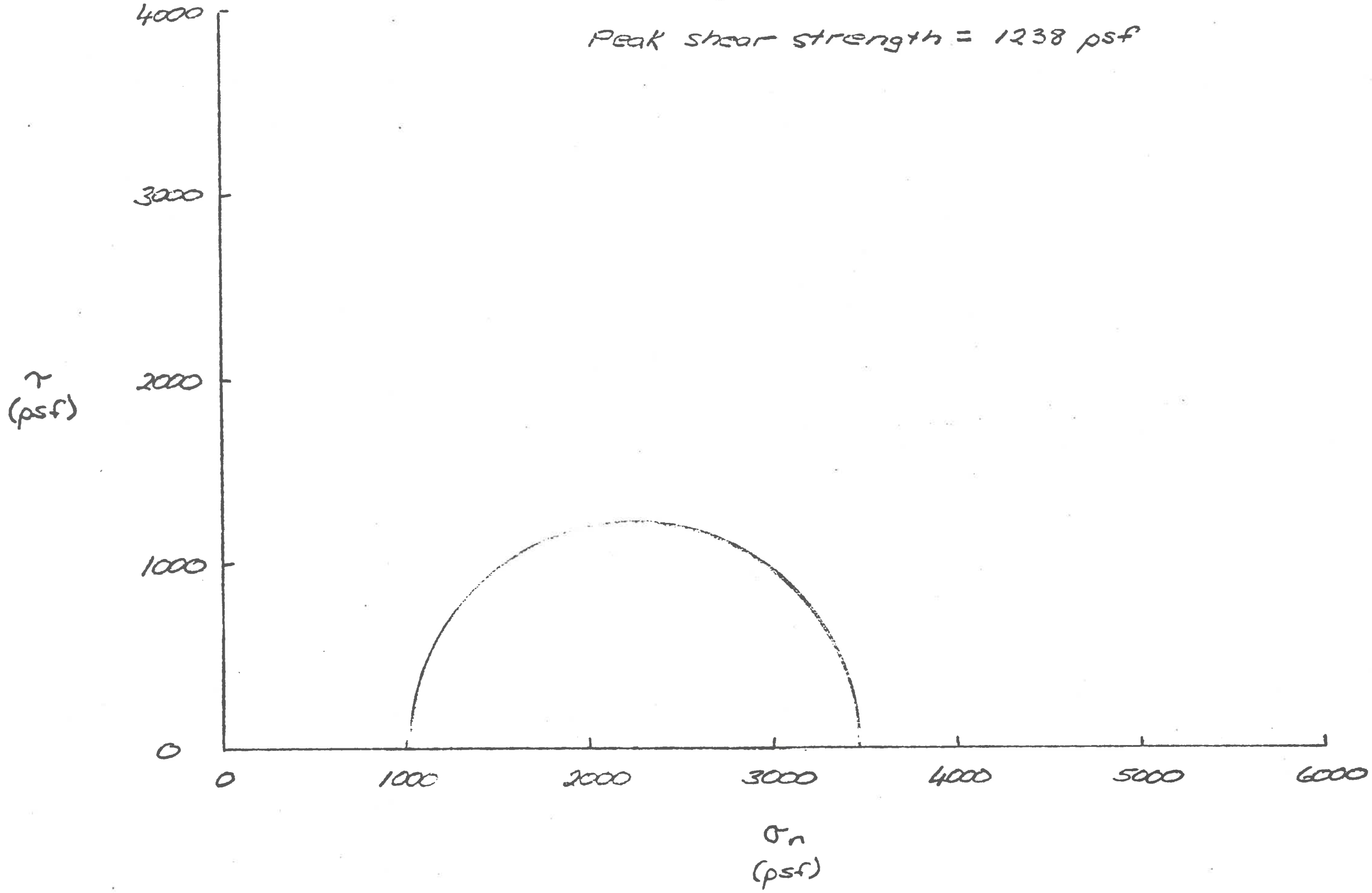
Tan clay with roots and seams of fine
sand. Deg. of sat. = 81%.



Peak shear strength = 1433 psf

Sample B-4

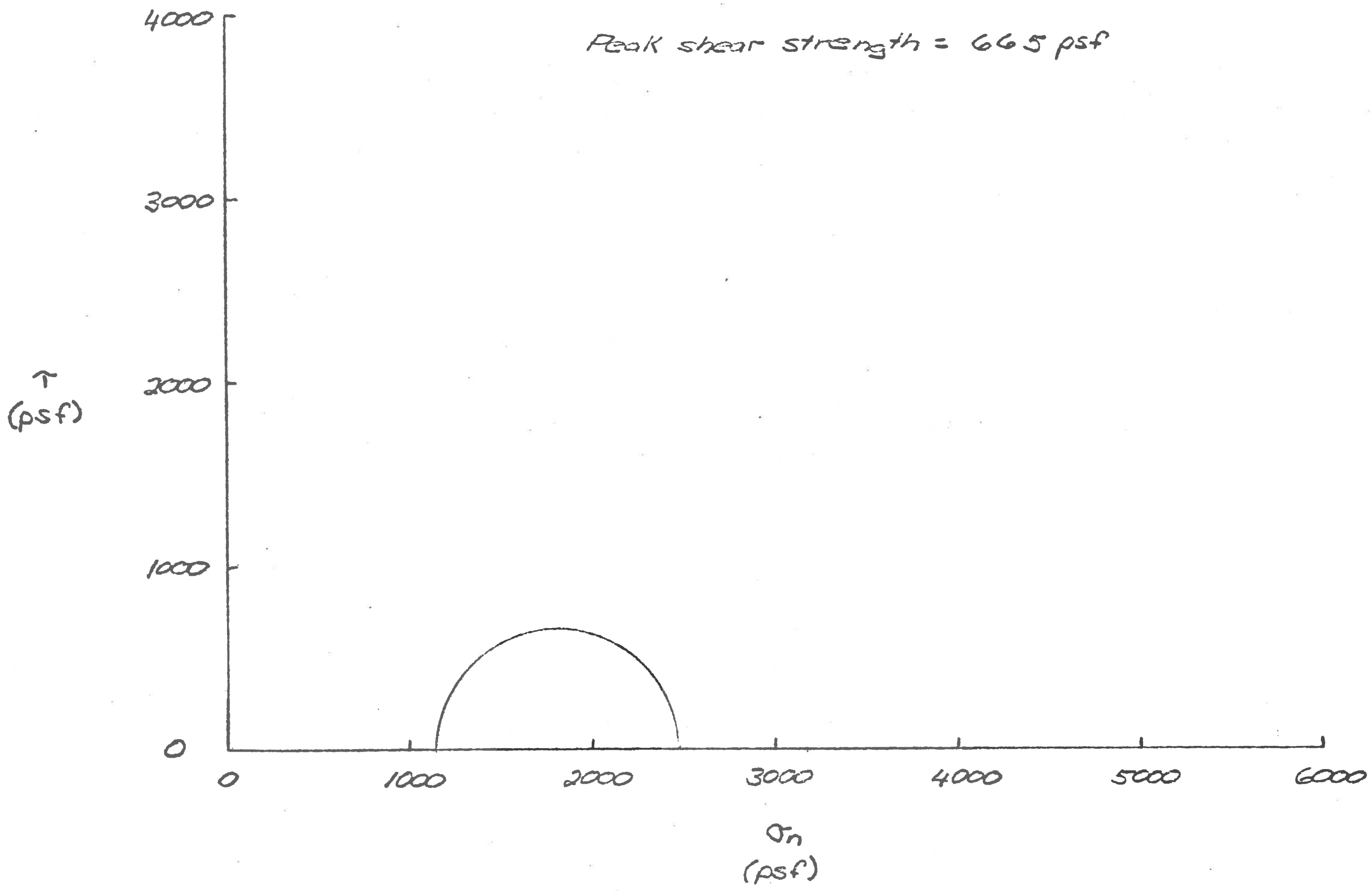
Brown sandy clay with roots and organic matter. Degree of saturation = 92%.



Peak shear strength = 1238 psf

Sample B-5

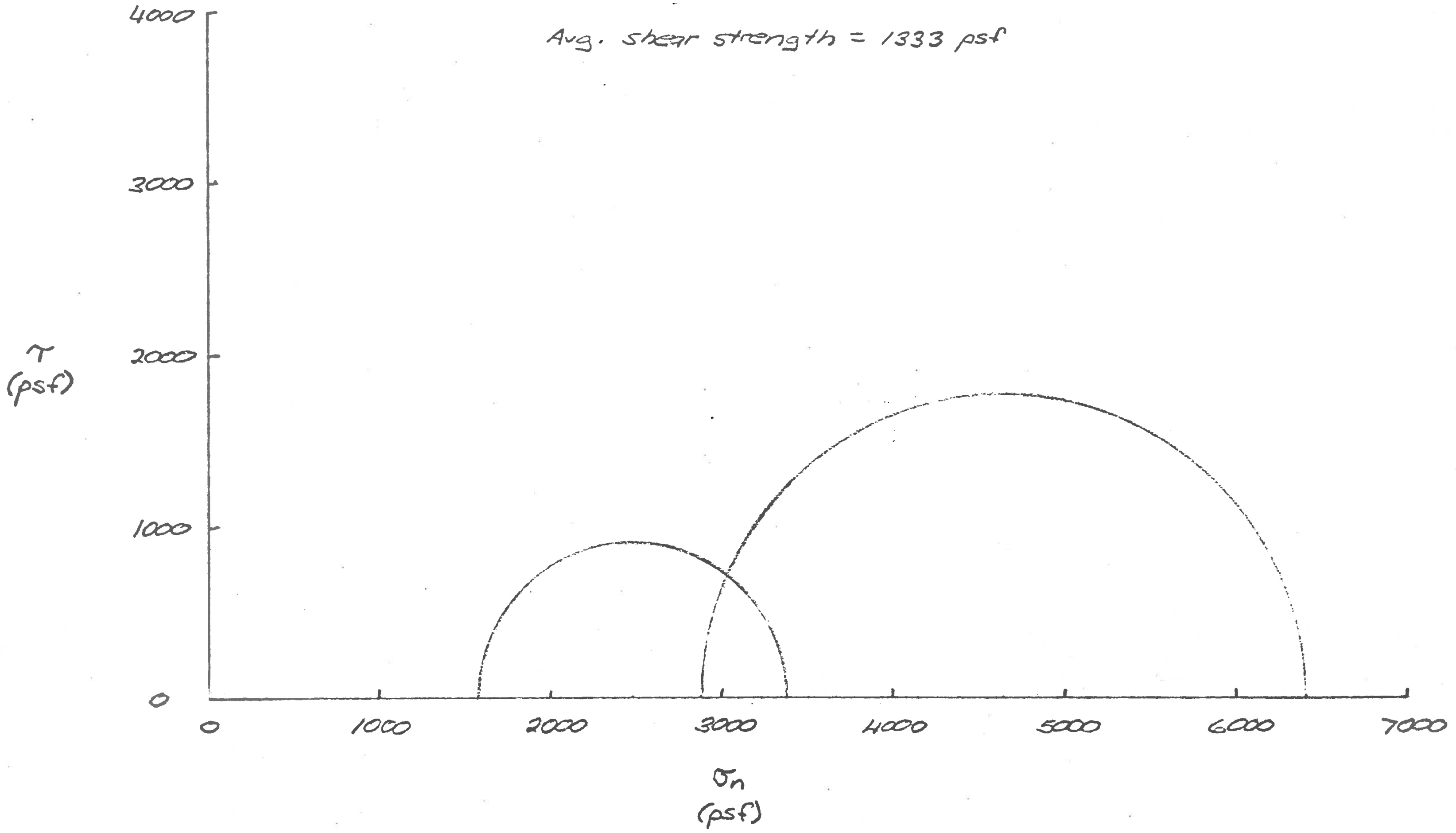
Note: Sample is tan clay with
very high content of fine
sand. Degree of Saturation
= 87%.



Peak shear strength = 665 psf

Sample B-6

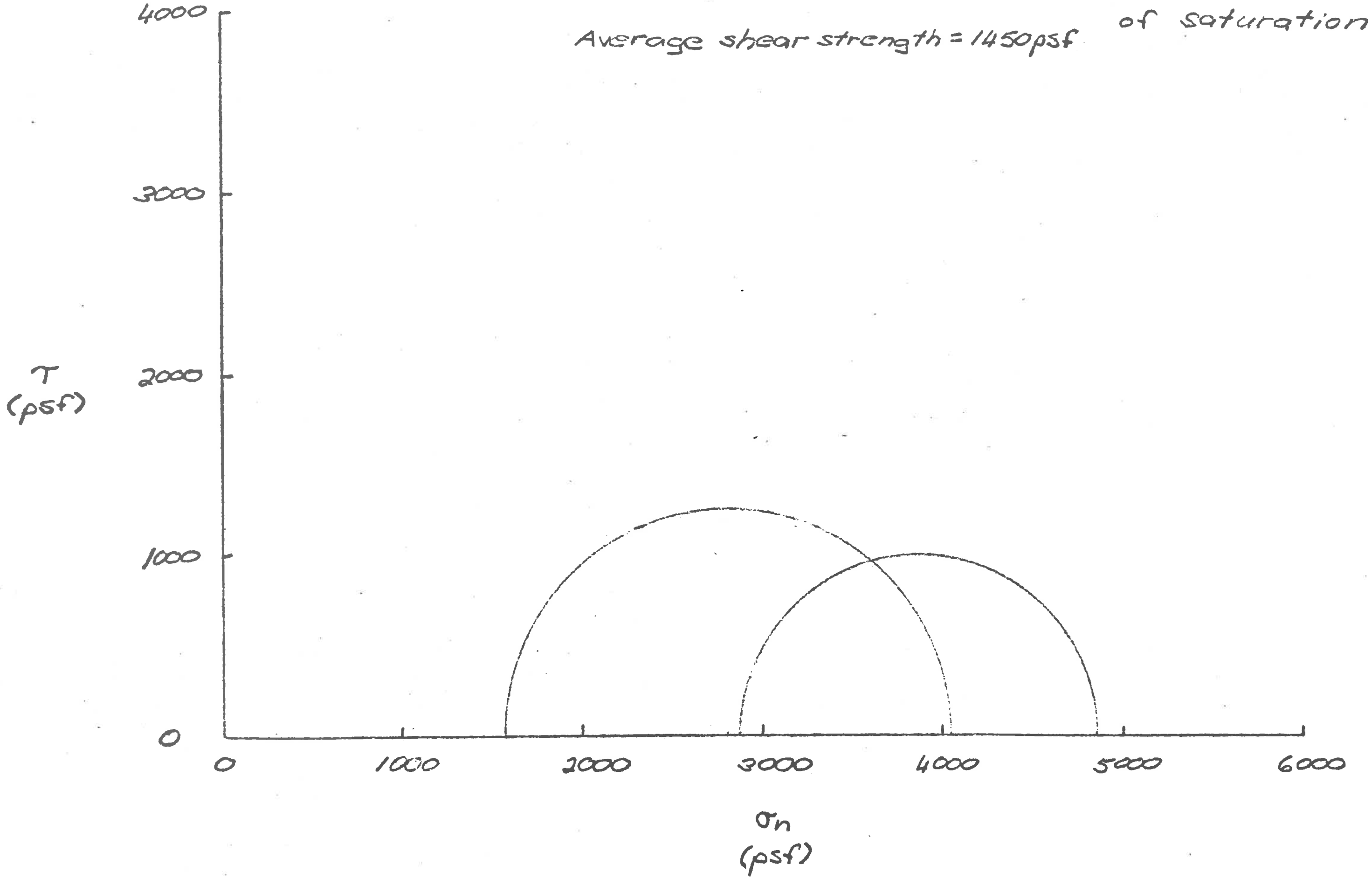
Note: Sample is very sandy gray to
tan clay w/ roots and organic
matter. Degree of saturation
= 88%.



Avg. shear strength = 1333 psf

Sample B-7

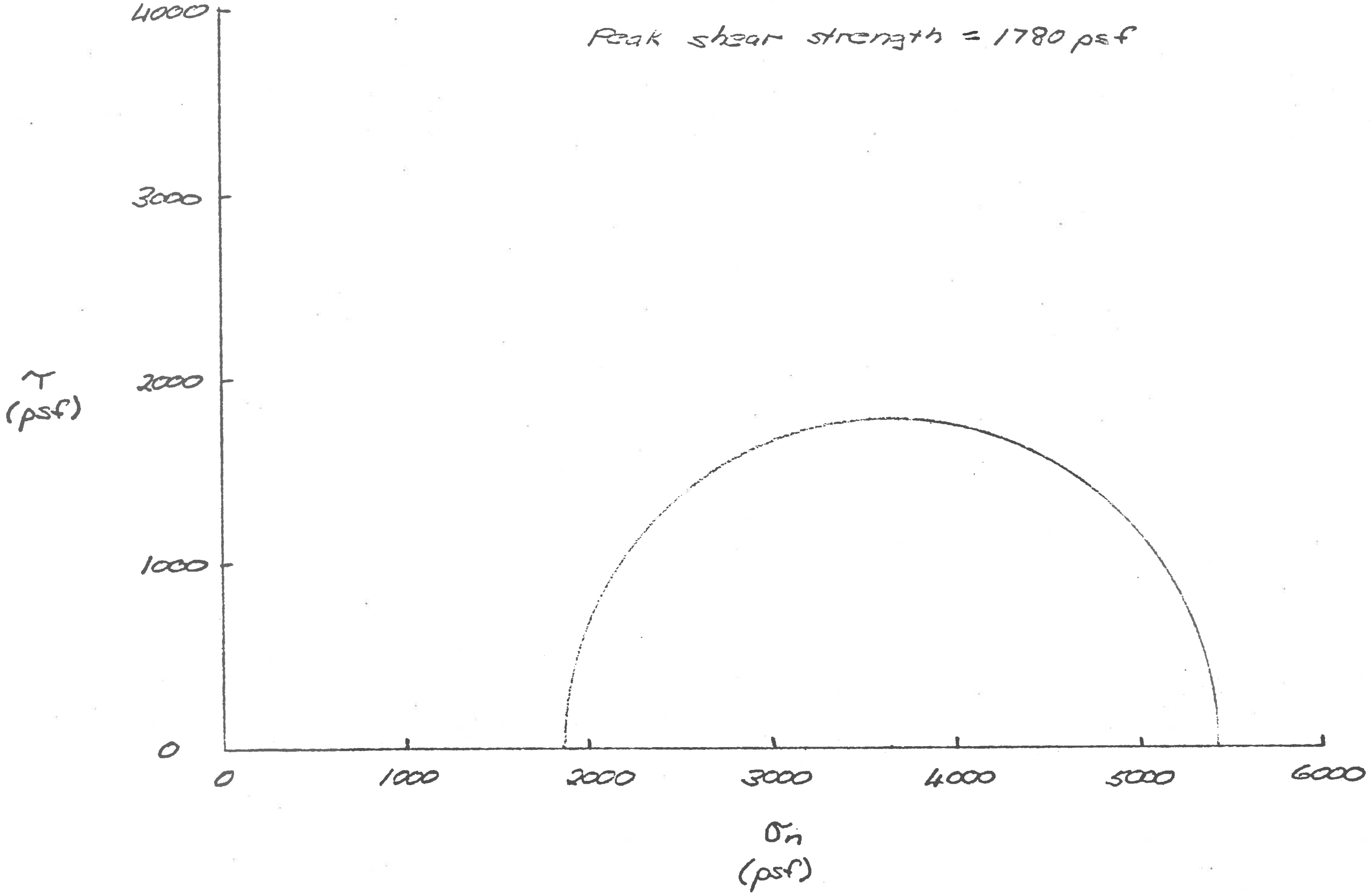
Remarks: Sample is mottled tan and gray clay w/ organic matter and very small traces of silt and fine sand. Degree of saturation = 96-99 %.



Average shear strength = 1450psf

Sample B-8

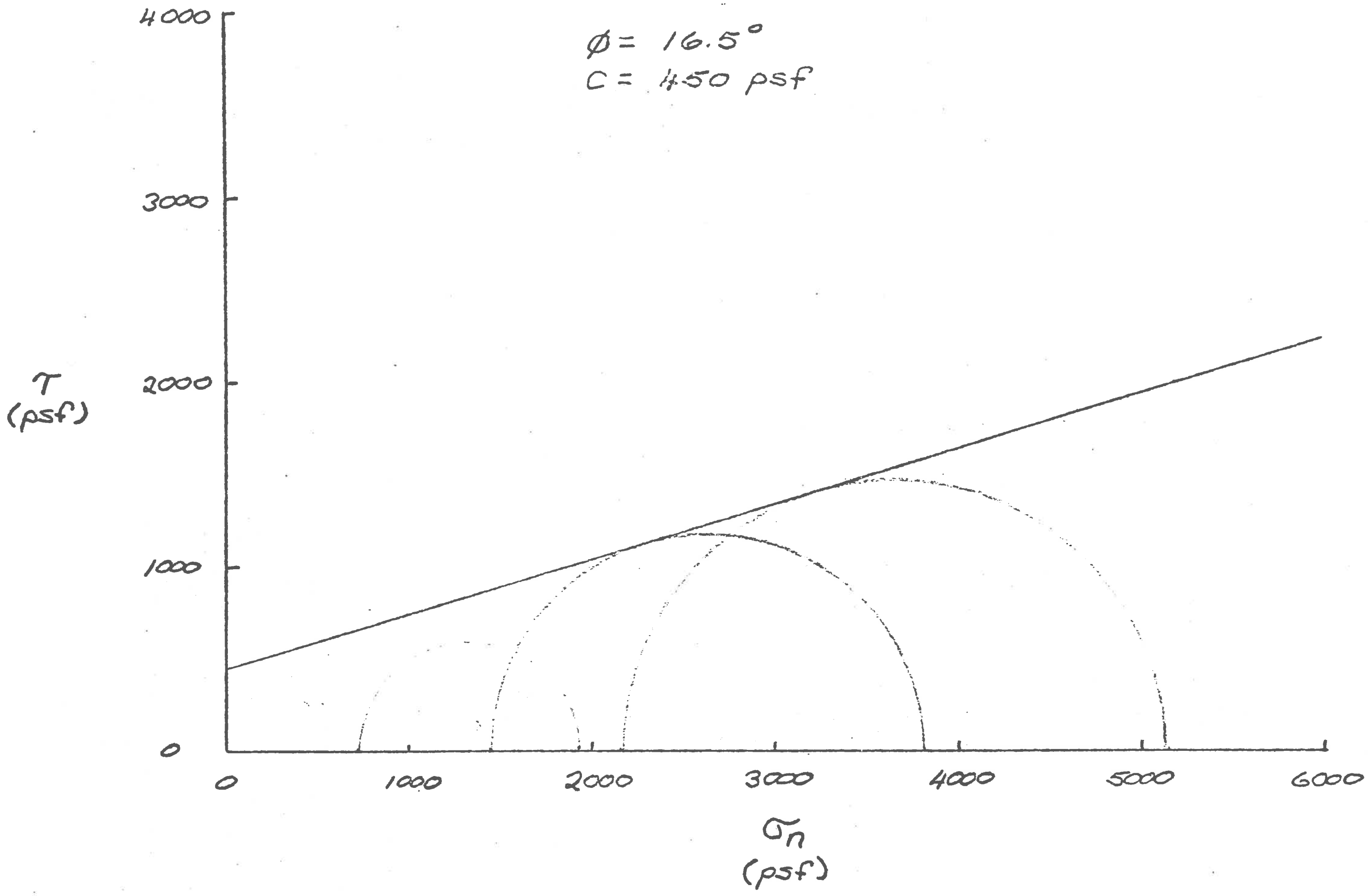
Remarks: Sample is stiff brown clay
mottled gray. Some silt.
Degree of saturation = 80%



Peak shear strength = 1780 psf

Sample C-2

Brown silty clay. Deg. of sat. = 96-100%.

