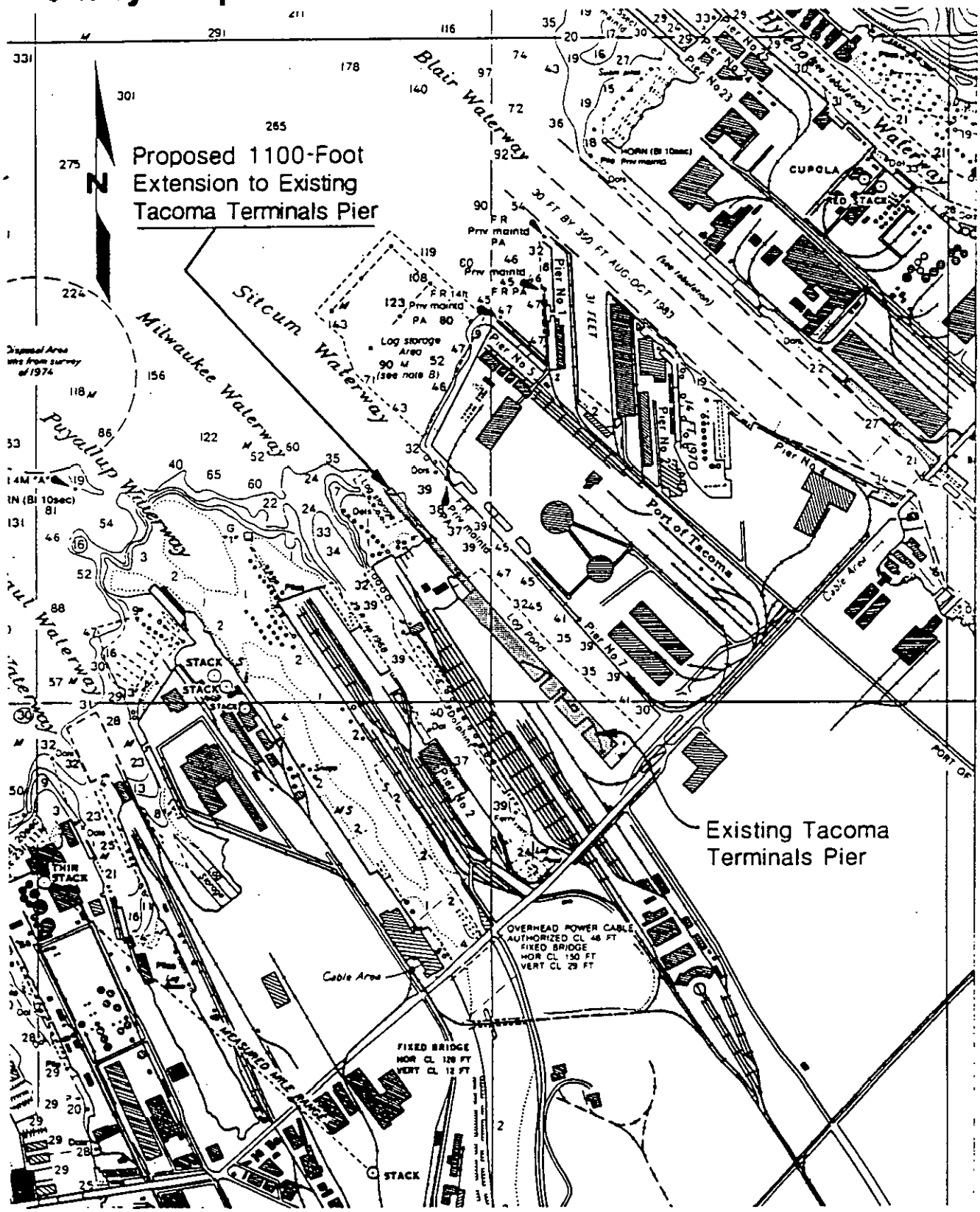
Subsurface Explorations and
Geotechnical Feasibility Study
Proposed Tacoma Terminals Pier Extension
Port of Tacoma, Washington