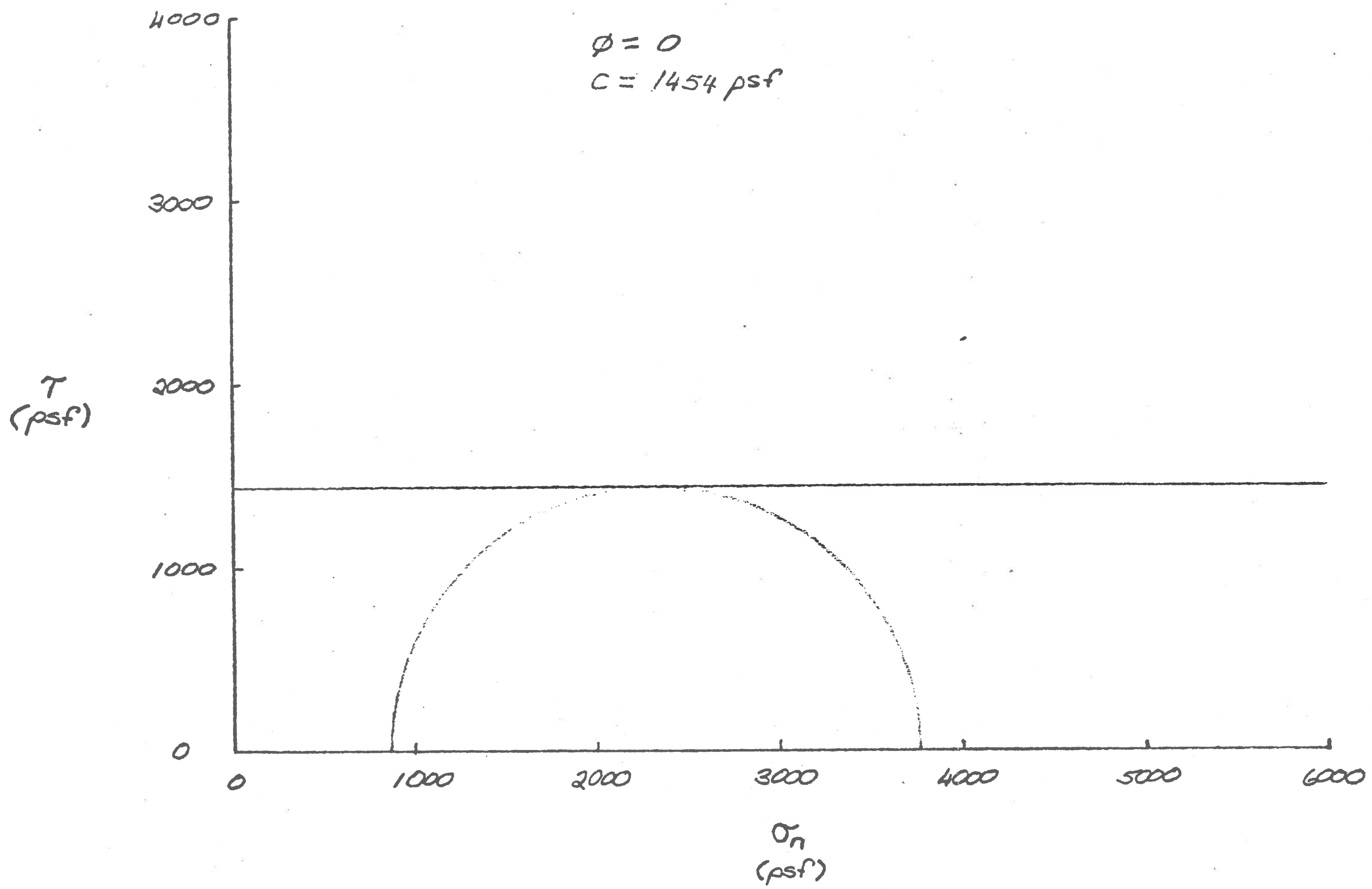


$\phi = 16.5°$

$C = 450$ psf

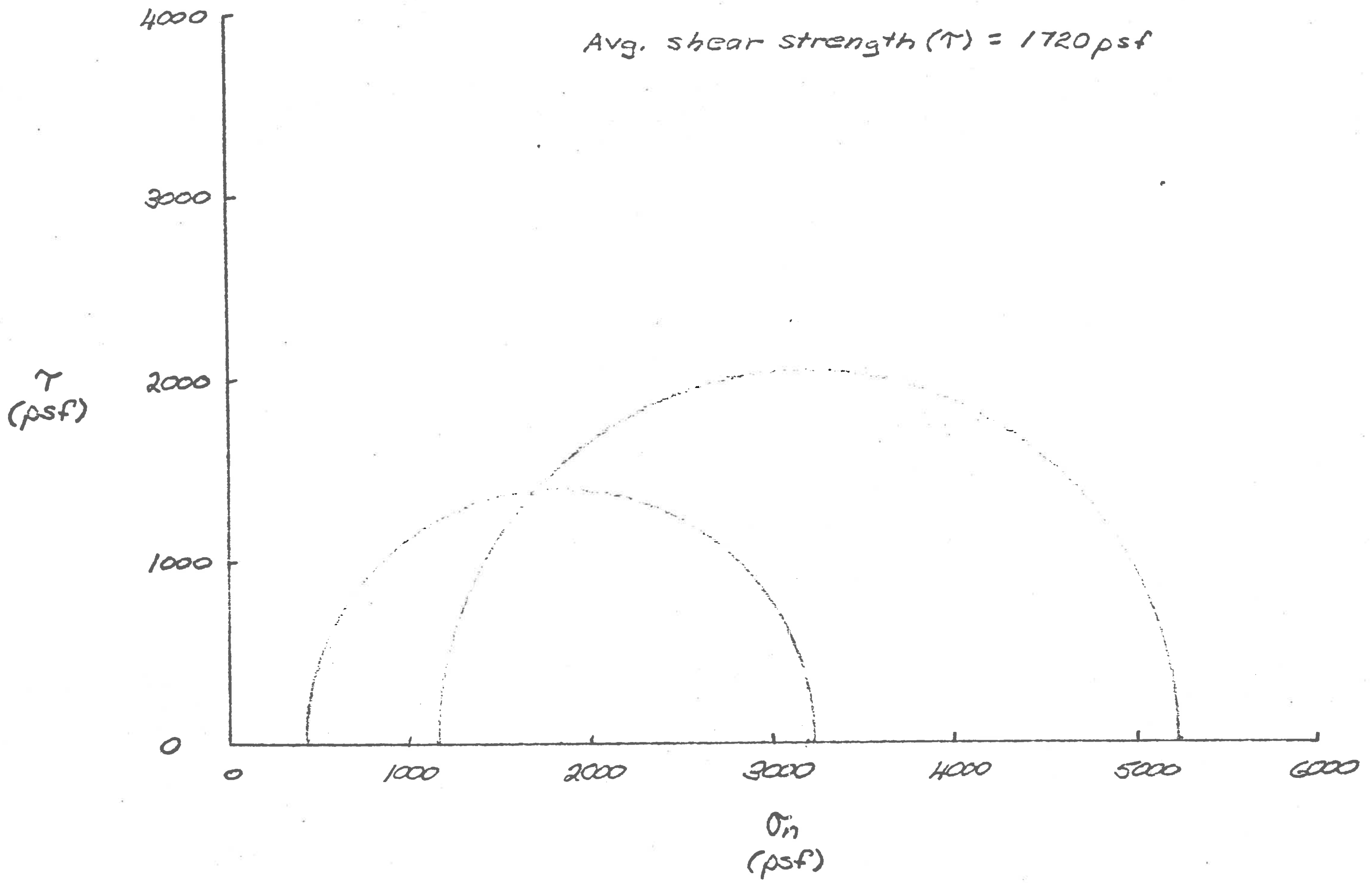
Sample C-3

Brown-gray clay with roots. Deg. of sat. = 100%.


$\phi = 0$
$c = 1454$ psf

Sample C-4

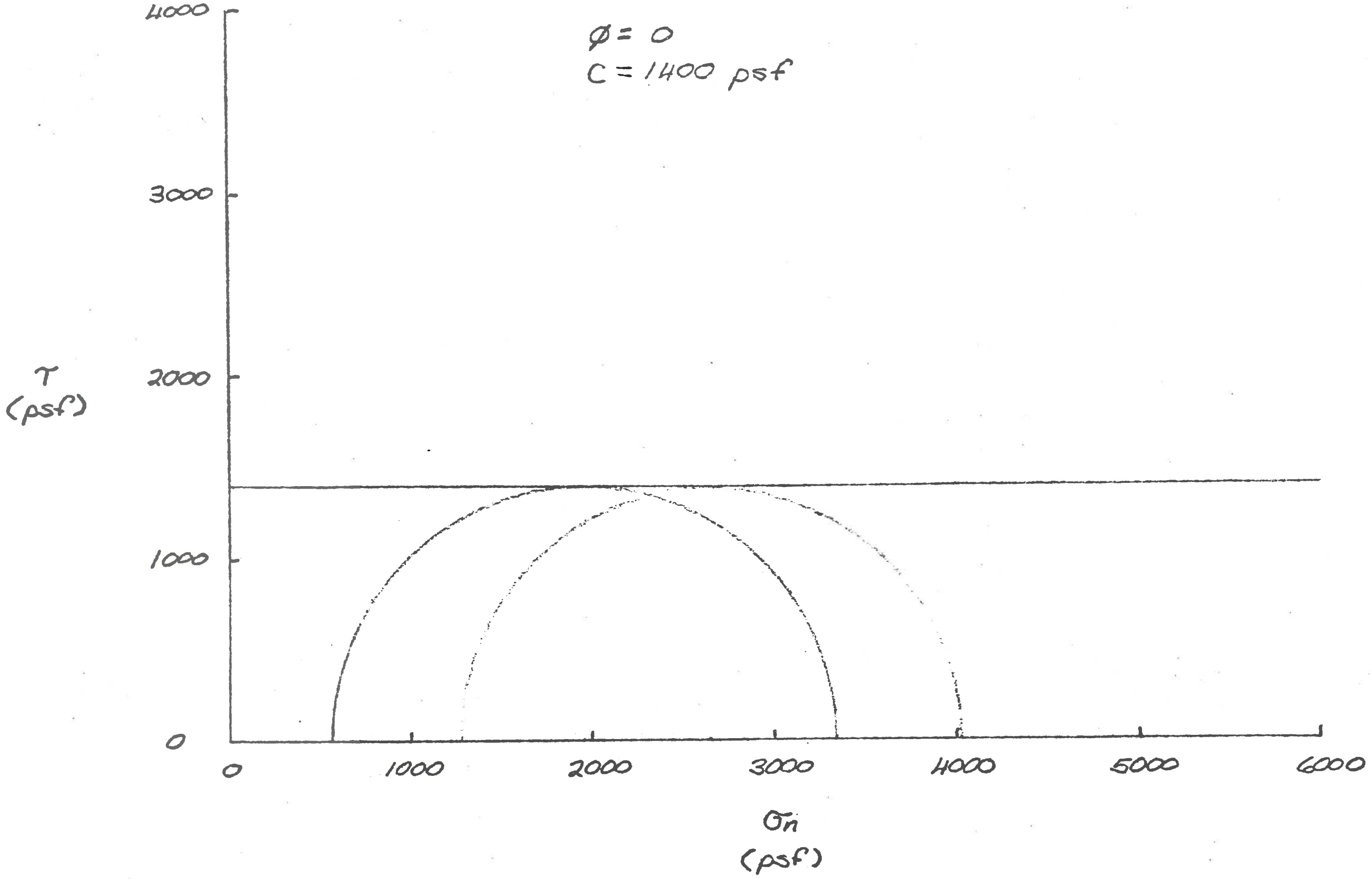
Brown-gray clay with traces of silt. Deg.
of sat. = 100%.



Avg. shear strength (τ) = 1720 psf

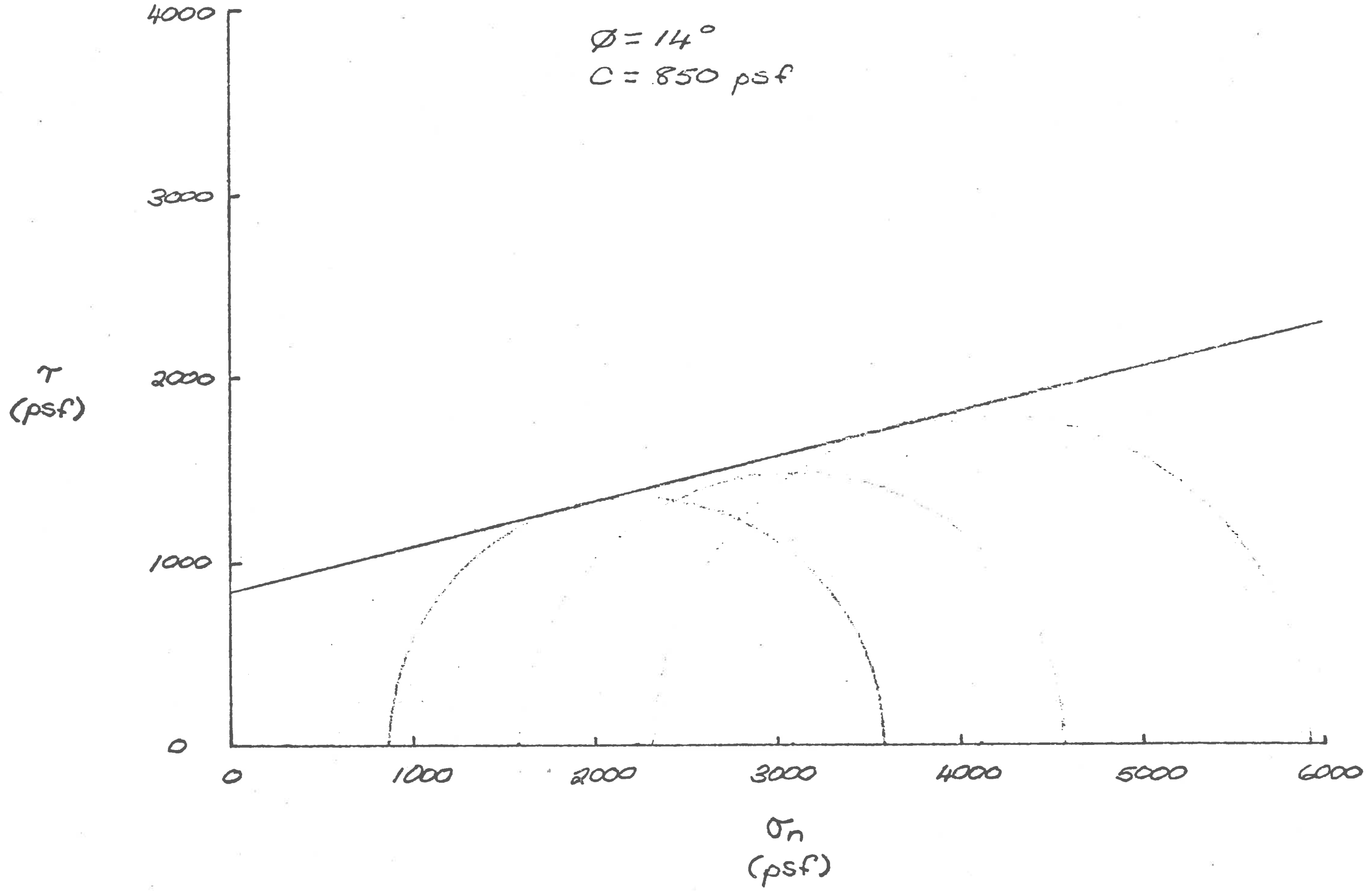
Sample C-5

Light gray clay with iron oxidized
spots. Deg. of sat. = 100%.



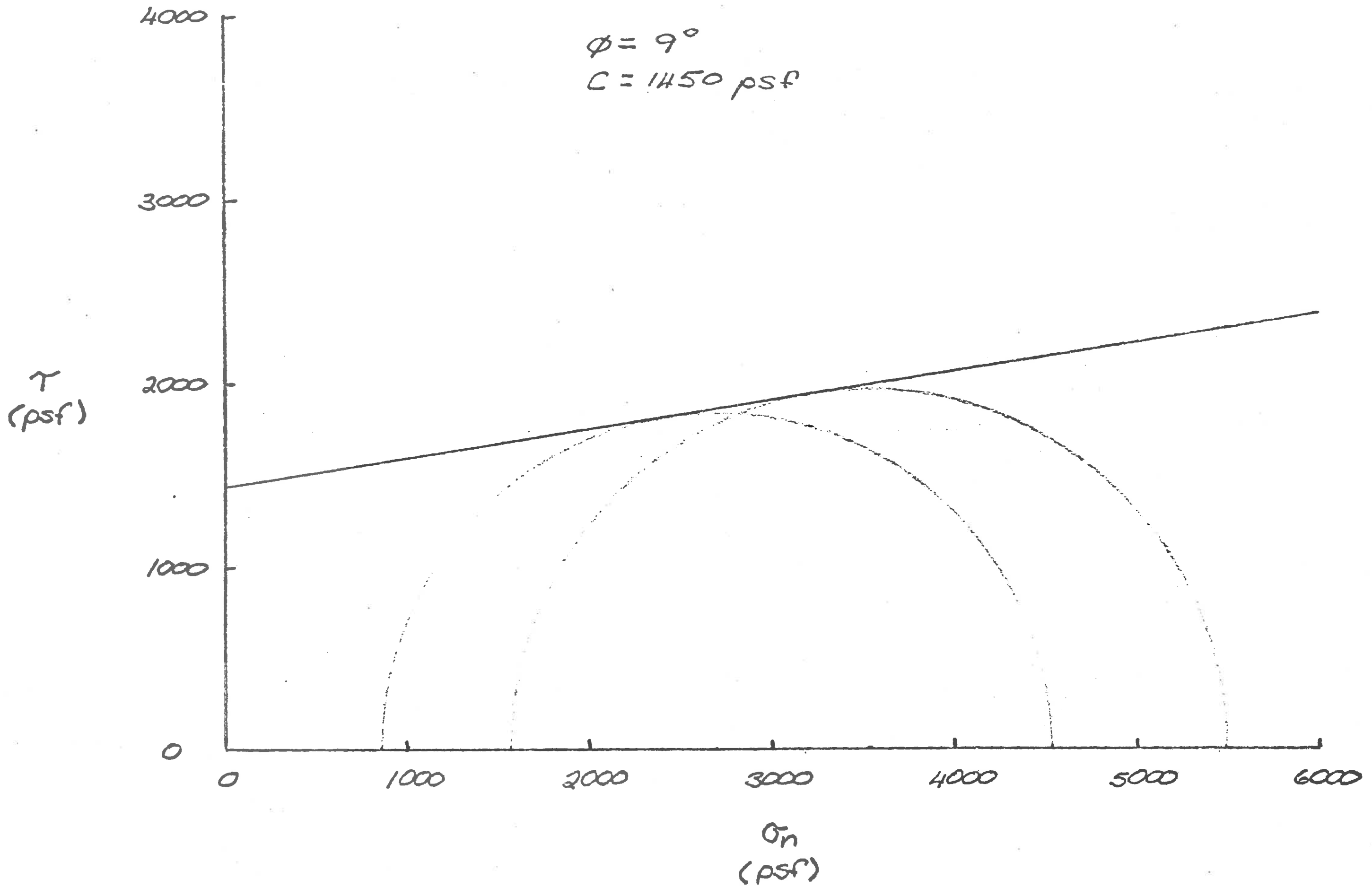
Sample C-6

Light brown-gray clay with traces
of silt. Deg. of sat. = 100%.



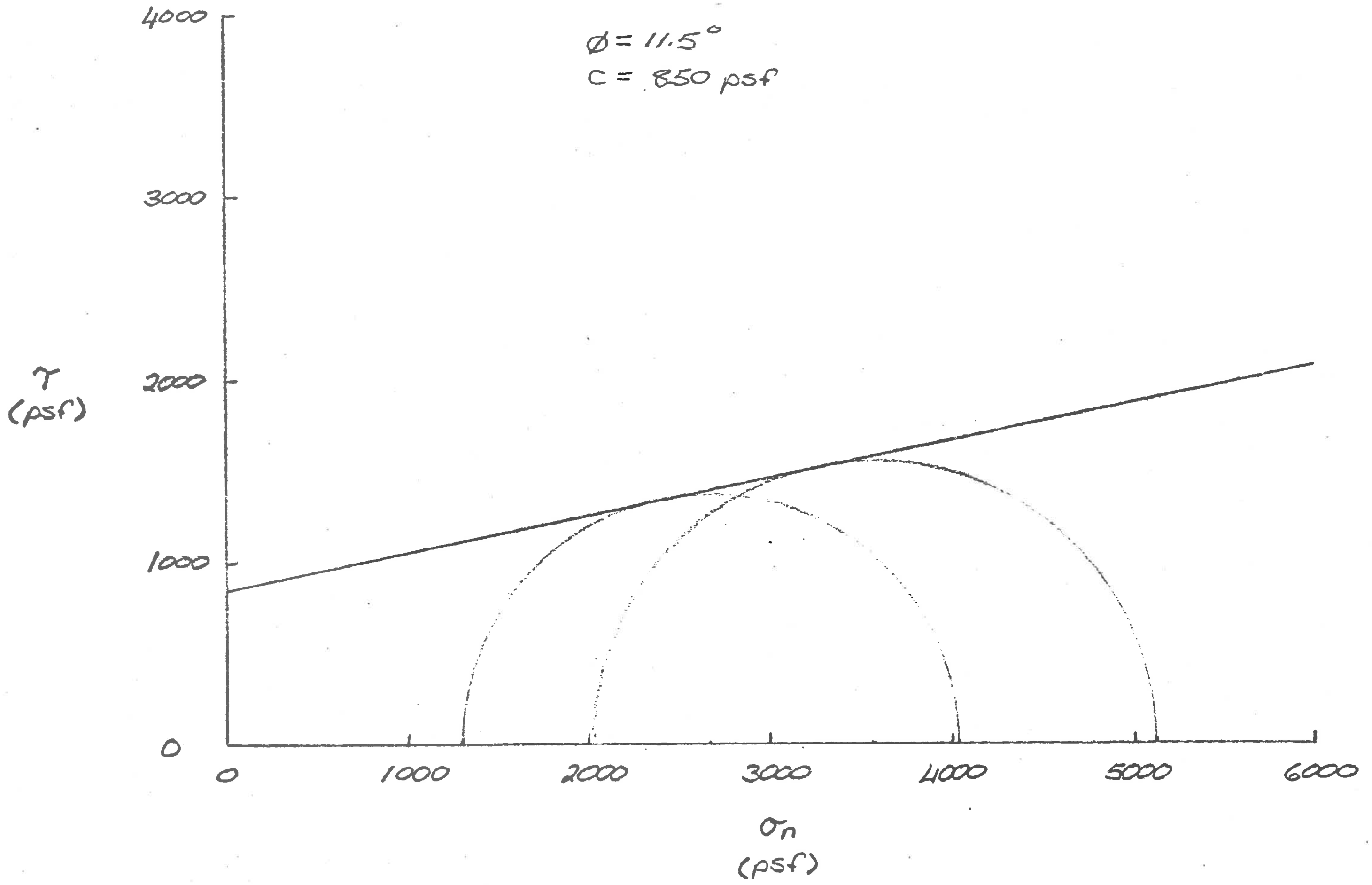
Sample C-7

Brown-gray clay with traces of silt. Deg of sat. = 94-100 %.