Prepared for
Port of Tacoma

December 29, 1986
J-1683

Vicinity Map—Tacoma Terminals Pier Extension



0 1250 2500

Scale in Feet

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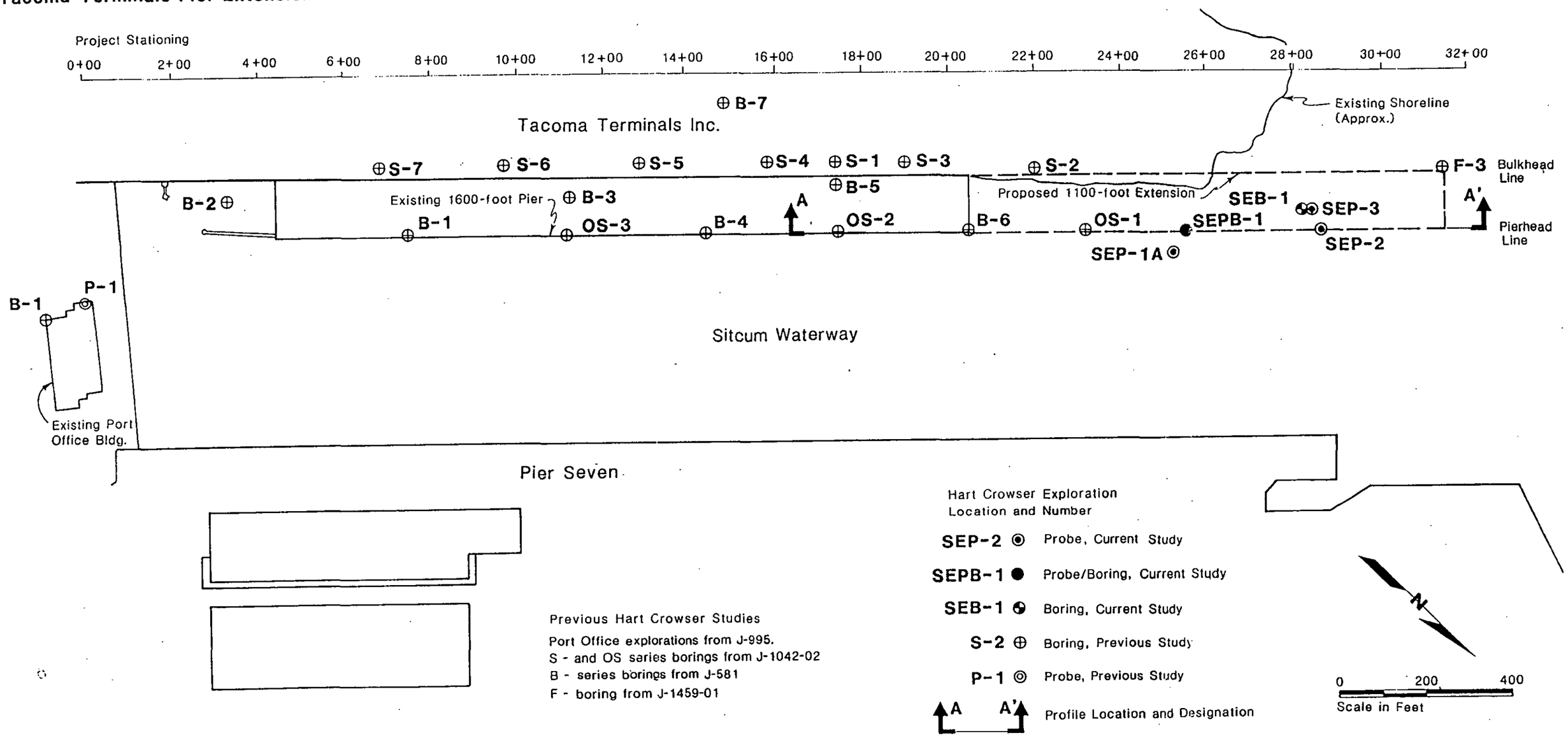
Figure 1

Site and Exploration Plan

Tacoma Terminals Pier Extension



Note: Base map prepared from Port of Tacoma drawing entitled Sitcum Waterway Soundings (EP-3966-14), dated April 18, 1985.

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Figure 2

APPENDIX A
FIELD EXPLORATIONS

The program of subsurface explorations for this project included completion of one boring, three electric cone penetrometer test (CPT) probes and one exploration consisting of a combination of boring and CPT probe. In addition, borings were accomplished by Hart Crowser for previous studies in the area. The results of our exploration program are presented on the exploration logs within this Appendix. Logs of selected borings from previous explorations are also included in this Appendix. The exploration logs are a representation of our interpretation of the drilling, cone penetrometer tests, sampling, and laboratory testing information. The depth where the soils or characteristics of the soils changed is noted. The change may be gradual. Soil samples recovered in the explorations were visually classified in the field in general accordance with the method presented on Figure A-1. A explanation for the field exploration logs defining symbols and abbreviations utilized is also presented on Figure A-1 for borings.

The exploration locations are presented on Figure 2. The explorations were located in the field by hand taping and back siting from existing survey stakes. The approximate mudline elevation at the exploration locations, as presented on the exploration logs, are interpreted from bottom sounding elevations and corrected for tides by comparison to tide gages of the time of sounding. The location and elevation of the explorations should be considered accurate to the degree implied by the method used.

Auger Borings

A total of two rotary-wash borings, designated SEB-1 and SEPB-1, were drilled from March 22 to 23, 1986. Boring SEB-1 was completed to a depth

of 131.5 feet below mudline. Boring SEPB-1 was first probed to 90 feet below mudline using the electric CPT probe discussed below. The auger boring at this location was then drilled to 90 feet without sampling. Sampling began at 90 feet and extended to 126.5 feet. The borings were advanced with a barge-mounted drill rig under subcontract to Hart Crowser, Inc. using conventional drilling methods. The drilling was accomplished under the continuous observation of an engineering geologist or geotechnical engineer from our firm. Detailed field logs were prepared of each boring. Samples were obtained on 2-1/2 to 5-foot depth intervals using the Standard Penetration Test (SPT) procedure and thin-walled Shelby tubes.

The Standard Penetration Test procedure as described in ASTM D 1587, was used to obtain disturbed samples. A standard 2-inch outside diameter, split-spoon sampler is driven into the soil a distance of 18 inches using a 140-pound hammer, free-falling 30 inches. The number of blows required to drive the sampler the last 12 inches is the Standard Penetration Resistance. This resistance, or blow count, provides a measure of the relative density of granular soils and consistency of cohesive soils. The blow counts are plotted on the boring logs at the respective sample depths. Samples were recovered from the split-barrel sampler, field classified and placed in water-tight jars and taken to our laboratory for further testing. The Standard Penetration Test is a useful quantitative tool from which density/consistency is determined. The results must be used in conjunction with other tests and engineering judgment.

In fine-grained soils, a 3-inch diameter thin-walled steel (Shelby) tube sampler was pushed hydraulically or advanced with a hydraulically activated Osterburg Sampler, to obtain a relatively undisturbed sample for classification and testing. The tubes were sealed in the field and taken to our laboratory for extrusion and classification.

The boring logs from this study are presented on Figures A-3 and A-4.

Cone Penetrometer Probes

A total of four offshore electric cone penetrometer test (CPT) probes were accomplished as part of this study. Three probes (SEP-1A, SEP-2, SEP-3) were completed to depths ranging from approximately 23 to 88 feet below mudline. SEPB-1, as previously described, is a combination of boring and probe. This exploration was probed to 90 feet.

The probes were advanced from an anchored barge through stiffness casing fixed to a splayed anchor footing at mudline. The stiffness casing and splayed anchor footing provided reaction to advance the probes and allowed vertical barge movement, resulting from wave and tidal action, without affecting the probe advance rate. The hydraulic ram was fixed to the top of the stiffness casing. During periods of calm water, the stiffness casing was occasionally chained to the support barge to increase the available reaction. Bentonite drilling mud was pumped through the cone rod to injection ports behind the cone sleeve to reduce rod friction during penetration. All probing was completed under the continuous observation of a geotechnical engineer or engineering geologist from our firm. The principles of the electric cone penetrometer are illustrated on Figure A-2. The probe logs are presented on Figures A-4 through A-7.

The cone probe continuously measured tip resistance and sleeve friction during advance using internal strain gages specifically designed and calibrated for this purpose. Additional data consisting of pore pressure response were measured using a pressure transducer coupled to the soil by means of a porous filter stone mounted immediately behind the cone tip. The electric cone penetrometer used for these tests was a sonic type electric probe conforming to ASTM D 3441.

The probe data are electronically encoded below ground surface and accoustically transmitted up the cone rod to a surface microphone. The signal is then amplified and transmitted to the signal recorder. This

recorder produces both digital and analog records of the tip resistance, sleeve friction, and pore water pressures with depth.