Sample C-8

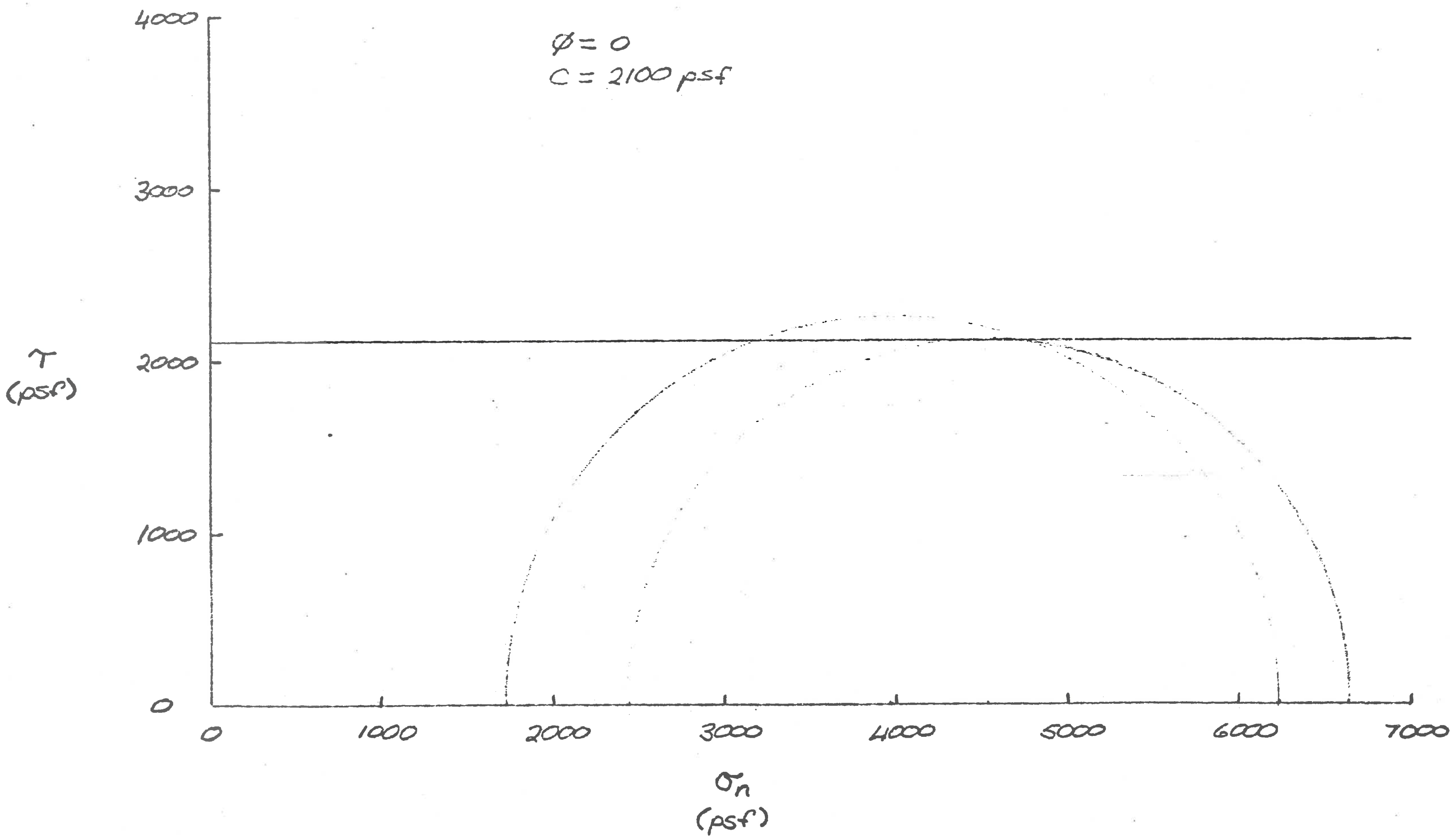
Light gray clay with oxidized spots and
traces of silt. Deg. of sat. = 100%.



$\phi = 11.5^\circ$
c = 850 psf

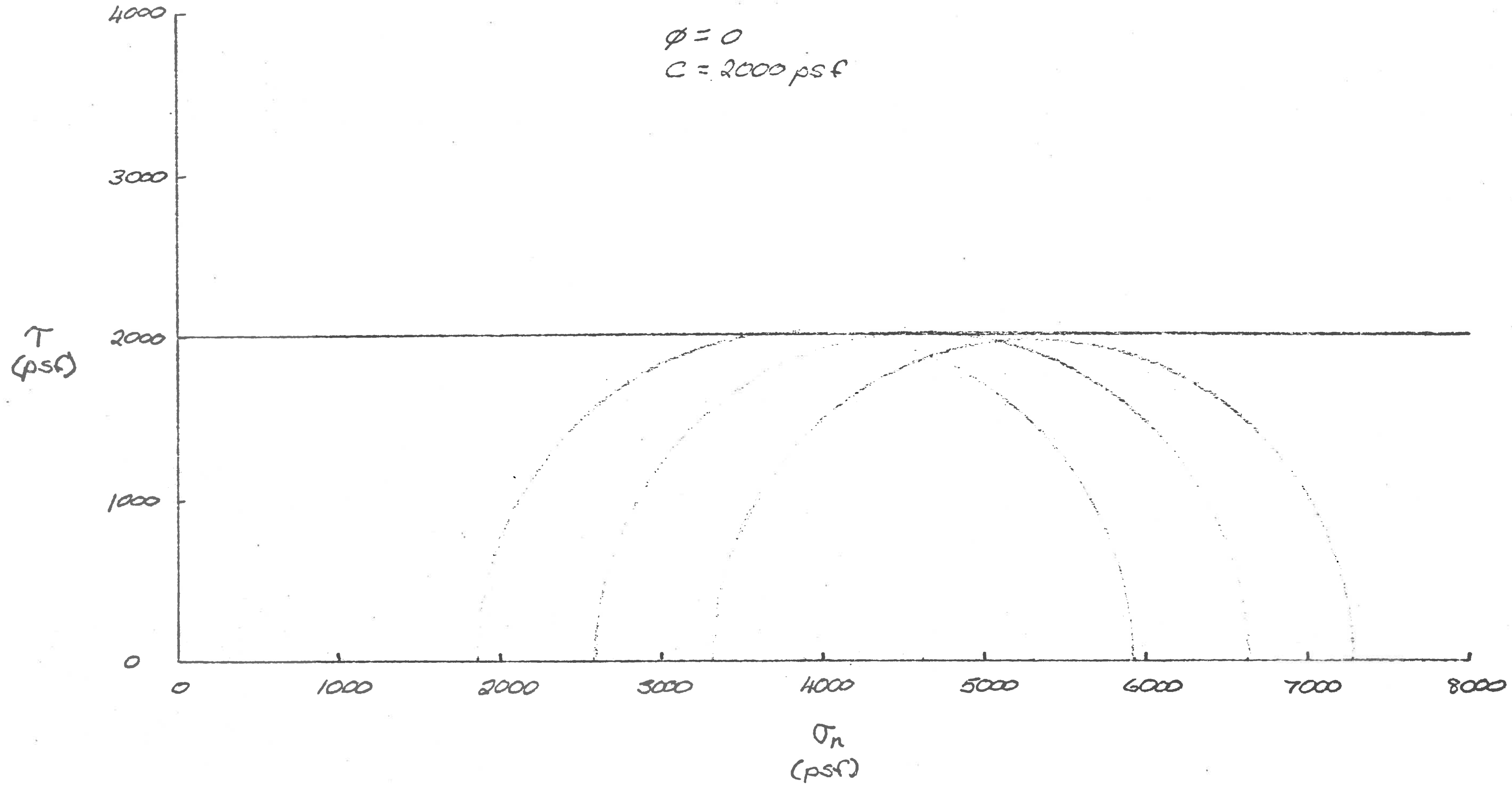
Sample C-10

Brown clay. Deg. of sat. = 98 - 100%.



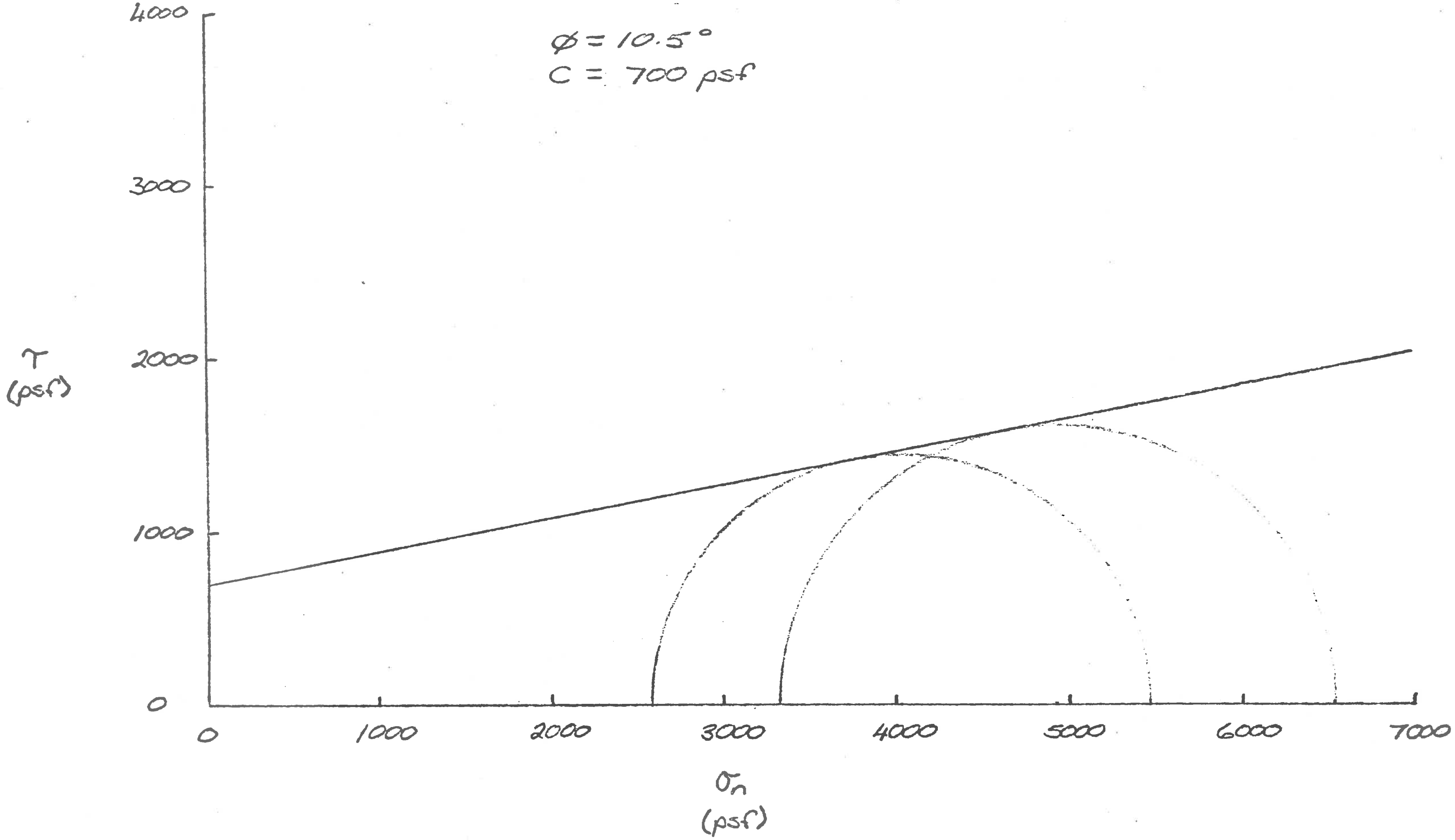
Sample C-11

Brown-gray clay. Deg. of sat. = 89-96%.



Sample C-12

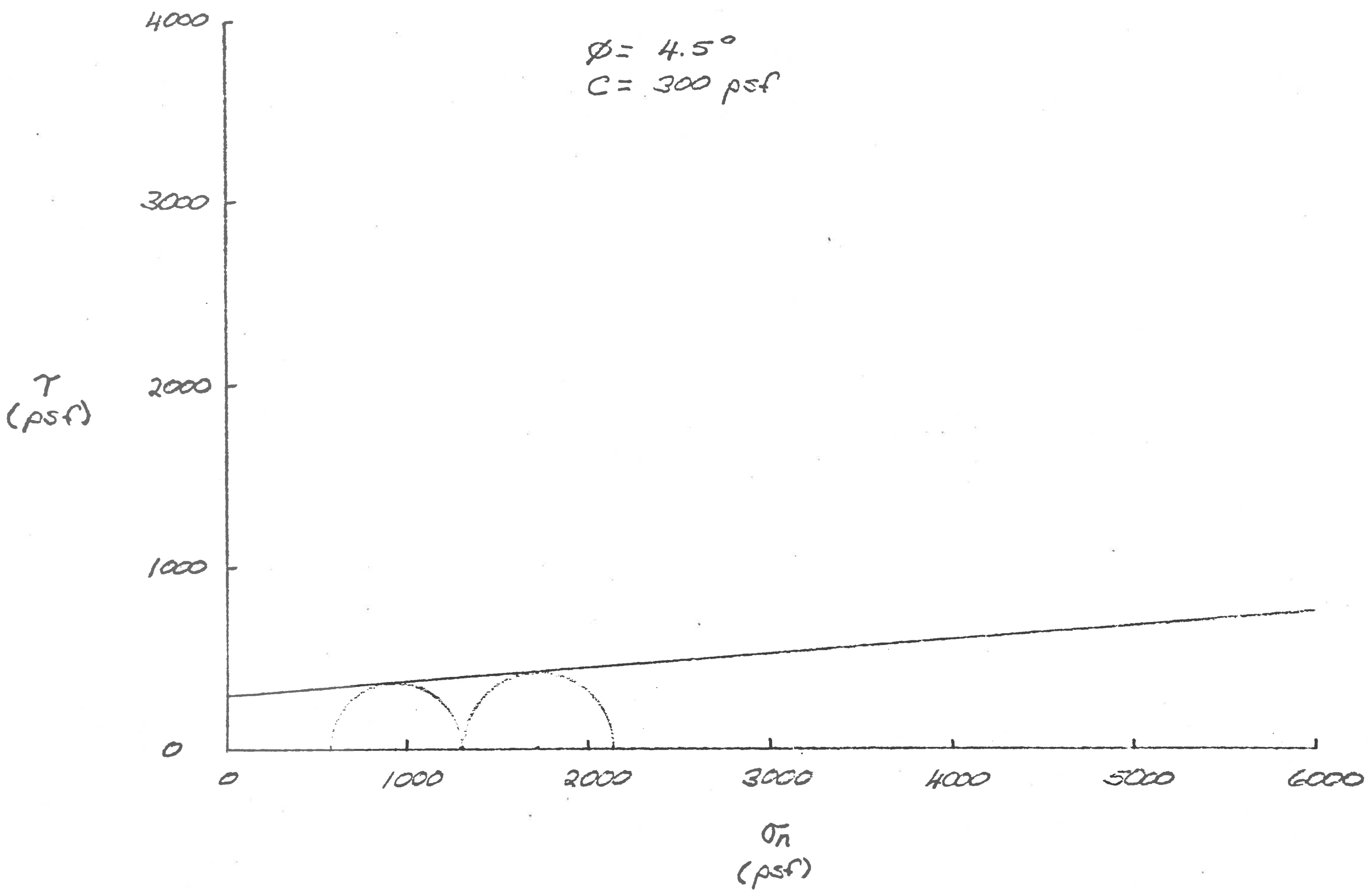
Gray clay with oxidized spots and
limonite nodules. Deg. of sat. = 94-95%.



$\phi = 10.5°$
$C = 700$ psf

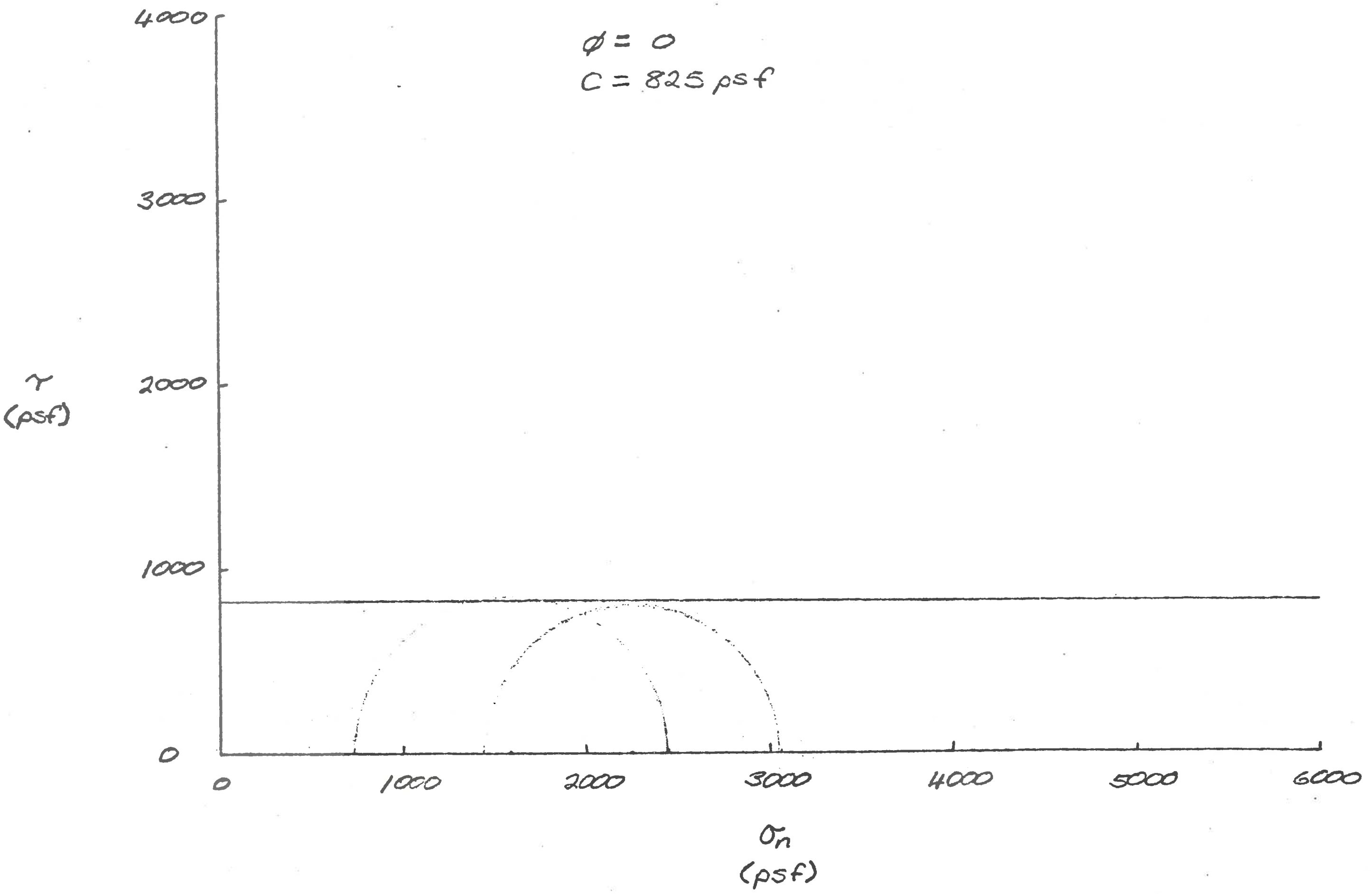
Sample D-2

Red silty clay. Deg. of sat. = 88-100%.



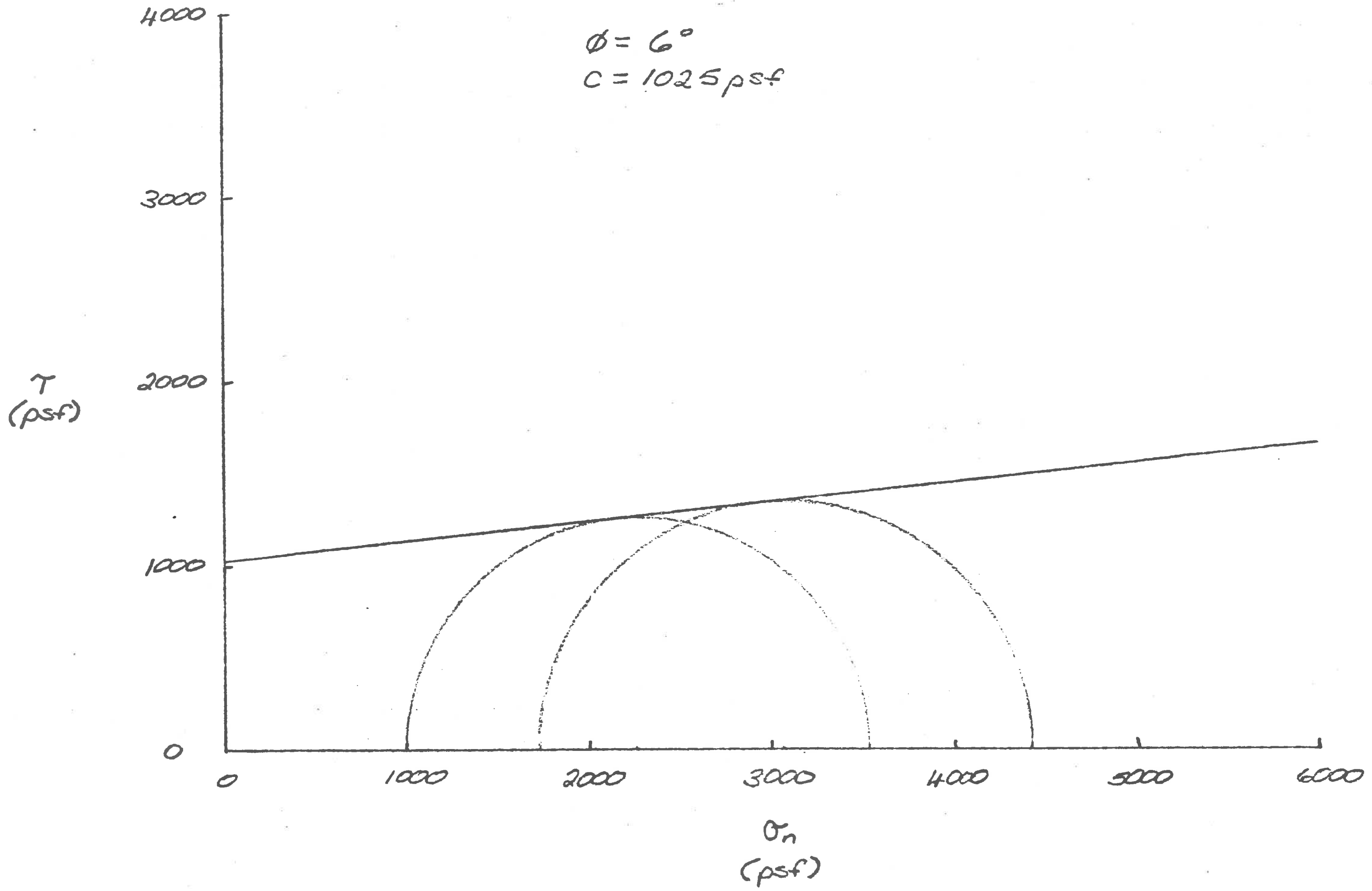
Sample D-3

Red silty clay. Deg. of sat. = 100%.



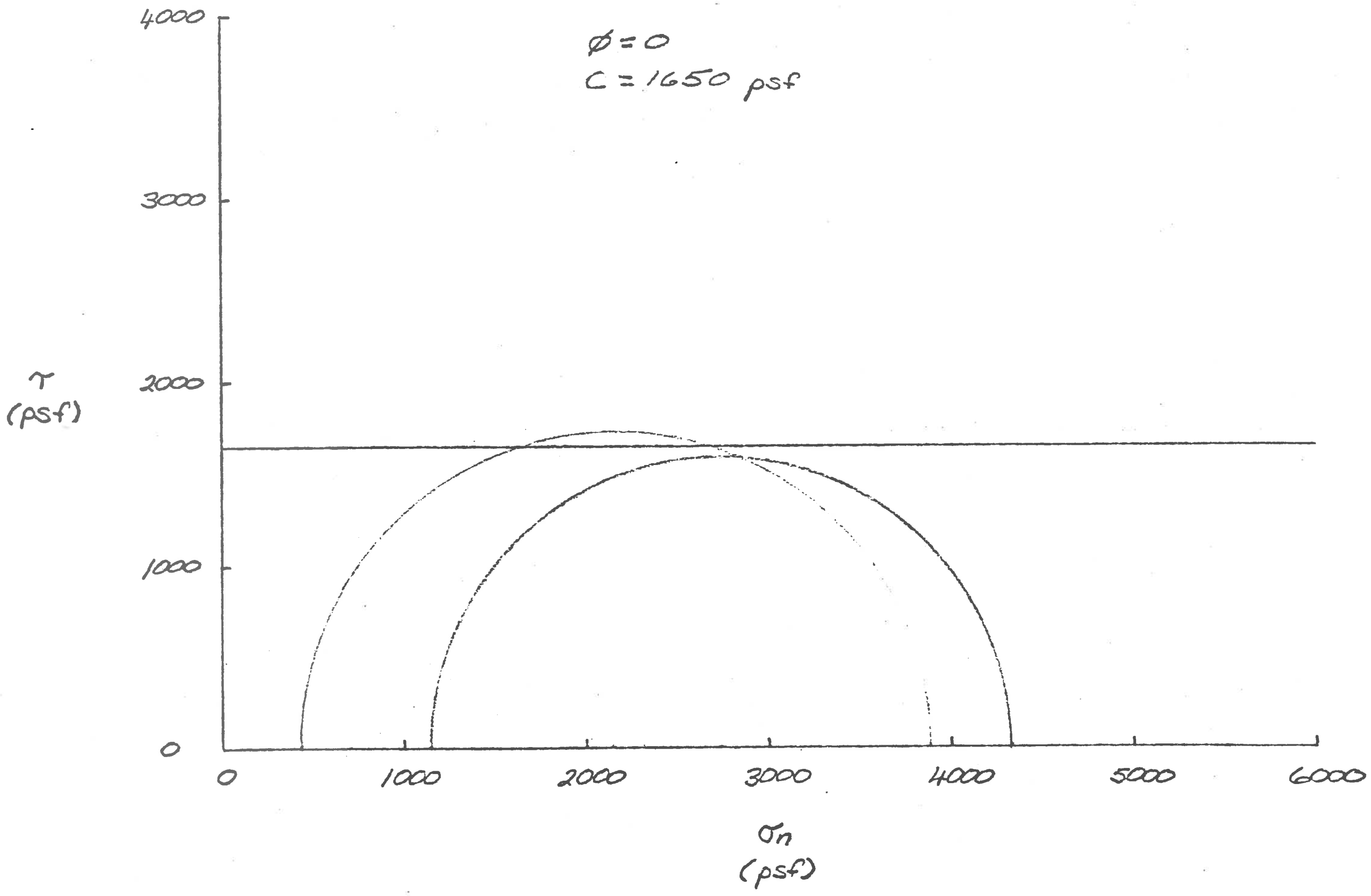
Sample D-4

Red silty clay. Deg. of sat. = 99-100%



Sample D-5

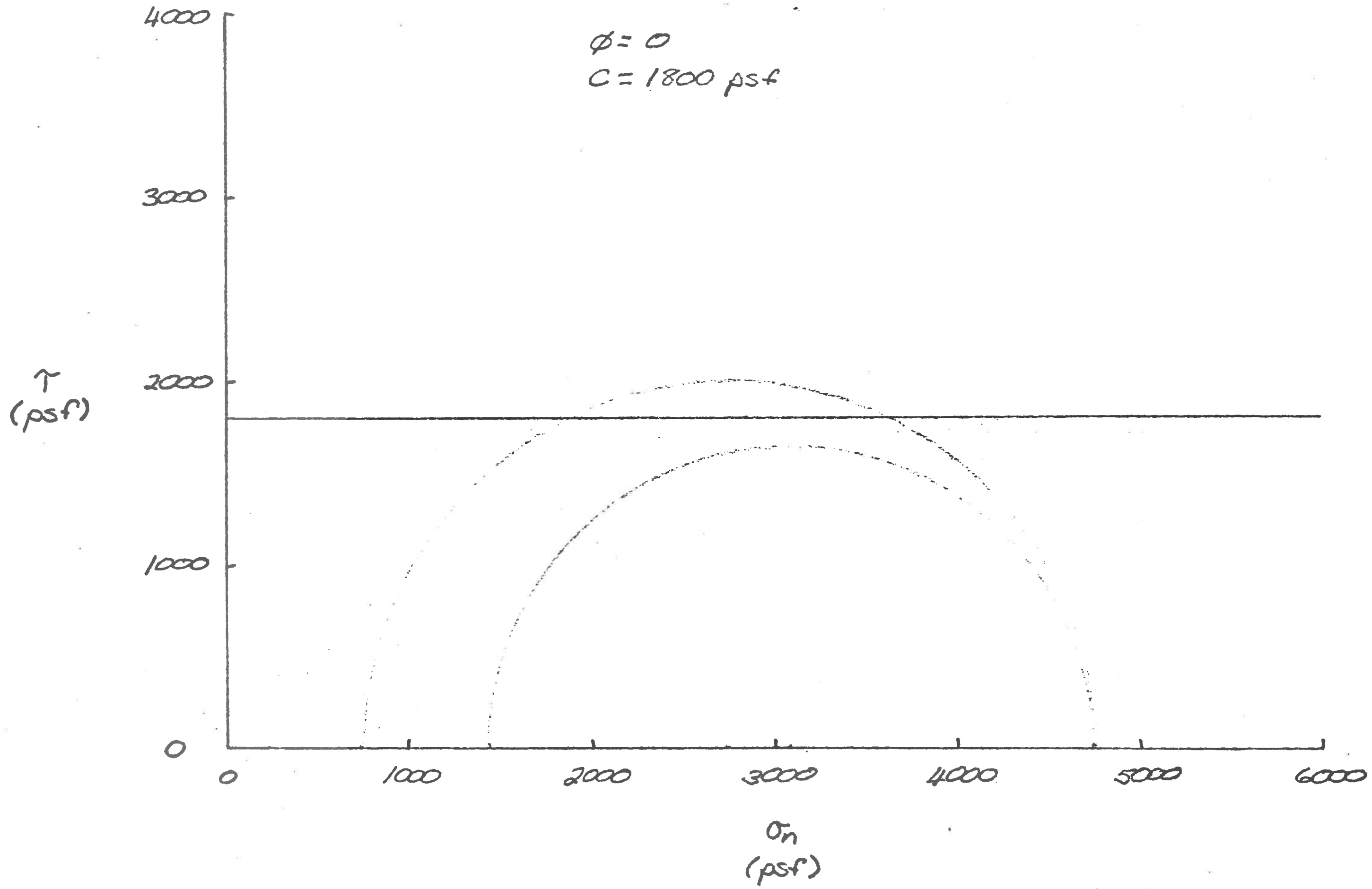
Red clay with traces of silt. Deg. of sat. = 100%



$\phi = 0$
C = 1650 psf

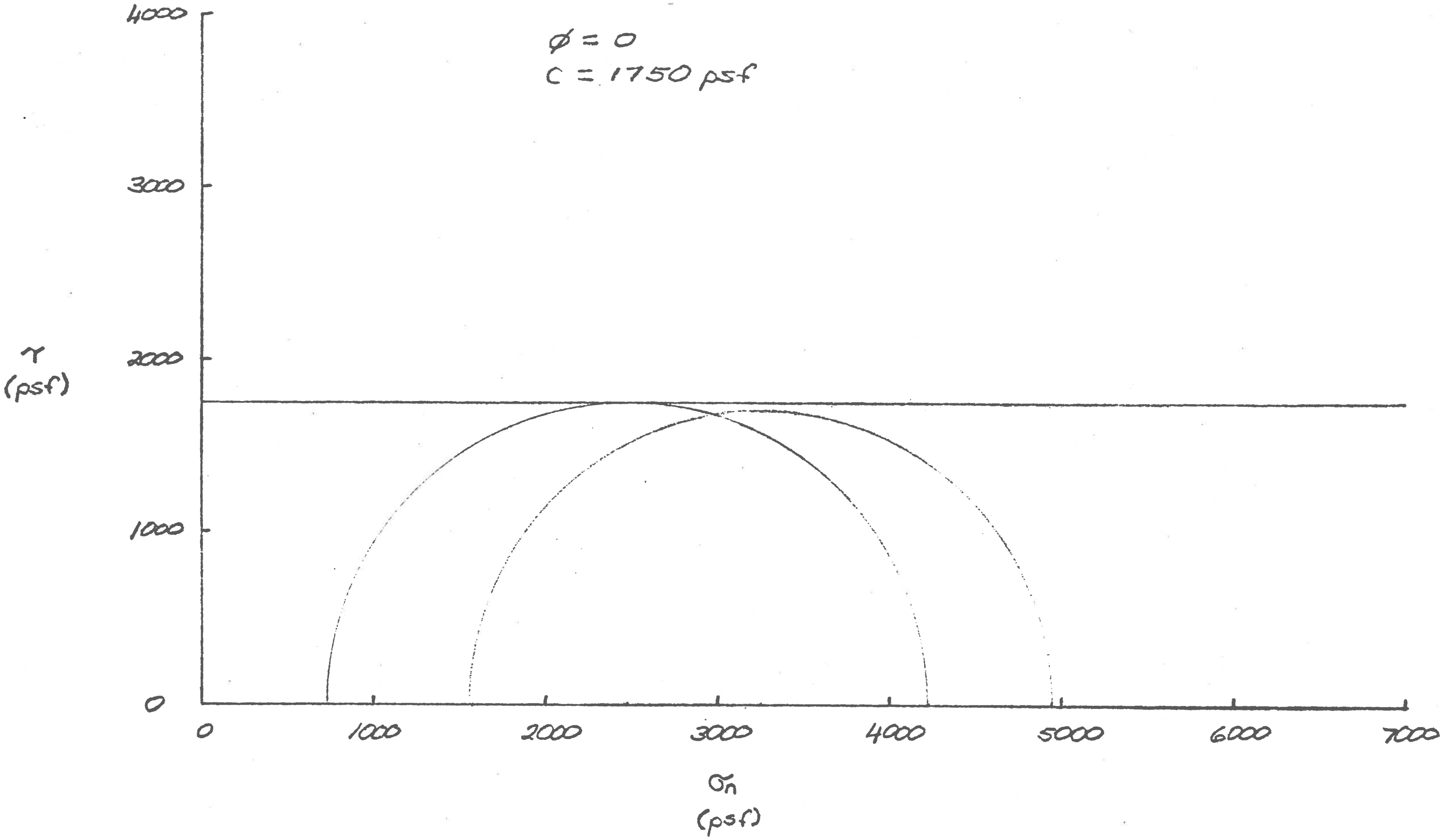
Sample D-6

Red clay with traces of silt. Deg. of
sat. = 100%.



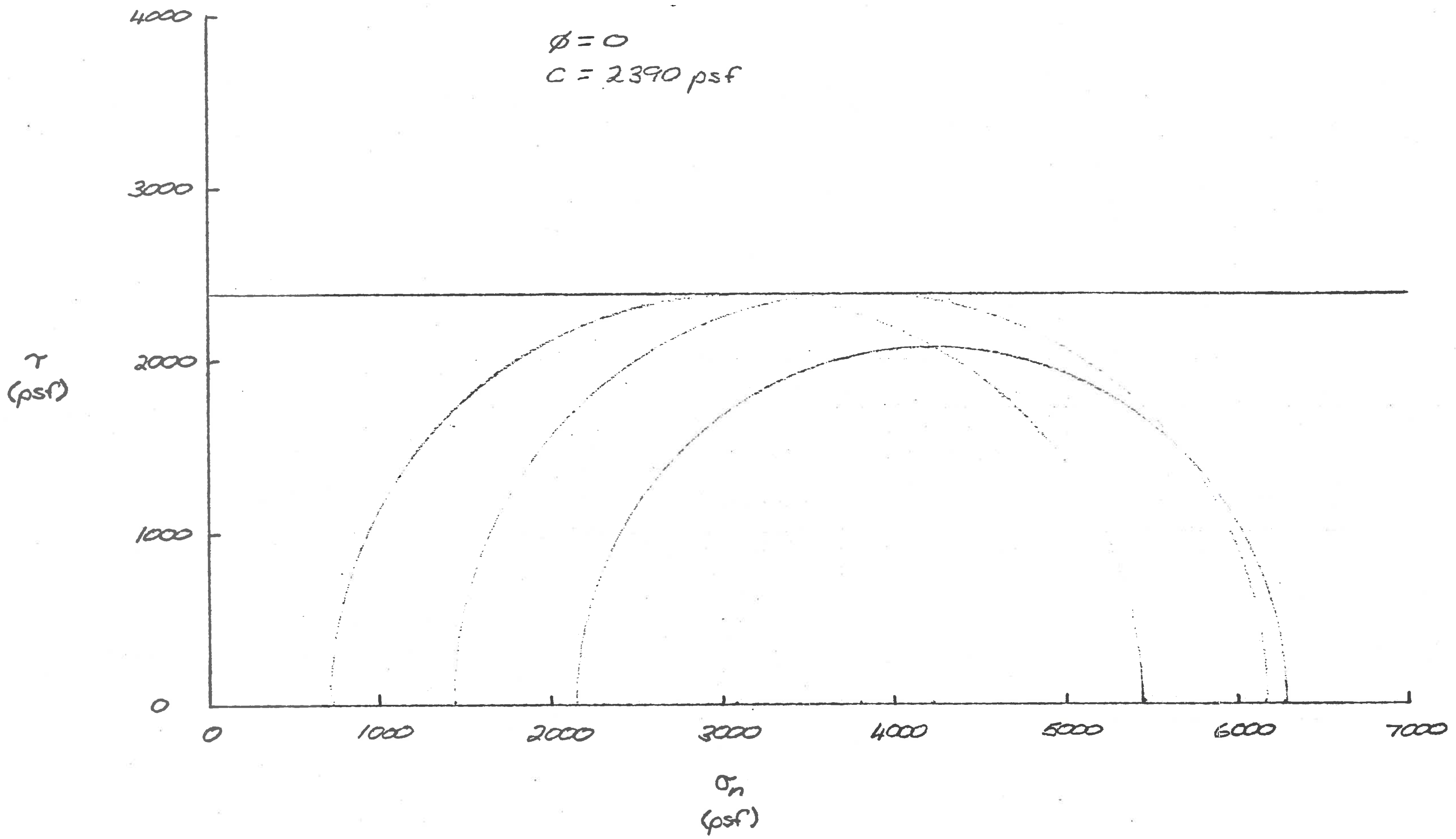
<u>Sample D-7</u>

Red silty clay. Deg. of sat. = 95-100%.



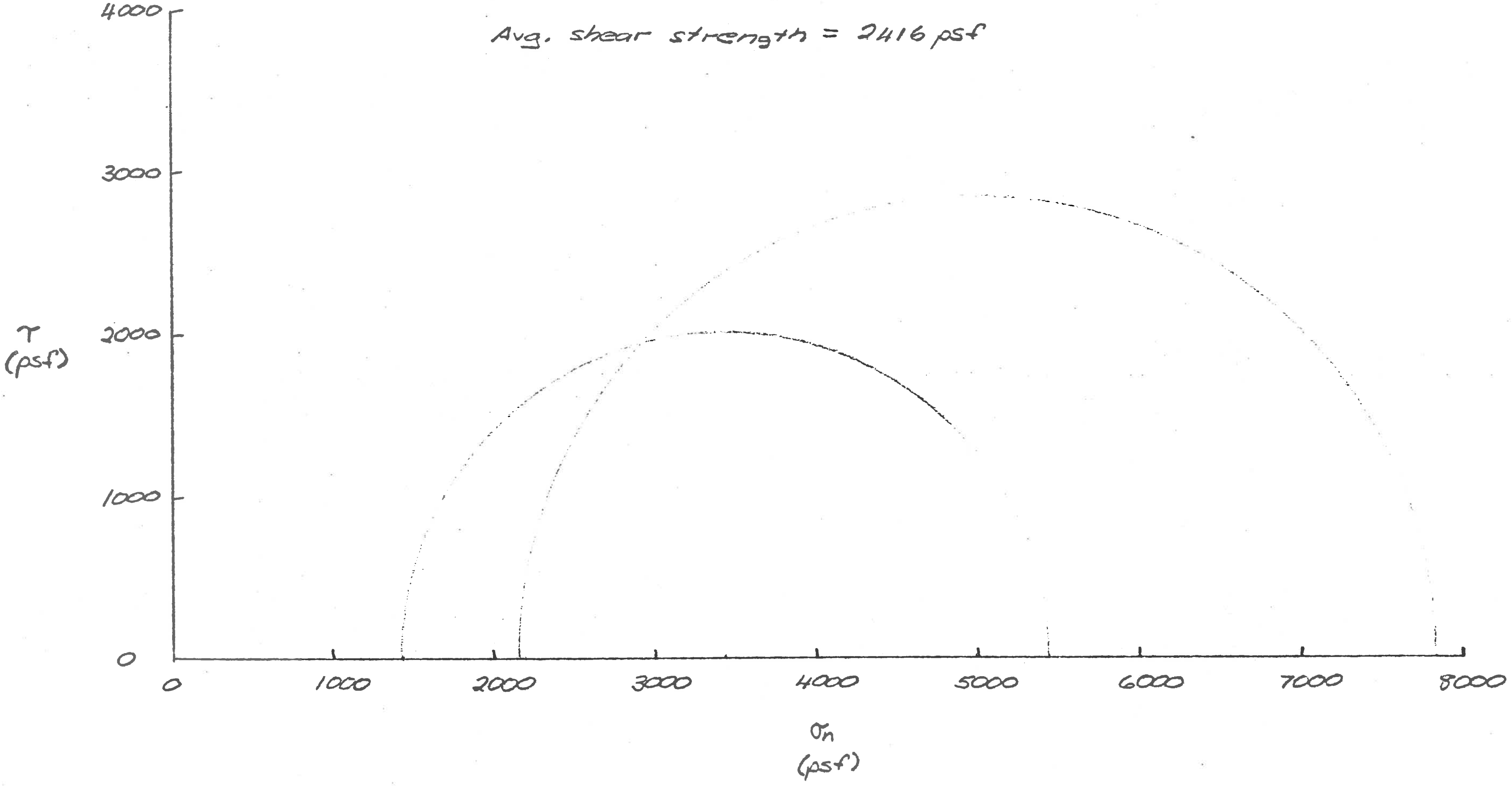
Sample D-8

Red silty clay. Deg. of sat. = 100%.



Sample D-9

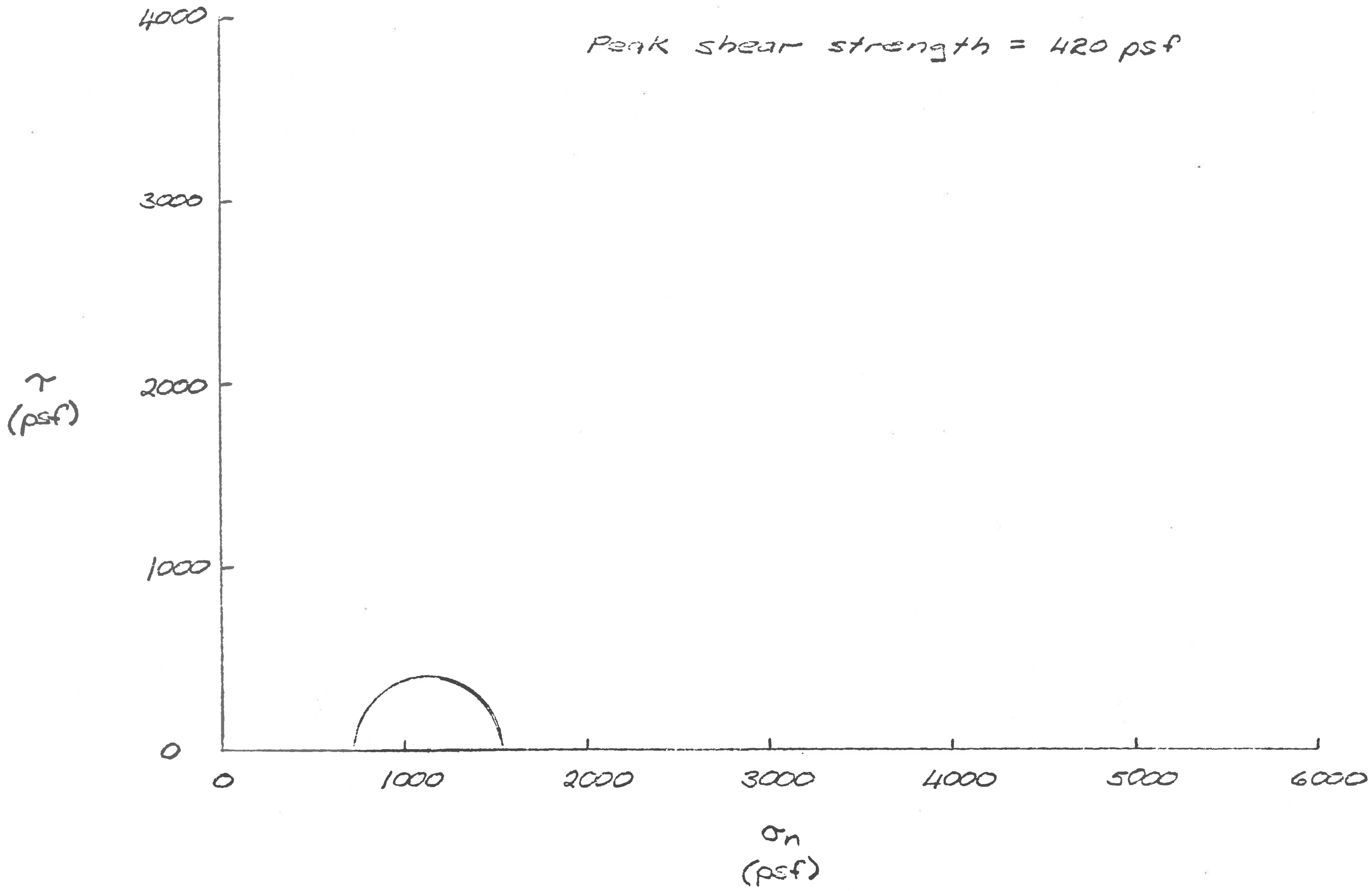
Red clay. Deg. of sat. = 100%.