The digital probe records were computer processed in our Seattle office to obtain plots of the original field data. These data include the actual tip resistance, the sleeve friction, and the pore water pressure. Modification of the field data was accomplished to transfer the information into a form more usable for soil identification. The field data were modified to give the additional output shown on the final logs: the corrected cone penetration resistance, the friction ratio, and the dynamic pore pressure ratio.

The correction to the measured penetration resistance for cone tip geometry arises because pore water is able to penetrate the joint behind the cone tip. The pore water exerts a pressure on the trailing surface of the cone tip creating a force opposite to the penetration resistance force. Consequently, the measured penetration resistance must be increased by an amount equal to the area ratio of the trailing surface to the cone tip multiplied by the measured pore water pressure. Similar logic applies to the friction sleeve, but in this instance, the friction correction is essentially zero.

The friction ratio consists of the ratio of sleeve friction to corrected penetration resistance expressed as a percentage. The dynamic pore pressure ratio is the ratio of the increase (or decrease) in pore pressure above hydrostatic conditions to the cavity expansion stress, where the capacity expansion stress is given as the corrected penetration resistance minus the total overburden stress.

Estimation of soil type, as reported on the logs, was based on correlation with site-specific boring data and on the identification chart presented on part of Figure A-2. The soil consistency or density is empirically related to the cone penetration resistance through relationships between cone penetration resistance and standard penetration numbers.

Previous Explorations

Numerous explorations were accomplished in the area by Hart Crowser for previous studies, as shown on Figure 2. Six of these explorations, designated B-1, B-2, B-6, OS-1, OS-2, and F-3 located near the proposed development were considered for the present study. The borings were accomplished using similar methods as described above for auger borings. Logs of these six borings are shown on Figure A-8 through A-13.

Key to Exploration Logs

Sample Descriptions

Classification of soils in this report is based on visual field and laboratory observations which include density/consistency, moisture condition, grain size, and plasticity estimates and should not be construed to imply field nor laboratory testing unless presented herein. Visual-manual classification methods of ASTM D 2488 were used as an identification guide.

Soil descriptions consist of the following:
Density/consistency, moisture, color, minor constituents, MAJOR CONSTITUENT, additional remarks.

Density/Consistency

Soil density/consistency in borings is related primarily to the Standard Penetration Resistance. Soil density/consistency in test pits is estimated based on visual observation and is presented parenthetically on the test pit logs.

SAND or GRAVEL Density	Standard Penetration Resistance in Blows/Foot	SILT or CLAY Consistency	Standard Penetration Resistance in Blows/Foot	Approximate Shear Strength in TSF
Very loose	0 - 4	Very soft	0 - 2	<0.125
Loose	4 - 10	Soft	2 - 4	0.125 - 0.25
Medium dense	10 - 30	Medium stiff	4 - 8	0.25 - 0.5
Dense	30 - 50	Stiff	8 - 15	0.5 - 1.0
Very dense	>50	Very stiff	15 - 30	1.0 - 2.0
		Hard	>30	>2.0

Moisture

Dry	Little perceptible moisture
Damp	Some perceptible moisture, probably below optimum
Moist	Probably near optimum moisture content
Wet	Much perceptible moisture, probably above optimum

Minor Constituents

	Estimated Percentage
Not identified in description	0 - 5
Slightly (clayey, silty, etc.)	5 - 12
Clayey, silty, sandy, gravelly	12 - 30
Very (clayey, silty, etc.)	30 - 50

Legends

Sampling

BORING SAMPLES

- Split Spoon
- Shelby Tube
- Cuttings
- Core Run
- * No Sample Recovery
- P Tube Pushed, Not Driven

TEST PIT SAMPLES

- Grab (Jar)
- Bag
- Shelby Tube

Ground Water Observations

- Surface Seal
- Ground Water Level on Date (ATD) At Time of Drilling
- Observation Well Tip or Slotted Section
- Ground Water Seepage (Test Pits)

Test Symbols

GS	Grain Size Classification
CN	Consolidation
TUU	Triaxial Unconsolidated Undrained
TCU	Triaxial Consolidated Undrained
TCD	Triaxial Consolidated Drained
QU	Unconfined Compression
DS	Direct Shear
K	Permeability
PP	Pocket Penetrometer Approximate Compressive Strength in TSF
TV	Torvane Approximate Shear Strength in TSF
CBR	California Bearing Ratio
MD	Moisture Density Curve
AL	Atterberg Limits