Avg. shear strength = 2416 psf

Sample D-11

very silty and sandy red clay. Deg. of
sat. = 98%.



Peak shear strength = 420 psf

APPENDIX D

New York State Computer Program Listing

```
FORTRAN IV G LEVEL  20                MAIN               DATE = 72033          18/01/03              PAGE

 0001               DIMENSION SOILHL(50),SOILVL(50),SOILHR(50),SOILVR(50),WEIGHT(50)
 0002               DIMENSION COHES(50),PHI(50),WATRHL(10),WATRVL(10),WATRHR(10)
 0003               DIMENSION WATRVR(10),BET(10),XSEC(100),ASEC(100),NSOIL(20)
 0004               DIMENSION RFS(20),HFS(20),VFS(10),CRAD(100),CHOR(100),CVER(100)
 0005               DIMENSION XRAD(20)
 0006           184 CONTINUE
              C  PRINT HEADING
 0007               PRINT 1
 0008             1 FORMAT(1H1,12X,14HNEW YORK STATE,5X,28HDEPARTMENT OF TRANSPORTATIO
                   1N,//,24X,24HSLOPE STABILITY ANALYSIS,//,10X,26HPROGRAM NO. S517300
                   2/SOILSL,5X,23HDEVELOPED FEBRUARY,1970,///)
              C  READ INITIALIZATION DATA
 0009               READ 2,NSL,NWL,INPUT,IALLFS,ITER,NUMCEN
 0010             2 FORMAT(6I2)
              C  READ SOIL DATA AND CONVERT PHI TO RADIANS
 0011               DO 4 I=1,NSL
 0012               READ 3, SOILHL(I),SOILVL(I),SOILHR(I),SOILVR(I),WEIGHT(I),PHI(I),C
                   1OHES(I)
 0013             3 FORMAT(7F10.4)
 0014             4 PHI(I)=PHI(I)/57.29578
              C  READ WATER TABLE DATA AND COMPUTE SLOPE ANGLE OF EACH LINE
 0015               DO 5 I=1,NWL
 0016               READ 3,WATRHL(I),WATRVL(I),WATRHR(I),WATRVR(I)
 0017             5 BET(I)=ATAN((WATRVL(I)-WATRVR(I))/(WATRHR(I)-WATRHL(I)))
              C  PRINT OR DO NOT PRINT INPUT DATA DEPENDING ON OPTION INPUT
 0018               IF(INPUT) 6,6,8
 0019             6 PRINT 7
 0020             7 FORMAT(24X,24HINPUT DATA NOT REQUESTED,//)
 0021               GO TO 14
 0022             8 PRINT 9
 0023             9 FORMAT(31X,10HINPUT DATA,//,10X,10HSOIL LINES,/,5H LINE,2X,6HSOILH
                   1L,3X,6HSOILVL,3X,6HSOILHR,3X,6HSOILVR,3X,6HWEIGHT,3X,3HPHI,3X,5HCO
                   2HES,/,9X,4(2HFT,7X),3HPCF,4X,3HDEG,4X,3HPSF,/)
 0024               DO 10 I=1,NSL
 0025               DPHI=PHI(I)*57.29578
 0026            10 PRINT 11, I,SOILHL(I),SOILVL(I),SOILHR(I),SOILVR(I),WEIGHT(I),DPHI
                   1,COHES(I)
 0027            11 FORMAT(2X,I3,5F9.2,F6.1,F9.2)
 0028               PRINT 12
 0029            12 FORMAT(//,10X,17HWATER TABLE LINES,/,5H LINE,2X,6HWATRHL,3X,6HWATR
                   1VL,3X,6HWATRHR,3X,6HWATRVR,/,9X,4(2HFT,7X),/)
 0030               DO 13 I=1,NWL
 0031            13 PRINT 11, I,WATRHL(I),WATRVL(I),WATRHR(I),WATRVR(I)
              C  LOOP FOR MULTIPLE STARTING CENTERS
 0032            14 DO 124 ICEN=1,NUMCEN
              C  READ STARTING CENTER DATA
 0033               READ 3,HORZON,VERTCL,RADIUS,RADINC,GRID
              C  PRINT SEARCH INFORMATION
```

```
FORTRAN IV G LEVEL  20                MAIN             DATE = 72033          18/01/03             PAGE

 0034                PRINT 15,RADINC,GRID
 0035             15 FORMAT(//,10X,19HRADIUS INCREMENT IS,F5.1,5X,17HGRID INCREMENT IS,
                    1F5.1)
               C  PRINT OR DO NOT PRINT HEADINGS DEPENDING ON OPTION IALLFS
 0036                IF(IALLFS) 18,18,16
 0037             16 PRINT 17
 0038             17 FORMAT(//,2X,6HSEPMOM,3X,6HDRVMOM,3X,6HPHIMOM,3X,6HCHSMOM,3X,20HHO
                    1RZON VERTCL RADIUS,/,2X,4(6HFT-KIP,3X),3(4H  FT,3X),12HFSNYS  FSBI
                    2S,/)
 0039             18 NUMRAD=0
 0040                NUMLOC=0
 0041                IVER=0
 0042             19 INDEX=0
 0043                IHOR=0
 0044             20 IRAD=0
 0045                NUMLOC=NUMLOC+1
 0046             21 K=0
 0047                NUMRAD=NUMRAD+1
               C  COMPUTE INTERSECTIONS OF CIRCLE WITH SOIL STRATA LINES
 0048                DO 32 I=1,NSL
 0049                A=(SOILVR(I)-SOILVL(I))/(SOILHR(I)-SOILHL(I))
 0050                B=SOILVL(I)-VERTCL-SOILHL(I)*A
 0051                C=B*B+HORZON*HORZON-RADIUS*RADIUS
 0052                D=(A*B-HORZON)*(A*B-HORZON)-(A*A+1)*C
 0053                IF(D)  32,22,22
 0054             22 X1=(HORZON-A*B-SQRT(D))/(A*A+1)
 0055                IF  (X1-(HORZON-RADIUS))151,152,152
 0056            151 X1=HORZON-RADIUS
 0057            152 X2=(HORZON-A*B+SQRT(D))/(A*A+1)
               C  STORE INTERSECTIONS AND DISCONTINUITIES IN XSEC
 0058                IF(SOILHL(I)-X1) 23,25,25
 0059             23 IF(SOILHR(I)-X1) 27,24,24
 0060             24 K=K+1
 0061                XSEC(K)=X1
 0062                GO TO 27
 0063             25 IF(SOILHL(I)-X2) 26,26,27
 0064             26 K=K+1
 0065                XSEC(K)=SOILHL(I)
 0066             27 IF(SOILHR(I)-X2) 28,28,30
 0067             28 IF(SOILHR(I)-X1) 32,29,29
 0068             29 K=K+1
 0069                XSEC(K)=SOILHR(I)
 0070                GO TO 32
 0071             30 IF(SOILHL(I)-X2) 31,31,32
 0072             31 K=K+1
 0073                XSEC(K)=X2
 0074             32 CONTINUE
               C  K IS THE NUMBER OF ELEMENTS IN XSEC
```

```
      SLICE=SLICE+WEIGHT(M)*WIDTH*(YS-YC)
      YC=YS
   83 IF(M-1) 85,85,84
   84 M=M-1
      GO TO 79
   85 ALPHA=ATAN((HORZON-XS)/(VERTCL-YCI))
      PARTA=PARTA+(SLICE+SEEP*SIN(BET(L)))*SIN(ALPHA)+SEEP*COS(BET(L))*(
     1VERTCL-YCI-(YW-YCI)/2.)/RADIUS
      PARTB=PARTB+(COHES(NSOIL(1))*WIDTH+(SLICE+SEEP*SIN(BET(L)))*TAN(PH
     1I(NSOIL(1))))/(FSOLD*COS(ALPHA)+TAN(PHI(NSOIL(1)))*SIN(ALPHA))
   86 PARTC=PARTC+(COHES(NSOIL(1))*WIDTH+(SLICE+SEEP*SIN(BET(L)))*TAN(PH
     1I(NSOIL(1))))*TAN(PHI(NSOIL(1)))*SIN(ALPHA)/((FSOLD*COS(ALPHA)+TAN
     2(PHI(NSOIL(1)))*SIN(ALPHA))**2)
   87 CONTINUE
      FSBIS=FSOLD*(1.-(PARTA-PARTB)/(PARTA-PARTC))
C  IF FSBIS IS NOT NEARLY EQUAL TO FSOLD, REPLACE FSOLD WITH FSBIS AND
C  COMPUTE A NEW FSBIS
      IF(ABS(FSBIS-FSOLD)-.001) 89,89,88
   88 FSOLD=FSBIS
      GO TO 65
C  SEARCH USING FSNYS OR FSBIS DEPENDING ON OPTION ITER
   89 IF(ITER) 90,90,91
   90 IRAD=IRAD+1
      RFS(IRAD)=FSNYS
      GO TO 92
   91 IRAD=IRAD+1
      RFS(IRAD)=FSBIS
C  PRINT OR DO NOT PRINT FACTORS OF SAFETY DEPENDING ON OPTION IALLFS
   92 IF(IALLFS) 95,95,93
C  CONVERT MOMENT COMPONENTS OF FSNYS TO FT-KIPS
   93 SEPMOM=SEPMOM*.001
      DRVMOM=DRVMOM*.001
      CHSMOM=CHSMOM*.001
      PHIMOM=PHIMOM*.001
      PRINT 94, SEPMOM,DRVMOM,PHIMOM,CHSMOM,HORZON,VERTCL,RADIUS,FSNYS,F
     1SBIS
   94 FORMAT (4F9.0,3F7.1,2F7.3)
C  IF ONLY ONE FS HAS BEEN COMPUTED AT THIS LOCATION, INCREASE RADIUS BY
C  RADINC AND COMPUTE NEW FS
   95 IF(IRAD-1) 97,97,96
C  IF FS IS LESS THAN PREVIOUS FS, INCREASE RADIUS BY RADINC AND COMPUTE
C  NEW FS. IF GREATER, CHANGE CIRCLE CENTER LOCATION
   96 IF(RFS(IRAD)-RFS(IRAD-1)) 97,97,98
   97 RADIUS=RADIUS+RADINC
      GO TO 21
   98 IHOR=IHOR+1
      XRAD(IHOR)=RADIUS-RADINC
C  HFS IS THE MINIMUM FS COMPUTED AT A CIRCLE CENTER LOCATION
```

```
              C  DELETE DUPLICATE ELEMENTS FROM XSEC
 0075          215 K1=K-1
 0076                DO 35 I=1,K1
 0077                II=I+1
 0078                DO 35 J=II,K
 0079                IF(XSEC(I)-XSEC(J)) 35,33,35
 0080            33 DO 34 L=J,K1
 0081            34 XSEC(L)=XSEC(L+1)
 0082                K=K-1
 0083                K1=K1-1
 0084                J=J-1
 0085            35 CONTINUE
              C  ARRANGE ELEMENTS OF XSEC IN ORDER OF MAGNITUDE AND STORE IN ASEC
              C  K IS NOW THE NUMBER OF ELEMENTS IN ASEC
 0086                DO 40 I=1,K
 0087            36 DO 39 J=I,K
 0088                IF(I-J) 37,39,37
 0089            37 IF(XSEC(I)-XSEC(J)) 39,38,38
 0090            38 B=XSEC(J)
 0091                XSEC(J)=XSEC(I)
 0092                XSEC(I)=B
 0093            39 CONTINUE
 0094            40 ASEC(I)=XSEC(I)
 0095                IF (K-1)163,163,164
 0096           163 NUMRAD=NUMRAD-1
 0097                GO TO 97
              C  INITIALIZE COMPONENTS OF NEW YORK STATE FACTOR OF SAFETY
 0098           164 SEPMOM=0.
 0099                CHSMOM=0.
 0100                PHIMOM=0.
 0101                DRVMOM=0.
 0102                L=1
              C  LOOP FOR NUMBER OF SEGMENTS K1
 0103                DO 62 I=1,K1
              C  DETERMINE WIDTH OF ALL SLICES IN SEGMENT I
 0104                IF((ASEC(I+1)-ASEC(I))-2.) 41,41,42
 0105            41 NSLIC=1
 0106                GO TO 47
 0107            42 IF((ASEC(I+1)-ASEC(I))-(.1*RADIUS)) 43,43,44
 0108            43 NSLIC=5
 0109                GO TO 47
 0110            44 IF((ASEC(I+1)-ASEC(I))-(.5*RADIUS)) 45,45,46
 0111            45 NSLIC=10
 0112                GO TO 47
 0113            46 NSLIC=20
 0114            47 ASLIC=NSLIC
              C  NSLIC IS THE NUMBER OF SLICES IN SEGMENT I
 0115                WIDTH=(ASEC(I+1)-ASEC(I))/ASLIC
```

```
0116              XS=ASEC(I)-WIDTH/2.
            C  LOOP FOR SLICES IN SEGMENT
0117              DO 61 J=1,NSLIC
            C  XS IS THE X-COORDINATE OF THE CENTERLINE OF THE SLICE
0118              XS=XS+WIDTH
            C  YC IS THE Y-COORDINATE OF THE CIRCLE AT XS
0119              YC=VERTCL-SQRT((RADIUS*RADIUS)-((XS-HORZON)*(XS-HORZON)))
0120              YCI=YC
0121           48 IF(XS-WATRHR(L)) 50,50,49
0122           49 L=L+1
0123              GO TO 48
            C  YW IS THE Y-COORDINATE OF THE WATER TABLE AT XS
0124           50 YW=WATRVL(L)-(XS-WATRHL(L))*TAN(BET(L))
0125              IF(YW-YC) 51,51,52
            C  SEEP IS THE SEEPAGE FORCE
0126           51 SEEP=0
0127              GO TO 53
0128           52 SEEP=WIDTH*(YW-YC)*62.4*SIN(BET(L))
0129           53 SEPMOM=SEPMOM+SEEP*(SIN(BET(L))*(HORZON-XS)+COS(BET(L))*(VERTCL-YC
             1-(YW-YC)/2.))
            C  COMPUTE SLICE WHICH IS THE WEIGHT OF SLICE
0130              SLICE=0.
0131              N=0
0132              M=NSL
0133           54 YS=SOILVL(M)-((XS-SOILHL(M))*(SOILVL(M)-SOILVR(M))/(SOILHR(M)-SOIL
             1HL(M)))
0134              IF(YS-YC) 58,58,55
0135           55 IF(XS-SOILHL(M)) 58,58,56
0136           56 IF(SOILHR(M)-XS) 58,58,57
0137           57 N=N+1
0138              NSOIL(N)=M
0139              SLICE=SLICE+WEIGHT(M)*WIDTH*(YS-YC)
            C  YS IS THE Y-COORDINATE OF SOIL LINE M AT SLICE CENTERLINE
0140              YC=YS
0141           58 IF(M-1) 60,60,59
0142           59 M=M-1
0143              GO TO 54
0144           60 DRVMOM=DRVMOM+SLICE*(HORZON-XS)
            C  NSOIL(1) IS THE NUMBER OF THE SOIL LINE WHICH DESCRIBES THE SOIL
            C  PROPERTIES AT THE BOTTOM OF THE SLICE
0145              PHIMOM=PHIMOM+SLICE*TAN(PHI(NSOIL(1)))*(VERTCL-YCI)
0146           61 CHSMOM=CHSMOM+COHES(NSOIL(1))*WIDTH*(RADIUS/(VERTCL-YCI))*RADIUS
0147           62 CONTINUE
            C  FSOLD IS THE OLD FACTOR OF SAFETY FOR BISHOP ITERATION
0148              FSNYS=(PHIMOM+CHSMOM)/(DRVMOM+SEPMOM)
0149              FSOLD=FSNYS+.2
            C  IF FSNYS IS LESS THAN 0.60,TERMINATE PROGRAM
0150              IF(FSNYS-.6) 63,65,65
```

```
      63 PRINT 64
      64 FORMAT(/,5X,33HA NEW YORK STATE FACTOR OF SAFETY,/,12X,18HOF LESS
        1THAN 0.600,/,11X,20HHAS BEEN ENCOUNTERED)
         GO TO 125
C     INITIALIZE COMPONENTS OF BISHOP SAFETY FACTOR
      65 PARTA=0.
         PARTB=0.
         PARTC=0.
         L=1
C     LOOP FOR NUMBER OF SEGMENTS K1
         DO 87 I=1,K1
C     DETERMINE WIDTH OF ALL SLICES IN SEGMENT I
         IF((ASEC(I+1)-ASEC(I))-2.) 66,66,67
      66 NSLIC=1
         GO TO 72
      67 IF((ASEC(I+1)-ASEC(I))-(.1*RADIUS)) 68,68,69
      68 NSLIC=5
         GO TO 72
      69 IF((ASEC(I+1)-ASEC(I))-(.5*RADIUS)) 70,70,71
      70 NSLIC=10
         GO TO 72
      71 NSLIC=20
      72 ASLIC=NSLIC
         WIDTH=(ASEC(I+1)-ASEC(I))/ASLIC
         XS=ASEC(I)-WIDTH/2.
C     LOOP FOR SLICES IN SEGMENT
         DO 86 J=1,NSLIC
         XS=XS+WIDTH
         YC=VERTCL-SQRT((RADIUS*RADIUS)-((XS-HORZON)*(XS-HORZON)))
         YCI=YC
      73 IF(XS-WATRHR(L)) 75,75,74
      74 L=L+1
         GO TO 73
      75 YW=WATRVL(L)-(XS-WATRHL(L))*TAN(BET(L))
         IF(YW-YC) 76,76,77
      76 SEEP=0.
         GO TO 78
      77 SEEP=WIDTH*(YW-YC)*62.4*SIN(BET(L))
      78 SLICE=0.
         N=0
         M=NSL
      79 YS=SOILVL(M)-((XS-SOILHL(M))*(SOILVL(M)-SOILVR(M))/(SOILHR(M)-SOIL
        1HL(M)))
         IF(YS-YC) 83,83,80
      80 IF(XS-SOILHL(M)) 83,83,81
      81 IF(SOILHR(M)-XS) 83,83,82
      82 N=N+1
         NSOIL(N)=M
```

```
0226              HFS(IHOR)=RFS(IRAD-1)
            C  IF ONLY ONE LOCATION HAS BEEN USED, INCREASE HORZON BY GRID AND
            C  COMPUTE NEW HFS
0227              IF(IHOR-1) 99,99,100
0228           99 RADIUS=RADIUS-RADINC*2.
0229              HORZON=HORZON+GRID
0230              GO TO 20
            C  IF HFS AT NEW LOCATION IS LESS THAN HFS AT PREVIOUS LOCATION,
            C  CONTINUE IN SAME HORIZONTAL DIRECTION. IF GREATER, AND MORE THAN
            C  TWO LOCATIONS HAVE BEEN TRIED ON SAME HORIZONTAL LINE, INCREASE
            C  VERTCL BY GRID AND COMPUTE MINIMUM HFS ON NEW HORIZONTAL LINE. IF
            C  GREATER AND ONLY TWO LOCATIONS HAVE BEEN TRIED, PROCEED TOWARD LEFT
            C  ON SAME HORIZONTAL LINES
0231          100 IF(HFS(IHOR)-HFS(IHOR-1)) 101,101,102
            C  IF INDEX IS ZERO, SEARCH IS PROCEEDING TO RIGHT, IF POSITIVE, SEARCH
            C  IS PROCEEDING TO LEFT ON HORIZONTAL LINE PRESENTLY BEING SEARCHED
0232          101 IF(INDEX) 99,99,104
0233          102 IF(IHOR-2) 103,103,106
0234          103 INDEX=1
0235              HORZON=HORZON-GRID*2.
0236              RADIUS=RADIUS-RADINC*2.
0237              GO TO 20
0238          104 IF(HFS(IHOR)-HFS(1)) 105,105,109
0239          105 INDEX=INDEX+1
0240              HORZON=HORZON-GRID
0241              RADIUS=RADIUS-RADINC*2.
0242              GO TO 20
0243          106 IF(INDEX) 107,107,109
0244          107 IVER=IVER+1
0245              CRAD(IVER)=XRAD(IHOR-1)
0246              CHOR(IVER)=HORZON-GRID
0247              CVER(IVER)=VERTCL
            C  VFS IS THE MINIMUM HFS ON HORIZONTAL LINE
0248              VFS(IVER)=HFS(IHOR-1)
0249              RADIUS=RADIUS-RADINC*2.+GRID
0250              HORZON=HORZON-GRID
0251              VERTCL=VERTCL+GRID
0252          108 IF(IVER-1) 19,19,112
0253          109 IVER=IVER+1
0254              CHOR(IVER)=HORZON+GRID
0255              CVER(IVER)=VERTCL
0256              RADIUS=RADIUS-RADINC*2.+GRID
0257              HORZON=HORZON+GRID
0258              VERTCL=VERTCL+GRID
0259              IF(INDEX-1) 110,110,111
0260          110 VFS(IVER)=HFS(1)
0261              CRAD(IVER)=XRAD(1)
0262              GO TO 108
```

```
FORTRAN IV G LEVEL  20                  MAIN                DATE = 72033          18/01/03              PAGE

 0263          111 VFS(IVER)=HFS(IHOR-1)
 0264              CRAD(IVER)=XRAD(IHOR-1)
 0265              IF(IVER-1) 19,19,112
 0266          112 IF(VFS(IVER)-VFS(IVER-1)) 19,19,113
             C  PRINT OUT WHICH FS HAS BEEN USED IN SEARCH, MINIMUM SAFETY FACTOR,
             C  AND LOCATION AND RADIUS OF CRITICAL CIRCLE
 0267          113 IF(ITER) 114,114,116
 0268          114 PRINT 115, VFS(IVER-1)
 0269          115 FORMAT(//,5X,36HSEARCH HAS USED NYS FACTOR OF SAFETY,/,5X,31HTHE M
                  1INIMUM FACTOR OF SAFETY IS, F6.3)
 0270              GO TO 118
 0271          116 PRINT 117, VFS(IVER-1)
 0272          117 FORMAT(//,5X,39HSEARCH HAS USED BISHOP FACTOR OF SAFETY,/,5X,31HTH
                  1E MINIMUM FACTOR OF SAFETY IS,F6.3)
 0273          118 PRINT 121, CHOR(IVER-1),CVER(IVER-1),CRAD(IVER-1)
 0274          121 FORMAT(5X,42HTHE CRITICAL CIRCLE CENTER COORDINATES ARE,/,10X,10HH
                  1ORZON IS ,F6.1,10X,10HVERTCL IS ,F6.1,/,20X,10HRADIUS IS ,F6.1)
             C  PRINT OUT NUMBER OF SAFETY FACTORS COMPUTED AND NUMBER OF LOCATIONS
 0275          122 PRINT 123, NUMRAD,NUMLOC
 0276          123 FORMAT(/,5X,I5,3X,39HFACTORS OF SAFETY HAVE BEEN COMPUTED AT,I5,3X
                  1,9HLOCATIONS)
 0277          124 CONTINUE
 0278              GO TO 184
 0279          125 STOP
 0280              END

  *OPTIONS IN EFFECT*  NOID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP
  *OPTIONS IN EFFECT*  NAME = MAIN    , LINECNT =       50
  *STATISTICS*    SOURCE STATEMENTS =       280,PROGRAM SIZE =     12396
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

APPENDIX E

New York State Example Output

```
                 NEW YORK STATE     DEPARTMENT OF TRANSPORTATION

                            SLOPE STABILITY ANALYSIS

               PROGRAM NO. S517300/SOILSL      DEVELOPED FEBRUARY,1970


                                    INPUT DATA

             SOIL LINES
 LINE   SOILHL    SOILVL    SOILHR    SOILVR    WEIGHT   PHI    COHES
          FT        FT        FT        FT       PCF     DEG     PSF

    1   -15.00     0.0       0.0       0.0     120.00   36.0     0.0
    2     0.0      0.0       2.50     -1.00    120.00   36.0     0.0
    3   -15.00    -1.00      2.50     -1.00    112.00    3.0   700.00
    4     2.50    -1.00     10.00     -4.00    112.00    3.0   700.00
    5   -15.00    -4.00     10.00     -4.00    106.00    0.0   200.00
    6    10.00    -4.00     17.50     -7.00    106.00    0.0   200.00
    7   -15.00    -7.00     17.50     -7.00    108.00    3.0   200.00
    8    17.50    -7.00     25.00    -10.00    108.00    3.0   200.00
    9   -15.00   -10.00     25.00    -10.00    110.00    0.0   300.00
   10    25.00   -10.00     37.50    -15.00    110.00    0.0   300.00
   11   -15.00   -15.00     37.50    -15.00    112.00    5.0   300.00
   12    37.50   -15.00     50.00    -20.00    112.00    5.0   300.00
   13   -15.00   -20.00     50.00    -20.00    115.00   10.0   800.00
   14    50.00   -20.00     70.00    -20.00    115.00   10.0   800.00
   15   -15.00   -21.00     70.00    -21.00     52.50   10.0   800.00
   16   -15.00   -35.00     70.00    -35.00     90.00   40.0  5000.00


            WATER TABLE LINES
 LINE   WATRHL    WATRVL    WATRHR    WATRVR
          FT        FT        FT        FT

    1   -15.00    -21.00     70.00    -21.00


            RADIUS INCREMENT IS  2.0     GRID INCREMENT IS  2.0


 SEPMOM   DRVMOM   PHIMOM   CHSMOM   HORZON VERTCL RADIUS
 FT-KIP   FT-KIP   FT-KIP   FT-KIP     FT     FT     FT    FSNYS   FSBIS

      0.      150.      41.     258.    25.0    0.0   20.0   1.994   2.015
      0.      214.     105.     542.    25.0    0.0   22.0   3.026   3.080
      0.       90.      21.     180.    27.0    0.0   18.0   2.236   2.261
      0.      139.      37.     246.    27.0    0.0   20.0   2.031   2.059
      0.      202.      97.     528.    27.0    0.0   22.0   3.087   3.141
      0.      107.      26.     210.    23.0    0.0   18.0   2.206   2.215
      0.      159.      44.     275.    23.0    0.0   20.0   2.009   2.029
      0.      224.     112.     550.    23.0    0.0   22.0   2.950   3.008
      0.      123.      28.     236.    25.0    2.0   20.0   2.140   2.151
      0.      185.      48.     302.    25.0    2.0   22.0   1.890   1.906
      0.      259.     121.     620.    25.0    2.0   24.0   2.856   2.906
      0.      112.      25.     218.    27.0    2.0   20.0   2.172   2.188
      0.      171.      43.     292.    27.0    2.0   22.0   1.959   1.980
      0.      245.     112.     609.    27.0    2.0   24.0   2.947   2.995
      0.      134.      31.     252.    23.0    2.0   20.0   2.114   2.121
      0.      196.      52.     319.    23.0    2.0   22.0   1.891   1.912
      0.      273.     130.     626.    23.0    2.0   24.0   2.768   2.824
      0.      150.      33.     280.    25.0    4.0   22.0   2.076   2.083
```

0.	223.	55.	342.	25.0	4.0	24.0	1.779	1.793
0.	308.	137.	695.	25.0	4.0	26.0	2.703	2.750
0.	136.	29.	260.	27.0	4.0	22.0	2.117	2.128
0.	205.	50.	340.	27.0	4.0	24.0	1.901	1.917
0.	290.	127.	688.	27.0	4.0	26.0	2.808	2.851
0.	164.	36.	293.	23.0	4.0	22.0	2.005	2.013
0.	237.	60.	361.	23.0	4.0	24.0	1.779	1.800
0.	322.	148.	701.	23.0	4.0	26.0	2.635	2.687
0.	180.	38.	324.	25.0	6.0	24.0	2.007	2.013
0.	264.	63.	379.	25.0	6.0	26.0	1.669	1.684
0.	358.	155.	772.	25.0	6.0	28.0	2.585	2.630
0.	163.	33.	304.	27.0	6.0	24.0	2.069	2.075
0.	242.	57.	389.	27.0	6.0	26.0	1.839	1.852
0.	340.	143.	764.	27.0	6.0	28.0	2.672	2.714
0.	197.	42.	330.	23.0	6.0	24.0	1.886	1.898
0.	278.	69.	402.	23.0	6.0	26.0	1.693	1.714
0.	372.	166.	779.	23.0	6.0	28.0	2.543	2.590
0.	213.	43.	361.	25.0	8.0	26.0	1.898	1.907
0.	308.	71.	417.	25.0	8.0	28.0	1.584	1.598
0.	409.	173.	851.	25.0	8.0	30.0	2.506	2.547
0.	193.	38.	352.	27.0	8.0	26.0	2.026	2.030
0.	283.	65.	430.	27.0	8.0	28.0	1.747	1.761
0.	391.	161.	843.	27.0	8.0	30.0	2.569	2.608
0.	232.	48.	368.	23.0	8.0	26.0	1.796	1.808
0.	320.	78.	445.	23.0	8.0	28.0	1.633	1.653
0.	421.	186.	859.	23.0	8.0	30.0	2.479	2.523
0.	248.	49.	400.	25.0	10.0	28.0	1.813	1.822
0.	351.	79.	456.	25.0	10.0	30.0	1.524	1.537
0.	459.	192.	932.	25.0	10.0	32.0	2.450	2.489
0.	224.	43.	391.	27.0	10.0	28.0	1.938	1.943
0.	326.	73.	473.	27.0	10.0	30.0	1.674	1.688
0.	442.	178.	924.	27.0	10.0	32.0	2.495	2.531
0.	266.	54.	408.	23.0	10.0	28.0	1.736	1.748
0.	362.	87.	489.	23.0	10.0	30.0	1.591	1.610
0.	471.	206.	941.	23.0	10.0	32.0	2.435	2.476
0.	283.	55.	439.	25.0	12.0	30.0	1.749	1.758
0.	395.	88.	496.	25.0	12.0	32.0	1.479	1.491
0.	510.	212.	1016.	25.0	12.0	34.0	2.409	2.445
0.	259.	49.	430.	27.0	12.0	30.0	1.849	1.857
0.	369.	81.	516.	27.0	12.0	32.0	1.620	1.634
0.	493.	197.	1007.	27.0	12.0	34.0	2.441	2.475
0.	300.	61.	449.	23.0	12.0	30.0	1.695	1.706
0.	404.	97.	535.	23.0	12.0	32.0	1.563	1.581
0.	521.	227.	1026.	23.0	12.0	34.0	2.405	2.443
0.	317.	61.	480.	25.0	14.0	32.0	1.705	1.714
0.	438.	97.	537.	25.0	14.0	34.0	1.448	1.458
0.	561.	232.	1102.	25.0	14.0	36.0	2.380	2.414
0.	294.	54.	471.	27.0	14.0	32.0	1.784	1.791
0.	412.	90.	561.	27.0	14.0	34.0	1.581	1.594
0.	544.	216.	1092.	27.0	14.0	36.0	2.404	2.436
0.	335.	67.	490.	23.0	14.0	32.0	1.664	1.674
0.	446.	106.	581.	23.0	14.0	34.0	1.543	1.560
0.	571.	249.	1112.	23.0	14.0	36.0	2.383	2.419
0.	352.	67.	523.	25.0	16.0	34.0	1.674	1.682
0.	481.	106.	579.	25.0	16.0	36.0	1.424	1.434
0.	611.	253.	1191.	25.0	16.0	38.0	2.363	2.395
0.	329.	60.	512.	27.0	16.0	34.0	1.735	1.742
0.	454.	99.	607.	27.0	16.0	36.0	1.554	1.566
0.	595.	235.	1180.	27.0	16.0	38.0	2.377	2.407
0.	370.	74.	533.	23.0	16.0	34.0	1.643	1.653
0.	488.	117.	629.	23.0	16.0	36.0	1.528	1.544
0.	622.	272.	1201.	23.0	16.0	38.0	2.370	2.405
0.	387.	74.	566.	25.0	18.0	36.0	1.653	1.661
0.	525.	116.	622.	25.0	18.0	38.0	1.406	1.415
0.	662.	275.	1281.	25.0	18.0	40.0	2.349	2.380
0.	364.	66.	554.	27.0	18.0	36.0	1.702	1.708

0.	498.	108.	655.	27.0	18.0	38.0	1.532	1.544
0.	647.	256.	1269.	27.0	18.0	40.0	2.357	2.386
0.	404.	81.	577.	23.0	18.0	36.0	1.630	1.639
0.	530.	128.	678.	23.0	18.0	38.0	1.518	1.533
0.	672.	295.	1293.	23.0	18.0	40.0	2.362	2.395
0.	422.	81.	610.	25.0	20.0	38.0	1.636	1.643
0.	568.	126.	667.	25.0	20.0	40.0	1.394	1.402
0.	714.	298.	1373.	25.0	20.0	42.0	2.342	2.371
0.	400.	72.	597.	27.0	20.0	38.0	1.676	1.682
0.	540.	118.	703.	27.0	20.0	40.0	1.518	1.529
0.	698.	277.	1361.	27.0	20.0	42.0	2.344	2.371
0.	439.	89.	622.	23.0	20.0	38.0	1.620	1.628
0.	573.	139.	728.	23.0	20.0	40.0	1.513	1.527
0.	723.	319.	1386.	23.0	20.0	42.0	2.358	2.390
0.	457.	88.	655.	25.0	22.0	40.0	1.624	1.631
0.	612.	136.	712.	25.0	22.0	42.0	1.385	1.392
0.	765.	321.	1468.	25.0	22.0	44.0	2.339	2.367
0.	435.	79.	641.	27.0	22.0	40.0	1.656	1.662
0.	583.	127.	752.	27.0	22.0	42.0	1.507	1.517
0.	750.	298.	1454.	27.0	22.0	44.0	2.337	2.363
0.	474.	96.	668.	23.0	22.0	40.0	1.614	1.622
0.	615.	150.	779.	23.0	22.0	42.0	1.510	1.523
0.	773.	343.	1481.	23.0	22.0	44.0	2.359	2.389
0.	492.	95.	701.	25.0	24.0	42.0	1.617	1.623
0.	656.	147.	757.	25.0	24.0	44.0	1.378	1.385
0.	816.	344.	1564.	25.0	24.0	46.0	2.339	2.365
0.	470.	85.	687.	27.0	24.0	42.0	1.642	1.647
0.	627.	137.	802.	27.0	24.0	44.0	1.500	1.509
0.	802.	320.	1550.	27.0	24.0	46.0	2.333	2.358
0.	509.	104.	715.	23.0	24.0	42.0	1.610	1.618
0.	658.	162.	831.	23.0	24.0	44.0	1.509	1.521
0.	819.	368.	1542.	23.0	24.0	46.0	2.333	2.361
0.	527.	102.	748.	25.0	26.0	44.0	1.612	1.618
0.	700.	157.	804.	25.0	26.0	46.0	1.374	1.380
0.	867.	368.	1662.	25.0	26.0	48.0	2.342	2.368
0.	505.	92.	733.	27.0	26.0	44.0	1.632	1.637
0.	670.	148.	854.	27.0	26.0	46.0	1.495	1.503
0.	853.	343.	1647.	27.0	26.0	48.0	2.332	2.355
0.	544.	112.	763.	23.0	26.0	44.0	1.609	1.616
0.	700.	174.	883.	23.0	26.0	46.0	1.509	1.521
0.	857.	393.	1580.	23.0	26.0	48.0	2.302	2.331
0.	563.	110.	796.	25.0	28.0	46.0	1.609	1.615
0.	744.	168.	852.	25.0	28.0	48.0	1.372	1.378
0.	912.	392.	1719.	25.0	28.0	50.0	2.315	2.339
0.	541.	99.	779.	27.0	28.0	46.0	1.625	1.629
0.	713.	159.	906.	27.0	28.0	48.0	1.492	1.500
0.	905.	366.	1746.	27.0	28.0	50.0	2.333	2.356
0.	579.	120.	811.	23.0	28.0	46.0	1.610	1.617
0.	740.	185.	923.	23.0	28.0	48.0	1.498	1.509
0.	890.	418.	1639.	23.0	28.0	50.0	2.311	2.339
0.	598.	117.	844.	25.0	30.0	48.0	1.609	1.614
0.	787.	180.	900.	25.0	30.0	50.0	1.372	1.377
0.	951.	417.	1761.	25.0	30.0	52.0	2.290	2.315
0.	576.	106.	827.	27.0	30.0	48.0	1.620	1.624
0.	757.	169.	959.	27.0	30.0	50.0	1.491	1.499
0.	956.	389.	1847.	27.0	30.0	52.0	2.338	2.360
0.	614.	129.	861.	23.0	30.0	48.0	1.613	1.619
0.	774.	197.	924.	23.0	30.0	50.0	1.448	1.461
0.	920.	445.	1720.	23.0	30.0	52.0	2.354	2.382
0.	633.	125.	894.	25.0	32.0	50.0	1.610	1.615
0.	828.	190.	939.	25.0	32.0	52.0	1.363	1.368
0.	985.	442.	1816.	25.0	32.0	54.0	2.291	2.316
0.	612.	114.	876.	27.0	32.0	50.0	1.618	1.622
0.	800.	181.	1012.	27.0	32.0	52.0	1.492	1.499
0.	1002.	413.	1905.	27.0	32.0	54.0	2.313	2.334
0.	648.	137.	911.	23.0	32.0	50.0	1.617	1.623

```
 0.      804.      209.       927.    23.0     32.0     52.0   1.412    1.426
 0.      946.      472.      1802.    23.0     32.0     54.0   2.405    2.433
 0.      668.      133.       944.    25.0     34.0     52.0   1.612    1.617
 0.      864.      202.       935.    25.0     34.0     54.0   1.315    1.322
 0.     1016.      468.      1899.    25.0     34.0     56.0   2.330    2.354
 0.      647.      121.       925.    27.0     34.0     52.0   1.617    1.621
 0.      843.      192.      1067.    27.0     34.0     54.0   1.493    1.501
 0.     1042.      437.      1950.    27.0     34.0     56.0   2.291    2.312
 0.      679.      145.       938.    23.0     34.0     52.0   1.594    1.600
 0.      831.      222.       944.    23.0     34.0     54.0   1.404    1.417
 0.      969.      499.      1886.    23.0     34.0     56.0   2.462    2.490
 0.      703.      142.       995.    25.0     36.0     54.0   1.616    1.620
 0.      897.      213.       933.    25.0     36.0     56.0   1.279    1.286
 0.     1044.      495.      1984.    25.0     36.0     58.0   2.375    2.399
 0.      682.      129.       975.    27.0     36.0     54.0   1.618    1.621
 0.      884.      203.      1121.    27.0     36.0     56.0   1.496    1.503
 0.     1078.      461.      1998.    27.0     36.0     58.0   2.282    2.303
 0.      707.      153.       943.    23.0     36.0     54.0   1.551    1.557
 0.      855.      235.       981.    23.0     36.0     56.0   1.422    1.436
 0.      990.      526.      1972.    23.0     36.0     58.0   2.523    2.549
 0.      736.      148.      1037.    25.0     38.0     56.0   1.611    1.615
 0.      926.      225.       932.    25.0     38.0     58.0   1.250    1.258
 0.     1069.      522.      2070.    25.0     38.0     60.0   2.425    2.449
 0.      718.      136.      1026.    27.0     38.0     56.0   1.620    1.623
 0.      921.      214.      1124.    27.0     38.0     58.0   1.453    1.460
 0.     1110.      487.      2083.    27.0     38.0     60.0   2.315    2.337
 0.      731.      162.       948.    23.0     38.0     56.0   1.518    1.525
 0.      877.      249.      1018.    23.0     38.0     58.0   1.445    1.458
 0.     1009.      553.      2059.    23.0     38.0     60.0   2.587    2.613
 0.      764.      157.      1042.    25.0     40.0     58.0   1.568    1.572
 0.      952.      238.       963.    25.0     40.0     60.0   1.261    1.269
 0.     1092.      548.      2158.    25.0     40.0     62.0   2.479    2.502
 0.      753.      144.      1078.    27.0     40.0     58.0   1.623    1.626
 0.      954.      226.      1128.    27.0     40.0     60.0   1.419    1.428
 0.     1139.      513.      2170.    27.0     40.0     62.0   2.354    2.376
 0.      753.      170.       953.    23.0     40.0     58.0   1.491    1.500
 0.      897.      263.      1056.    23.0     40.0     60.0   1.470    1.484
 0.     1027.      580.      2147.    23.0     40.0     62.0   2.655    2.680


SEARCH HAS USED BISHOP FACTOR OF SAFETY
THE MINIMUM FACTOR OF SAFETY IS 1.258
THE CRITICAL CIRCLE CENTER COORDINATES ARE
     HORZON IS    25.0          VERTCL IS    38.0
               RADIUS IS    58.0

  188    FACTORS OF SAFETY HAVE BEEN COMPUTED AT    63    LOCATIONS
```

APPENDIX F

LEASE I Example Output

```
*************************************************************************
*                                                                       *
*             INTEGRATED CIVIL ENGINEERING SYSTEM,  V1 M2               *
*                             - ICES -                                  *
*              FEB 02, 1972               TIME=22.51.04                 *
*                                                                       *
*************************************************************************
```

```
LEASE
        POINT DATA
        1   5     31
        2   20    31
        3   5     30
        4   22.5  30
        5   5     27
        6   30    27
        7   5     24
        8   37.5  24
        9   5     21
        10  45    21
        11  5     16
        12  57.5  16
        13  5     11
        14  70    11
        15  90    11
        16  5     10
        17  90    10
        LINE DATA
        1   1     2     1
        2   2     4     1
        3   3     4     2
        4   4     6     2
        5   5     6     3
        6   6     8     3
        7   7     8     4
        8   8     10    4
        9   9     10    5
        10  10    12    5
        11  11    12    6
```

```
        12   12    14    6

        13   13    14    7

        14   14    15    7

        15   16    17    8

        SOIL  DATA

        1    120   0     36

        2    112   700   3

        3    106   200   0

        4    108   200   3

        5    110   300   0

        6    112   300   5

        7    115   800   10

        8    52.5  800   10

        GRID   1   65 57   2   60 37   3   30 32   5     5

   ORDERED LINE ARRAY                                       BNDS ARRAY

   NO     PT     PT   SOIL              X-LEFT     Y-LEFT    X-RIGHT    Y-RIGHT        SLOPE
    1      1      2     1                 5.00      31.00      20.00      31.00         0.0
    2      2      4     1                20.00      31.00      22.50      30.00        -0.400
    4      4      6     2                22.50      30.00      30.00      27.00        -0.400
    6      6      8     3                30.00      27.00      37.50      24.00        -0.400
    8      8     10     4                37.50      24.00      45.00      21.00        -0.400
   10     10     12     5                45.00      21.00      57.50      16.00        -0.400
   12     12     14     6                57.50      16.00      70.00      11.00        -0.400
   14     14     15     7                70.00      11.00      90.00      11.00         0.0
    9      9     10     5                 5.00      21.00      45.00      21.00         0.0
    3      3      4     2                 5.00      30.00      22.50      30.00         0.0
   11     11     12     6                 5.00      16.00      57.50      16.00         0.0
    7      7      8     4                 5.00      24.00      37.50      24.00         0.0
   13     13     14     7                 5.00      11.00      70.00      11.00         0.0
    5      5      6     3                 5.00      27.00      30.00      27.00         0.0
   15     16     17     8                 5.00      10.00      90.00      10.00         0.0

           NUMBER OF TOPLINES IS    8


FSBSHP FSNRML RADIUS NO.SLCS. X=    60.00   Y=    37.00
 3.214   3.083   39.70    21
 3.192   3.065   38.54    19
 3.246   3.133   37.39    19
 3.242   3.112   39.41    21
 3.191   3.057   39.12    20
 3.222   3.090   38.83    20
 3.207   3.083   38.25    19
 3.220   3.100   37.96    19
 3.233   3.117   37.68    19
 3.373   3.260   36.23    17
 3.353   3.253   35.07    17
 3.458   3.371   33.92    16
 3.329   3.220   35.94    17
 3.345   3.239   35.65    17
```

```
   3.359   3.256    35.36    17
   3.370   3.274    34.78    17
   3.385   3.292    34.50    17
   3.410   3.321    34.21    17
   3.514   3.432    32.76    15
   3.634   3.565    31.60    14
   3.655   3.598    30.45    14
   3.745   3.696    29.29    12
   3.769   3.732    28.14    11
   3.717   3.689    26.98     9
   2.596   2.584    25.82     9
   3.142   3.133    24.67     7
   3.625   3.600    26.69     9
   3.455   3.434    26.40     9
   3.085   3.068    26.11     9
   2.704   2.694    25.53     9
   2.827   2.817    25.24     9
   2.977   2.969    24.96     8
   4.089   4.086    23.51     7
   6.295   6.295    22.35     5
 TOO FEW SLICES AT RAD=   21.20
 THE LOWEST FACTOR OF SAFETY FOUND WAS 2.596 AT R=   25.82

 FSBSHP FSNRML RADIUS NO.SLCS. X=   61.00  Y=   41.00
  3.225  3.119    41.73    21
  3.188  3.091    40.69    19
  3.310  3.219    39.66    19
  3.239  3.135    41.47    21
  3.242  3.141    41.21    21
  3.170  3.070    40.95    20
  3.216  3.120    40.43    19
  3.245  3.151    40.18    19
  3.278  3.185    39.92    19
  3.372  3.288    38.63    19
  3.403  3.326    37.59    17
  3.444  3.377    36.56    16
  3.558  3.495    35.53    15
  3.594  3.543    34.50    14
  3.667  3.624    33.46    14
  3.743  3.708    32.43    12
  3.656  3.630    31.40    11
  3.348  3.332    30.36    10
  2.738  2.730    29.33     9
  3.332  3.329    28.30     8
  3.010  2.996    30.11     9
  2.531  2.521    29.85     9
  2.629  2.621    29.59     9
  2.859  2.852    29.07     9
  3.007  3.001    28.82     8
  3.158  3.154    28.56     8
  4.392  4.391    27.27     7
  6.879  6.880    26.23     5
 16.690 16.690    25.20     4
 THE LOWEST FACTOR OF SAFETY FOUND WAS 2.531 AT R=   29.85

 FSBSHP FSNRML RADIUS NO.SLCS. X=   62.00  Y=   45.00
  3.275  3.190    44.05    21
  3.214  3.136    43.12    20
  3.361  3.289    42.19    19
  3.298  3.215    43.81    21
  3.316  3.240    43.58    21
  3.268  3.196    43.35    21
  3.314  3.238    42.89    19
  3.330  3.255    42.66    19
  3.345  3.272    42.42    19
  3.422  3.355    41.26    19
```

```
  3.410   3.351    40.34    17
  3.482   3.430    39.41    17
  3.446   3.381    41.03    18
  3.373   3.310    40.80    17
  3.392   3.331    40.57    17
  3.424   3.368    40.11    17
  3.452   3.397    39.87    17
  3.496   3.442    39.64    17
  3.608   3.562    38.48    16
  3.638   3.600    37.56    14
  3.689   3.658    36.63    14
  3.692   3.667    35.70    13
  3.496   3.478    34.78    11
  2.491   2.484    33.85    10
  2.911   2.906    32.92     9
  3.408   3.393    34.54    11
  3.250   3.237    34.31    11
  2.906   2.896    34.08    10
  2.582   2.576    33.62    10
  2.681   2.675    33.39    10
  2.790   2.785    33.15     9
  3.565   3.564    32.00     8
  4.739   4.739    31.07     7
  7.376   7.379    30.14     6
 18.481  18.481    29.21     4
THE LOWEST FACTOR OF SAFETY FOUND WAS 2.491 AT R=   33.85

FSBSHP FSNRML RADIUS NO.SLCS. X=    63.00   Y=    49.00
  3.321   3.254    46.62    21
  3.325   3.270    45.78    21
  3.437   3.379    44.94    19
  3.495   3.443    44.11    19
  3.476   3.430    43.27    17
  3.556   3.515    42.44    16
  3.513   3.462    43.90    18
  3.554   3.505    43.69    18
  3.503   3.455    43.48    17
  3.494   3.449    43.06    17
  3.511   3.468    42.85    17
  3.529   3.487    42.64    17
  3.684   3.648    41.60    16
  3.683   3.654    40.76    14
  3.706   3.683    39.93    14
  3.696   3.662    41.39    16
  3.706   3.673    41.18    16
  3.717   3.685    40.97    15
  3.693   3.665    40.55    14
  3.700   3.674    40.35    14
  3.704   3.679    40.14    14
  3.616   3.598    39.09    13
  3.154   3.143    38.26    11
  2.646   2.642    37.42    10
  3.107   3.105    36.58     9
  2.765   2.757    38.05    11
  2.471   2.466    37.84    10
  2.555   2.550    37.63    10
  2.745   2.742    37.21    10
  2.855   2.852    37.00    10
  2.976   2.973    36.79    10
  3.825   3.826    35.75     8
  5.141   5.143    34.91     6
  8.014   8.017    34.08     6
 20.426  20.426    33.24     4
THE LOWEST FACTOR OF SAFETY FOUND WAS 2.471 AT R=   37.84

FSBSHP FSNRML RADIUS NO.SLCS. X=    64.00   Y=    53.00
```

```
  3.402   3.352    49.40    21
  3.409   3.364    48.64    21
  3.525   3.479    47.88    19
  3.588   3.545    47.12    19
  3.657   3.621    46.37    18
  3.722   3.690    45.61    16
  3.765   3.737    44.85    16
  3.783   3.760    44.09    15
  3.688   3.670    43.33    13
  3.426   3.413    42.58    12
  2.455   2.451    41.82    10
  2.817   2.815    41.06    10
  3.280   3.268    42.39    12
  3.087   3.077    42.20    12
  2.562   2.555    42.01    12
  2.539   2.536    41.63    10
  2.626   2.623    41.44    10
  2.717   2.714    41.25    10
  3.332   3.331    40.30     9
  4.102   4.103    39.55     8
  5.532   5.535    38.79     7
  8.692   8.694    38.03     6
 TOO FEW SLICES AT RAD=    37.27
 THE LOWEST FACTOR OF SAFETY FOUND WAS 2.455 AT R=   41.82

 FSBSHP FSNRML RADIUS NO.SLCS. X=    65.00  Y=    57.00
  3.468   3.427    52.35    21
  3.523   3.488    51.66    21
  3.635   3.595    50.97    19
  3.697   3.664    50.28    19
  3.768   3.739    49.59    18
  3.814   3.789    48.90    16
  3.846   3.824    48.21    16
  3.823   3.806    47.52    15
  3.601   3.588    45.83    13
  2.998   2.990    46.14    12
  2.616   2.613    45.45    11
  3.004   3.003    44.76    10
  2.403   2.399    45.97    12
  2.471   2.467    45.80    12
  2.546   2.542    45.63    11
  2.706   2.703    45.28    11
  2.795   2.793    45.11    10
  2.895   2.894    44.94    10
  3.562   3.562    44.07     9
  4.405   4.407    43.38     8
  5.957   5.960    42.69     7
  9.442   9.444    42.00     5
 TOO FEW SLICES AT RAD=    41.31
 THE LOWEST FACTOR OF SAFETY FOUND WAS 2.403 AT R=   45.97

 FSBSHP FSNRML RADIUS NO.SLCS. X=    54.00  Y=    36.00
  2.821   2.647    43.83    23
  2.795   2.636    42.24    22
  2.813   2.669    40.64    21
  2.822   2.649    43.43    23
  2.823   2.651    43.03    23
  2.782   2.620    42.63    23
  2.810   2.654    41.84    22
  2.798   2.647    41.44    22
  2.850   2.703    41.04    22
  2.822   2.683    39.05    20
  2.826   2.704    37.45    19
  2.846   2.731    35.86    18
  2.988   2.890    34.27    17
  2.952   2.863    32.67    15
```

```
  3.085  3.011   31.08   15
  2.991  2.895   33.87   17
  3.015  2.922   33.47   17
  2.938  2.844   33.07   16
  2.973  2.888   32.28   15
  3.018  2.938   31.88   15
  3.000  2.924   31.48   15
  3.074  3.007   29.49   13
  3.186  3.137   27.89   12
  3.104  3.031   30.68   15
  3.067  2.993   30.28   13
  3.080  3.011   29.89   13
  3.094  3.033   29.09   13
  3.118  3.061   28.69   13
  3.128  3.076   28.29   12
  3.030  2.993   26.30   11
  2.095  2.077   24.71   10
  2.466  2.453   23.11    8
  2.951  2.919   25.90   10
  2.792  2.765   25.50   10
  2.427  2.404   25.10   10
  2.176  2.157   24.31    9
  2.260  2.244   23.91    9
  2.362  2.347   23.51    8
  3.093  3.087   21.52    7
  4.438  4.438   19.93    6
TOO FEW SLICES AT RAD=    18.33
THE LOWEST FACTOR OF SAFETY FOUND WAS 2.095 AT R=    24.71

FSBSHP FSNRML RADIUS NO.SLCS. X=    55.00  Y=    40.00
  2.738  2.597   45.45   23
  2.740  2.614   44.01   22
  2.810  2.693   42.56   22
  2.744  2.635   41.12   20
  2.766  2.670   39.67   20
  2.760  2.639   42.20   21
  2.761  2.643   41.84   20
  2.743  2.630   41.48   20
  2.759  2.653   40.75   20
  2.781  2.678   40.39   20
  2.759  2.660   40.03   20
  2.779  2.692   38.22   18
  2.924  2.848   36.78   17
  2.986  2.922   35.33   17
  3.021  2.967   33.89   15
  2.962  2.915   32.44   13
  2.988  2.954   30.99   12
  3.071  3.019   33.52   15
  3.054  3.003   33.16   14
  3.063  3.015   32.80   14
  3.002  2.959   32.08   13
  2.995  2.955   31.72   12
  2.997  2.960   31.36   12
  2.685  2.661   29.55   11
  2.128  2.116   28.10   10
  2.483  2.475   26.66    8
  2.430  2.411   29.19   10
  1.984  1.970   28.83   10
  2.053  2.040   28.46   10
  2.211  2.201   27.74   10
  2.305  2.295   27.38   10
  2.415  2.405   27.02    8
  3.205  3.203   25.21    8
  4.706  4.705   23.76    6
TOO FEW SLICES AT RAD=    22.32
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.984 AT R=    28.83
```

```
FSBSHP FSNRML RADIUS NO.SLCS. X=    56.00  Y=    44.00
 2.707  2.593   47.38   23
 2.768  2.667   45.06   22
 2.792  2.698   44.75   22
 2.721  2.635   43.43   20
 2.815  2.740   42.12   20
 2.717  2.621   44.42   21
 2.734  2.641   44.09   20
 2.757  2.666   43.76   20
 2.727  2.644   43.10   20
 2.732  2.652   42.77   20
 2.810  2.733   42.44   20
 2.865  2.797   40.80   19
 2.934  2.875   39.48   17
 2.969  2.921   38.17   17
 2.995  2.954   36.85   15
 3.017  2.983   35.53   14
 2.816  2.793   34.22   12
 1.999  1.986   32.90   11
 2.191  2.184   31.58   10
 2.744  2.724   33.89   12
 2.629  2.610   33.56   12
 2.498  2.481   33.23   12
 2.051  2.039   32.57   11
 2.038  2.029   32.24   10
 2.111  2.103   31.91   10
 2.625  2.620   30.27    9
 3.358  3.357   28.95    8
 4.994  4.992   27.63    6
TOO FEW SLICES AT RAD=    26.32
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.999 AT R=    32.90

FSBSHP FSNRML RADIUS NO.SLCS. X=    57.00  Y=    48.00
 2.760  2.669   49.58   23
 2.775  2.690   48.38   22
 2.799  2.721   47.17   22
 2.719  2.651   45.97   20
 2.828  2.767   44.77   20
 2.768  2.697   46.87   22
 2.712  2.638   46.57   20
 2.715  2.644   46.27   20
 2.729  2.663   45.67   20
 2.835  2.771   45.37   20
 2.819  2.757   45.07   20
 2.890  2.837   43.56   19
 2.898  2.852   42.36   17
 2.968  2.931   41.16   16
 2.918  2.897   39.95   16
 2.950  2.926   38.75   14
 2.982  2.948   40.86   16
 2.951  2.928   40.55   16
 2.947  2.926   40.25   16
 2.972  2.943   39.65   14
 2.966  2.939   39.35   14
 2.961  2.935   39.05   14
 2.562  2.547   37.55   12
 2.094  2.085   36.34   11
 2.276  2.271   35.14   10
 2.373  2.360   37.25   12
 1.984  1.974   36.94   12
 2.034  2.025   36.64   12
 2.152  2.144   36.04   11
 2.213  2.206   35.74   11
 2.280  2.274   35.44   11
 2.743  2.740   33.94    9
```

```
  3.547  3.547   32.73     7
  5.361  5.358   31.53     5
 TOO FEW SLICES AT RAD=    30.33
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.984 AT R=   36.94

 FSBSHP FSNRML RADIUS NO.SLCS. X=    58.00  Y=    52.00
  2.780  2.704   52.01    23
  2.800  2.729   50.91    22
  2.790  2.732   49.80    22
  2.824  2.769   48.70    20
  2.806  2.737   50.63    22
  2.811  2.744   50.35    22
  2.816  2.750   50.08    22
  2.786  2.731   49.53    22
  2.797  2.744   49.25    21
  2.731  2.674   48.97    20
  2.863  2.814   47.59    20
  2.893  2.850   46.49    19
  2.905  2.869   45.39    17
  2.973  2.945   44.28    16
  2.886  2.874   43.18    15
  2.847  2.830   42.07    14
  2.001  1.998   40.97    13
  2.207  2.202   39.87    11
  2.789  2.774   41.80    13
  2.688  2.677   41.52    13
  2.513  2.505   41.25    13
  2.033  2.026   40.69    12
  2.087  2.080   40.42    12
  2.147  2.141   40.14    11
  2.496  2.495   38.76    11
  2.878  2.876   37.66     9
  3.746  3.746   36.55     7
  5.751  5.748   35.45     6
 13.957 13.955   34.35     4
 THE LOWEST FACTOR OF SAFETY FOUND WAS 2.001 AT R=   40.97

 FSBSHP FSNRML RADIUS NO.SLCS. X=    59.00  Y=    56.00
  2.814  2.750   54.64    23
  2.833  2.775   53.63    22
  2.820  2.773   52.61    22
  2.871  2.826   51.59    20
  2.849  2.792   53.37    22
  2.862  2.806   53.12    22
  2.828  2.779   52.86    22
  2.811  2.767   52.36    22
  2.805  2.762   52.10    21
  2.852  2.806   51.85    20
  2.890  2.849   50.58    20
  2.922  2.888   49.56    19
  2.896  2.875   48.54    18
  2.944  2.923   47.53    16
  2.929  2.897   49.31    19
  2.920  2.895   49.05    19
  2.909  2.885   48.80    18
  2.946  2.919   48.29    17
  2.933  2.907   48.03    17
  2.942  2.918   47.78    16
  2.831  2.826   46.51    15
  2.674  2.663   45.49    13
  2.111  2.110   44.48    13
  2.337  2.333   43.46    11
  2.512  2.504   45.24    13
  2.011  2.008   44.98    13
  2.060  2.057   44.73    13
  2.164  2.164   44.22    13
```

```
  2.215  2.217   43.97    13
  2.270  2.266   43.71    11
  2.660  2.658   42.44    11
  3.021  3.020   41.42     9
  3.970  3.967   40.41     8
  6.125  6.122   39.39     6
 14.827 14.825   38.37     4
 THE LOWEST FACTOR OF SAFETY FOUND WAS 2.011 AT R=   44.98

 FSBSHP FSNRML RADIUS NO.SLCS. X=   48.00  Y=   35.00
  2.773  2.593   43.19    23
  2.755  2.588   41.44    21
  2.756  2.596   39.70    21
  2.771  2.593   42.75    23
  2.747  2.574   42.31    23
  2.747  2.579   41.88    23
  2.752  2.586   41.01    21
  2.748  2.584   40.57    21
  2.760  2.597   40.13    21
  2.740  2.592   37.95    19
  2.716  2.584   36.21    19
  2.769  2.648   34.46    17
  2.739  2.592   37.52    19
  2.720  2.581   37.08    19
  2.723  2.586   36.64    19
  2.719  2.592   35.77    18
  2.722  2.600   35.34    18
  2.786  2.669   34.90    18
  2.741  2.630   32.72    16
  2.830  2.733   30.98    15
  2.751  2.631   34.03    17
  2.753  2.635   33.59    16
  2.758  2.644   33.16    16
  2.770  2.663   32.28    16
  2.806  2.703   31.85    16
  2.806  2.706   31.41    15
  2.831  2.750   29.23    14
  2.979  2.913   27.49    13
  2.759  2.712   25.74    12
  1.785  1.753   24.00    10
  2.022  2.002   22.25     9
  2.795  2.753   25.31    11
  2.695  2.656   24.87    11
  2.418  2.378   24.43    10
  1.836  1.808   23.56    10
  1.894  1.869   23.13    10
  1.957  1.934   22.69    10
  2.309  2.297   20.51     8
  2.776  2.771   18.76     7
  4.066  4.061   17.02     5
 TOO FEW SLICES AT RAD=   15.28
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.785 AT R=   24.00

 FSBSHP FSNRML RADIUS NO.SLCS. X=   49.00  Y=   39.00
  2.670  2.525   44.72    23
  2.734  2.598   43.13    22
  2.642  2.519   41.54    21
  2.713  2.601   39.95    20
  2.684  2.546   42.73    21
  2.641  2.510   42.33    21
  2.641  2.514   41.94    21
  2.642  2.522   41.14    21
  2.693  2.576   40.74    21
  2.691  2.577   40.34    20
  2.630  2.530   38.36    19
  2.711  2.621   36.76    18
```

```
  2.626  2.514   39.55   19
  2.626  2.517   39.15   19
  2.624  2.520   38.75   19
  2.715  2.619   37.96   18
  2.689  2.598   37.56   18
  2.700  2.608   37.16   18
  2.630  2.548   35.17   16
  2.799  2.730   33.58   15
  2.641  2.549   36.37   17
  2.633  2.543   35.97   16
  2.666  2.579   35.57   16
  2.641  2.562   34.78   16
  2.643  2.569   34.38   16
  2.649  2.579   33.98   16
  2.657  2.601   31.99   14
  2.779  2.735   30.40   13
  2.760  2.695   33.18   15
  2.772  2.709   32.79   15
  2.643  2.584   32.39   14
  2.805  2.753   31.59   14
  2.775  2.724   31.19   13
  2.780  2.733   30.80   13
  2.401  2.371   28.81   12
  1.937  1.919   27.22   11
  1.997  1.985   25.62    9
  2.378  2.352   28.41   11
  1.939  1.918   28.01   11
  1.888  1.869   27.61   11
  1.990  1.974   26.82   11
  1.866  1.850   26.42   10
  1.929  1.916   26.02   10
  2.435  2.426   24.03    9
  2.847  2.843   22.44    7
  4.215  4.211   20.85    5
TOO FEW SLICES AT RAD=    19.26
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.866 AT R=   26.42

FSBSHP FSNRML RADIUS NO.SLCS. X=    50.00  Y=    43.00
 2.684  2.565   45.57   23
 2.665  2.556   45.12   22
 2.652  2.554   43.66   21
 2.650  2.561   42.20   20
 2.638  2.562   40.74   19
 2.700  2.630   39.29   18
 2.662  2.575   41.84   20
 2.569  2.485   41.47   19
 2.569  2.489   41.11   19
 2.642  2.567   40.38   18
 2.648  2.575   40.01   18
 2.670  2.598   39.65   18
 2.548  2.489   37.83   16
 2.666  2.617   36.37   15
 2.661  2.593   38.92   18
 2.647  2.590   38.56   17
 2.552  2.488   38.19   16
 2.572  2.516   37.46   16
 2.560  2.506   37.10   16
 2.691  2.638   36.74   15
 2.689  2.649   34.91   15
 2.573  2.544   33.46   13
 1.766  1.780   32.00   13
 1.979  1.967   30.54   11
 2.526  2.499   33.09   13
 2.442  2.420   32.73   13
 2.303  2.287   32.36   13
 1.777  1.789   31.63   12
```

```
   1.877   1.863    31.27    11
   1.926   1.914    30.91    11
   2.010   2.002    29.08     9
   2.534   2.528    27.63     9
   2.959   2.955    26.17     7
   4.419   4.414    24.71     5
 TOO FEW SLICES AT RAD=    23.25
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.766 AT R=    32.00

 FSBSHP FSNRML RADIUS NO.SLCS. X=    51.00  Y=    47.00
  2.640   2.543    48.70    23
  2.627   2.546    47.36    22
  2.622   2.543    46.02    21
  2.624   2.554    44.68    20
  2.561   2.476    47.03    21
  2.623   2.540    46.69    21
  2.622   2.541    46.36    21
  2.631   2.554    45.69    21
  2.649   2.574    45.35    21
  2.628   2.554    45.02    20
  2.641   2.579    43.34    19
  2.622   2.568    42.00    18
  2.497   2.452    40.66    16
  2.603   2.567    39.32    15
  2.622   2.571    41.67    18
  2.622   2.579    41.33    17
  2.576   2.537    41.00    17
  2.494   2.453    40.33    16
  2.607   2.568    39.99    16
  2.604   2.566    39.66    15
  2.564   2.536    37.98    15
  2.317   2.297    36.64    13
  1.851   1.846    35.30    13
  2.049   2.041    33.96    11
  2.173   2.155    36.31    13
  1.745   1.734    35.97    13
  1.796   1.788    35.64    13
  1.839   1.857    34.97    12
  1.855   1.873    34.63    12
  1.936   1.950    34.30    12
  2.324   2.324    32.62    10
  2.664   2.659    31.28     9
  3.097   3.093    29.94     7
  4.668   4.662    28.60     6
 10.440  10.435    27.26     4
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.745 AT R=    35.97

 FSBSHP FSNRML RADIUS NO.SLCS. X=    52.00  Y=    51.00
  2.638   2.558    51.08    23
  2.603   2.538    49.84    22
  2.619   2.554    48.60    21
  2.633   2.555    50.77    23
  2.629   2.554    50.46    23
  2.617   2.549    50.15    23
  2.594   2.531    49.53    22
  2.640   2.572    49.22    21
  2.621   2.554    48.91    21
  2.638   2.584    47.37    20
  2.606   2.557    46.13    18
  2.603   2.561    44.89    18
  2.521   2.497    43.65    17
  2.541   2.513    42.42    15
  2.590   2.550    44.58    17
  2.567   2.536    44.27    17
  2.557   2.530    43.96    17
  2.562   2.530    43.34    16
```

```
  2.557  2.526   43.03   16
  2.550  2.521   42.73   15
  2.427  2.408   41.18   15
  1.641  1.652   39.94   14
  1.893  1.889   38.70   13
  2.365  2.348   40.87   14
  2.269  2.255   40.56   14
  2.067  2.069   40.25   14
  1.733  1.724   39.63   13
  1.782  1.775   39.32   13
  1.835  1.830   39.01   13
  2.054  2.073   37.47   12
  2.439  2.439   36.23   10
  2.796  2.792   34.99    9
  3.566  3.562   33.75    8
  4.916  4.911   32.52    6
 10.967 10.963   31.28    4
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.641 AT R=   39.94

FSBSHP FSNRML RADIUS NO.SLCS. X=   53.00  Y=   55.00
  2.635  2.570   53.67   23
  2.600  2.547   52.52   22
  2.639  2.587   51.37   21
  2.642  2.579   53.38   23
  2.646  2.588   53.09   23
  2.611  2.556   52.80   23
  2.585  2.533   52.23   22
  2.625  2.569   51.94   21
  2.624  2.570   51.66   21
  2.609  2.569   50.22   20
  2.606  2.567   49.08   18
  2.600  2.568   47.93   18
  2.485  2.468   46.78   17
  2.461  2.441   45.63   15
  2.211  2.198   44.48   15
  1.694  1.707   43.34   14
  1.947  1.945   42.19   13
  2.046  2.036   44.20   14
  1.694  1.689   43.91   14
  1.685  1.698   43.62   14
  1.726  1.739   43.05   14
  1.831  1.826   42.76   13
  1.887  1.883   42.48   13
  2.117  2.139   41.04   12
  2.579  2.580   39.89   10
  3.033  3.036   38.75   10
  3.852  3.848   37.60    8
  5.173  5.167   36.45    6
 11.508 11.504   35.30    4
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.685 AT R=   43.62

FSBSHP FSNRML RADIUS NO.SLCS. X=   42.00  Y=   34.00
  2.869  2.698   37.12   19
  2.901  2.748   35.55   19
  2.963  2.802   33.98   17
  2.877  2.742   32.41   17
  2.875  2.745   30.84   15
  2.903  2.791   29.27   15
  2.961  2.815   32.02   15
  2.916  2.778   31.63   15
  2.898  2.765   31.23   15
  2.871  2.747   30.45   15
  2.873  2.754   30.06   15
  2.911  2.795   29.66   15
  2.889  2.787   27.70   13
  2.743  2.664   26.13   13
```

```
  2.532  2.468   24.56   11
  1.694  1.655   22.99   11
  2.008  1.984   21.42   10
  2.458  2.401   24.17   11
  2.351  2.300   23.78   11
  2.184  2.140   23.38   11
  1.859  1.824   22.60   10
  1.908  1.876   22.21   10
  1.956  1.928   21.81   10
  1.962  1.945   19.85    8
  2.080  2.069   18.28    7
  1.837  1.809   21.03    9
  1.878  1.855   20.64    9
  1.917  1.897   20.24    9
  2.178  2.164   19.46    8
  2.237  2.225   19.07    8
  2.292  2.282   18.67    8
  2.430  2.422   16.71    6
  3.041  3.032   15.14    5
  4.330  4.320   13.57    4
TOO FEW SLICES AT RAD=    12.00
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.694 AT R=    22.99

FSBSHP FSNRML RADIUS NO.SLCS. X=    43.00   Y=    38.00
  2.711  2.586   38.64   19
  2.784  2.665   37.22   19
  2.717  2.609   35.81   17
  2.796  2.697   34.39   17
  2.736  2.613   36.87   17
  2.746  2.626   36.52   17
  2.749  2.633   36.16   17
  2.715  2.610   35.45   17
  2.804  2.701   35.10   17
  2.790  2.689   34.75   17
  2.692  2.604   32.98   15
  2.782  2.708   31.56   15
  2.801  2.705   34.04   16
  2.814  2.721   33.68   16
  2.734  2.640   33.33   15
  2.689  2.604   32.62   15
  2.690  2.610   32.27   15
  2.755  2.679   31.91   15
  2.567  2.501   30.14   13
  2.416  2.369   28.73   13
  2.134  2.101   27.31   12
  1.768  1.746   25.90   11
  1.970  1.955   24.48   10
  1.722  1.693   26.96   12
  1.754  1.728   26.60   12
  1.582  1.556   26.25   11
  1.813  1.793   25.54   11
  1.863  1.843   25.19   10
  1.914  1.896   24.83   10
  2.071  2.097   23.06   10
  2.301  2.296   21.65    8
  2.425  2.418   20.23    6
  3.416  3.407   18.82    6
  4.379  4.372   17.40    4
TOO FEW SLICES AT RAD=    15.99
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.582 AT R=    26.25

FSBSHP FSNRML RADIUS NO.SLCS. X=    44.00   Y=    42.00
  2.684  2.587   40.52   19
  2.725  2.634   39.24   18
  2.682  2.603   37.95   17
  2.690  2.618   36.67   16
```

```
  2.743  2.655   38.92   18
  2.643  2.557   38.60   17
  2.610  2.528   38.28   17
  2.687  2.610   37.63   17
  2.713  2.637   37.31   17
  2.695  2.619   36.99   17
  2.591  2.531   35.39   15
  2.594  2.544   34.10   15
  2.686  2.617   36.35   16
  2.674  2.609   36.03   16
  2.660  2.608   35.71   16
  2.652  2.593   35.07   15
  2.623  2.567   34.74   15
  2.610  2.557   34.42   15
  2.477  2.437   32.82   14
  2.009  1.982   31.54   13
  1.693  1.672   30.25   12
  1.826  1.815   28.97   12
  1.972  1.947   31.21   13
  1.638  1.616   30.89   13
  1.665  1.644   30.57   12
  1.723  1.704   29.93   12
  1.755  1.739   29.61   12
  1.790  1.776   29.29   12
  1.959  1.950   27.68   10
  2.121  2.153   26.40   10
  2.437  2.432   25.12    8
  2.970  2.972   23.83    7
  3.672  3.665   22.55    6
  4.491  4.486   21.27    4
 TOO FEW SLICES AT RAD=   19.98
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.638 AT R=   30.89

 FSBSHP FSNRML RADIUS NO.SLCS. X=   45.00  Y=   46.00
  2.633  2.558   42.72   19
  2.648  2.588   41.55   18
  2.613  2.553   40.38   17
  2.593  2.542   39.21   16
  2.488  2.457   38.04   16
  2.429  2.395   36.87   15
  2.157  2.146   35.70   14
  1.614  1.598   34.53   13
  1.723  1.709   33.36   12
  2.012  2.007   35.40   14
  1.778  1.778   35.11   14
  1.591  1.575   34.82   13
  1.638  1.622   34.23   13
  1.664  1.649   33.94   13
  1.692  1.677   33.65   12
  1.856  1.850   32.19   12
  1.984  1.978   31.02   10
  2.145  2.171   29.84   10
  2.495  2.519   28.67    9
  3.188  3.188   27.50    7
  3.977  3.971   26.33    6
  5.408  5.406   25.16    5
 TOO FEW SLICES AT RAD=   23.99
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.591 AT R=   34.82

 FSBSHP FSNRML RADIUS NO.SLCS. X=   46.00  Y=   50.00
  2.606  2.548   45.19   19
  2.545  2.502   44.12   18
  2.553  2.508   43.04   17
  2.587  2.532   44.92   19
  2.614  2.559   44.65   18
  2.566  2.521   44.38   18
```

```
  2.525  2.485    43.85    18
  2.581  2.534    43.58    17
  2.556  2.510    43.31    17
  2.505  2.470    41.97    16
  2.338  2.319    40.89    16
  2.195  2.172    39.82    15
  1.557  1.564    38.75    14
  1.531  1.540    37.67    14
  1.770  1.760    36.60    12
  1.551  1.559    38.48    14
  1.545  1.554    38.21    14
  1.538  1.547    37.94    14
  1.681  1.670    37.41    13
  1.708  1.697    37.14    13
  1.739  1.729    36.87    12
  1.908  1.905    35.53    12
  1.961  1.982    34.45    11
  2.257  2.278    33.38    10
  2.612  2.639    32.31     9
  3.440  3.441    31.23     7
  4.395  4.397    30.16     7
  5.863  5.863    29.09     5
 11.267 11.267    28.01     3
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.531 AT R=   37.67

 FSBSHP FSNRML RADIUS NO.SLCS. X=    47.00  Y=    54.00
  2.553  2.510    47.89    19
  2.481  2.450    46.90    18
  2.478  2.446    45.90    17
  2.396  2.372    44.91    16
  2.159  2.150    43.92    16
  1.567  1.555    42.93    14
  1.590  1.600    41.94    14
  2.082  2.074    43.68    16
  2.033  2.016    43.43    15
  1.885  1.869    43.18    15
  1.586  1.575    42.69    14
  1.604  1.595    42.44    14
  1.593  1.602    42.19    14
  1.640  1.651    40.95    14
  1.830  1.823    39.96    12
  1.975  1.974    38.97    12
  1.988  2.009    37.98    11
  2.373  2.391    36.99    10
  2.743  2.766    36.00     9
  3.511  3.531    35.01     8
  4.785  4.789    34.02     7
  6.408  6.410    33.03     5
 TOO FEW SLICES AT RAD=    32.04
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.567 AT R=   42.93

 FSBSHP FSNRML RADIUS NO.SLCS. X=    36.00  Y=    33.00
  3.215  3.040    31.06    16
  3.223  3.067    29.67    16
  3.162  3.011    28.27    14
  3.114  2.989    26.88    14
  3.051  2.937    25.48    12
  2.813  2.730    24.08    12
  2.536  2.477    22.69    11
  1.753  1.701    21.29    10
  1.810  1.779    19.90     9
  2.264  2.199    22.34    10
  1.774  1.716    21.99    10
  1.779  1.725    21.64    10
  1.767  1.720    20.94    10
  1.778  1.735    20.60    10
```

```
  1.791   1.754    20.25    10
  1.812   1.787    18.50     8
  1.857   1.847    17.11     8
  2.363   2.354    15.71     7
  2.603   2.593    14.31     6
  3.146   3.131    12.92     5
  2.836   2.824    11.52     4
TOO FEW  SLICES AT RAD=    10.13
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.753 AT R=    21.29

FSBSHP FSNRML RADIUS NO.SLCS. X=    37.00  Y=    37.00
  2.949   2.833    32.56    16
  3.033   2.926    31.32    16
  2.827   2.737    30.08    14
  2.817   2.742    28.84    14
  2.645   2.586    27.60    13
  2.197   2.156    26.36    12
  1.804   1.773    25.12    11
  1.644   1.618    23.87    10
  1.687   1.670    22.63    10
  1.825   1.797    24.81    11
  1.846   1.822    24.50    11
  1.633   1.603    24.18    10
  1.656   1.633    23.56    10
  1.667   1.647    23.25    10
  1.677   1.658    22.94    10
  1.962   1.952    21.39     9
  1.993   1.985    20.15     8
  2.366   2.359    18.91     7
  2.704   2.741    17.67     7
  3.160   3.151    16.43     6
  3.898   3.905    15.19     5
  5.566   5.564    13.95     4
TOO FEW SLICES AT RAD=    12.71
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.633 AT R=    24.18

FSBSHP FSNRML RADIUS NO.SLCS. X=    38.00  Y=    41.00
  2.837   2.758    34.48    16
  2.763   2.696    33.37    16
  2.635   2.580    32.26    14
  2.430   2.386    31.15    14
  1.852   1.826    30.04    13
  1.719   1.695    28.93    12
  1.789   1.771    27.82    11
  1.648   1.648    29.76    13
  1.688   1.662    29.48    12
  1.703   1.678    29.21    12
  1.736   1.712    28.65    12
  1.752   1.731    28.37    12
  1.769   1.749    28.10    12
  1.754   1.772    26.71    11
  1.854   1.845    25.60    10
  1.792   1.776    27.54    11
  1.813   1.801    27.26    11
  1.777   1.793    26.98    11
  1.603   1.591    26.43    10
  1.818   1.810    26.15    10
  1.838   1.829    25.87    10
  1.933   1.926    24.49     9
  2.170   2.169    23.37     9
  2.418   2.411    22.26     7
  2.808   2.835    21.15     7
  3.114   3.148    20.04     7
  4.321   4.328    18.93     5
  6.375   6.376    17.82     4
TOO FEW SLICES AT RAD=    16.71
```

```
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.603 AT R=   26.43

FSBSHP FSNRML RADIUS NO.SLCS. X=    39.00  Y=    45.00
 2.631  2.578   36.77   16
 2.478  2.446   35.77   15
 2.247  2.213   34.76   14
 1.653  1.631   33.76   14
 1.645  1.649   32.76   13
 1.734  1.719   31.76   12
 1.665  1.645   33.51   14
 1.677  1.660   33.26   13
 1.658  1.661   33.01   13
 1.630  1.637   32.51   13
 1.615  1.622   32.26   13
 1.718  1.702   32.01   12
 1.795  1.786   30.75   11
 1.748  1.770   29.75   11
 1.837  1.831   28.75   10
 1.813  1.807   30.50   11
 1.790  1.807   30.25   11
 1.771  1.790   30.00   11
 1.721  1.744   29.50   11
 1.685  1.709   29.25   11
 1.795  1.789   29.00   10
 2.035  2.029   27.74    9
 2.282  2.282   26.74    9
 2.433  2.457   25.74    8
 2.916  2.937   24.74    7
 3.203  3.240   23.73    7
 4.845  4.852   22.73    5
 7.599  7.609   21.73    5
TOO FEW SLICES AT RAD=   20.72
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.615 AT R=   32.26

FSBSHP FSNRML RADIUS NO.SLCS. X=    40.00  Y=    49.00
 2.381  2.349   39.36   16
 2.037  2.026   38.44   15
 1.628  1.608   37.53   14
 1.676  1.662   36.62   14
 1.881  1.873   38.22   15
 1.554  1.551   37.99   15
 1.618  1.598   37.76   14
 1.640  1.622   37.30   14
 1.651  1.635   37.07   14
 1.663  1.648   36.85   14
 1.643  1.653   35.71   13
 1.769  1.758   34.79   12
 1.686  1.675   36.39   13
 1.665  1.672   36.16   13
 1.654  1.663   35.93   13
 1.632  1.643   35.48   13
 1.668  1.678   35.25   13
 1.680  1.688   35.02   13
 1.828  1.825   33.88   11
 1.699  1.722   32.97   11
 1.850  1.866   32.05   11
 1.841  1.840   33.65   11
 1.786  1.808   33.42   11
 1.760  1.781   33.19   11
 1.698  1.721   32.74   11
 1.778  1.800   32.51   11
 1.813  1.832   32.28   11
 2.160  2.156   31.14    9
 2.375  2.392   30.23    9
 2.572  2.593   29.31    8
 3.019  3.037   28.40    7
```

```
   3.419   3.450    27.49     7
   4.965   4.996    26.57     6
   8.858   8.868    25.66     4
 TOO FEW SLICES AT RAD=    24.75
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.554 AT R=    37.99

 FSBSHP FSNRML RADIUS NO.SLCS. X=    41.00   Y=    53.00
  1.899   1.892    42.19    16
  1.560   1.562    41.35    15
  1.662   1.649    40.51    14
  1.558   1.559    41.98    16
  1.551   1.553    41.77    15
  1.543   1.545    41.56    15
  1.568   1.570    41.14    15
  1.576   1.577    40.93    15
  1.650   1.636    40.72    14
  1.712   1.705    39.68    14
  1.680   1.692    38.84    13
  1.719   1.730    38.00    13
  1.683   1.693    39.47    13
  1.674   1.685    39.26    13
  1.665   1.677    39.05    13
  1.691   1.703    38.63    13
  1.698   1.709    38.42    13
  1.709   1.721    38.21    13
  1.821   1.839    37.16    11
  1.780   1.801    36.33    11
  1.961   1.977    35.49    11
  1.771   1.791    36.95    11
  1.774   1.795    36.74    11
  1.776   1.798    36.53    11
  1.850   1.871    36.12    11
  1.886   1.905    35.91    11
  1.923   1.940    35.70    11
  2.301   2.299    34.65     9
  2.498   2.515    33.81     9
  2.725   2.744    32.97     8
  3.075   3.097    32.14     8
  3.659   3.685    31.30     7
  5.319   5.349    30.46     6
 10.012 10.022    29.62     4
 TOO FEW SLICES AT RAD=    28.78
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.543 AT R=    41.56

 FSBSHP FSNRML RADIUS NO.SLCS. X=    30.00   Y=    32.00
  3.666   3.507    25.02    13
  3.433   3.308    23.80    12
  3.208   3.098    22.57    11
  2.622   2.546    21.35    11
  2.199   2.139    20.13    10
  2.071   2.025    18.91     9
  2.065   2.038    17.68     9
  2.061   2.031    16.46     7
  1.937   1.914    15.24     7
  2.037   2.014    14.02     7
  1.954   1.925    16.16     7
  1.887   1.861    15.85     7
  1.911   1.887    15.54     7
  1.965   1.943    14.93     7
  1.989   1.968    14.63     7
  2.017   1.995    14.32     7
  2.472   2.444    12.79     7
  2.571   2.542    11.57     5
  2.936   2.911    10.35     5
  3.884   3.896     9.13     5
 TOO FEW SLICES AT RAD=     7.90
```

```
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.887 AT R=   15.85

FSBSHP FSNRML RADIUS NO.SLCS. X=   31.00  Y=   36.00
  2.956  2.583   26.48   13
  2.564  2.507   25.41   12
  1.859  1.812   24.35   11
  2.027  1.992   23.28   11
  2.358  2.305   25.15   12
  2.026  1.978   24.88   12
  1.854  1.804   24.61   11
  1.861  1.817   24.08   11
  1.863  1.821   23.81   11
  2.016  1.978   23.55   11
  2.080  2.055   22.22   11
  1.845  1.830   21.15    9
  2.006  1.996   20.09    9
  2.091  2.071   21.95   10
  2.103  2.090   21.68   10
  1.850  1.831   21.42    9
  2.035  2.023   20.89    9
  2.036  2.025   20.62    9
  2.032  2.021   20.35    9
  2.075  2.064   19.02    9
  1.820  1.805   17.96    7
  2.261  2.244   16.89    7
  2.118  2.111   18.76    9
  2.181  2.178   18.49    8
  2.103  2.136   18.22    8
  1.839  1.824   17.69    7
  2.170  2.156   17.42    7
  2.214  2.198   17.16    7
  2.468  2.449   15.83    7
  2.677  2.671   14.76    6
  2.949  2.939   13.70    5
  3.771  3.798   12.63    5
  5.154  5.193   11.57    4
TOO FEW SLICES AT RAD=   10.50
THE LOWEST FACTOR OF SAFETY FOUND WAS 1.820 AT R=   17.96

FSBSHP FSNRML RADIUS NO.SLCS. X=   32.00  Y=   40.00
  1.908  1.870   28.46   13
  1.946  1.920   27.52   12
  1.931  1.909   26.58   11
  1.968  1.952   25.64   11
  1.956  1.934   27.29   12
  1.899  1.902   27.05   12
  1.922  1.899   26.82   11
  1.940  1.919   26.35   11
  1.950  1.931   26.11   11
  1.958  1.940   25.88   11
  1.990  1.985   24.71   11
  1.797  1.828   23.77   10
  2.019  2.009   22.83    9
  1.997  1.995   24.47   10
  1.921  1.945   24.24   10
  1.836  1.866   24.00   10
  1.921  1.913   23.53    9
  1.953  1.944   23.30    9
  1.984  1.974   23.06    9
  2.149  2.144   21.89    9
  2.092  2.120   20.95    8
  2.355  2.340   20.01    7
  2.186  2.183   21.65    9
  2.125  2.148   21.42    9
  2.119  2.145   21.18    8
  2.061  2.091   20.71    9
```

```
  2.267   2.254    20.48     7
  2.310   2.296    20.25     7
  2.484   2.474    19.07     7
  2.844   2.844    18.13     6
  3.057   3.088    17.19     6
  3.846   3.865    16.26     5
  5.476   5.499    15.32     4
 10.029  10.051    14.38     4
 TOO FEW SLICES AT RAD=    13.44
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.797 AT R=    23.77

 FSBSHP FSNRML RADIUS NO.SLCS. X=    33.00  Y=    44.00
  1.883   1.865    30.87    13
  1.849   1.858    30.03    12
  1.908   1.896    29.19    11
  1.891   1.876    30.66    13
  1.900   1.887    30.45    13
  1.869   1.877    30.24    12
  1.827   1.838    29.82    12
  1.804   1.817    29.61    12
  1.834   1.847    29.40    12
  1.917   1.912    28.36    11
  1.860   1.883    27.52    11
  1.901   1.923    26.68    10
  1.903   1.900    28.15    11
  1.862   1.861    27.94    11
  1.884   1.888    27.73    11
  1.859   1.883    27.31    10
  1.849   1.873    27.10    10
  1.879   1.902    26.89    10
  2.120   2.113    25.84     9
  2.198   2.217    25.00     9
  2.233   2.256    24.16     8
  2.463   2.454    23.33     7
  2.629   2.626    22.49     7
  2.905   2.928    21.65     7
  3.337   3.363    20.81     6
  4.016   4.032    19.97     5
  5.960   5.971    19.13     4
 10.984  10.994    18.30     4
 TOO FEW SLICES AT RAD=    17.46
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.804 AT R=    29.61

 FSBSHP FSNRML RADIUS NO.SLCS. X=    34.00  Y=    48.00
  1.879   1.873    33.62    13
  1.806   1.822    32.86    12
  1.863   1.859    32.10    11
  1.836   1.848    33.43    13
  1.818   1.831    33.24    13
  1.801   1.816    33.05    12
  1.806   1.821    32.67    12
  1.801   1.816    32.48    12
  1.791   1.807    32.29    12
  1.906   1.905    31.34    11
  1.900   1.921    30.58    11
  1.995   2.013    29.83    10
  1.932   1.932    31.15    11
  1.908   1.927    30.96    11
  1.904   1.924    30.77    11
  1.925   1.945    30.39    10
  1.947   1.967    30.20    10
  1.971   1.990    30.02    10
  2.250   2.247    29.07     9
  2.259   2.278    28.31     9
  2.337   2.358    27.55     8
  2.332   2.353    26.79     8
```

```
  2.884  2.885    26.04     7
  2.348  2.369    27.36     8
  2.347  2.368    27.17     8
  2.279  2.302    26.98     8
  2.609  2.606    26.60     7
  2.693  2.691    26.42     7
  2.785  2.784    26.23     7
  3.087  3.110    25.28     7
  3.681  3.703    24.52     6
  4.658  4.676    23.76     6
  6.559  6.562    23.00     4
 12.023 12.020    22.25     4
 TOO FEW SLICES AT RAD=    21.49
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.791 AT R=    32.29

 FSBSHP FSNRML RADIUS NO.SLCS. X=    35.00   Y=    52.00
  1.802  1.818    36.62    13
  1.728  1.746    35.93    12
  1.910  1.908    35.23    11
  1.781  1.798    36.45    13
  1.782  1.799    36.27    12
  1.765  1.782    36.10    12
  1.746  1.763    35.75    12
  1.764  1.781    35.58    12
  1.783  1.798    35.41    12
  1.963  1.980    34.54    11
  1.997  2.015    33.85    11
  2.107  2.123    33.15    10
  2.394  2.392    32.46     9
  2.348  2.369    31.77     9
  2.388  2.411    31.08     8
  2.355  2.371    32.29     9
  2.347  2.365    32.11     9
  2.336  2.355    31.94     9
  2.368  2.389    31.60     9
  2.386  2.407    31.42     9
  2.394  2.416    31.25     9
  2.531  2.552    30.38     8
  3.116  3.133    29.69     7
  3.367  3.389    29.00     7
  4.069  4.089    28.30     6
  5.208  5.220    27.61     6
  7.225  7.224    26.92     4
 13.182 13.170    26.22     4
 TOO FEW SLICES AT RAD=    25.53
 THE LOWEST FACTOR OF SAFETY FOUND WAS 1.728 AT R=    35.93

 THE MINIMUM FACTOR OF SAFETY IS  1.531 FOR X=    46.00   Y=    50.00   R=    37.67

 FINISH


 GOOD-BYE
```