Water Content in Percent
Liquid Limit
Natural
Plastic Limit

γ_w Wet Unit Weight in PCF

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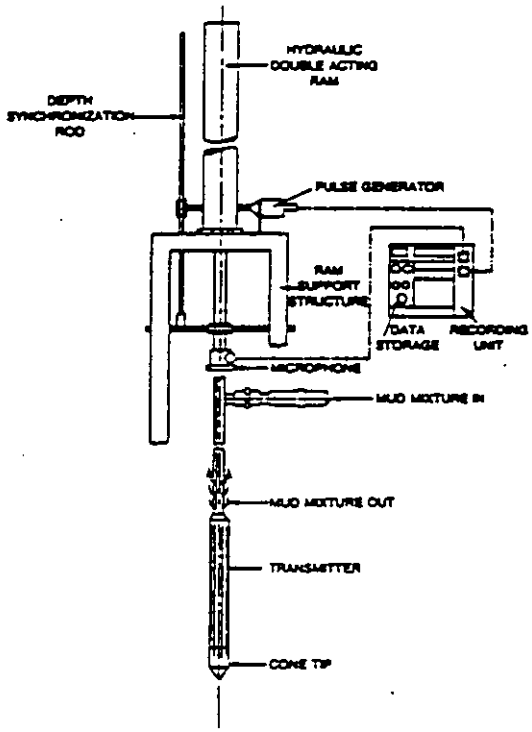
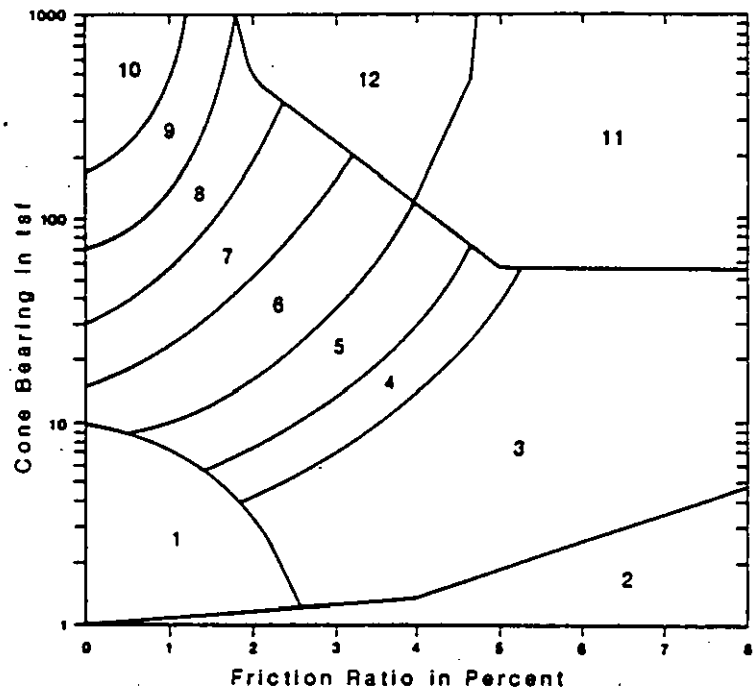
Figure A-1

Electric Cone Penetrometer

Schematic



Simplified Classification Chart (Robertson and Campanella, 1984)



1. Sensitive fine-grained
2. Organic material
3. CLAY
4. Silty CLAY to CLAY
5. Clayey SILT to silty CLAY
6. Sandy SILT to clayey SILT
7. Silty SAND to sandy SILT
8. SAND to silty SAND
9. SAND
10. Gravelly SAND to SAND
11. Very stiff fine grained*
12. SAND to clayey SAND*

*Overconsolidated or cemented.

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Figure A-2

APPENDIX B
LABORATORY TESTING PROGRAM

A laboratory testing program was performed for this study to evaluate the basic index and geotechnical engineering properties of the site soils. Laboratory tests were performed on both disturbed and relatively undisturbed samples. The laboratory tests performed and the procedures followed are outlined below.

Soil Classification

Soil samples recovered in the explorations were visually classified in the field and then taken to our laboratory where the classifications were verified in a relatively controlled environment. Visual-manual field and laboratory observations include density/consistency, moisture condition, grain size and plasticity estimates.

The classifications of selected samples were checked by performing laboratory tests such as Atterberg limits determinations and grain size analyses. Classifications were made in general accordance with the Unified Soil Classification (USC) System, ASTM D 2487, as presented on Figure B-1.

Water Content Determinations

Water contents were determined for most samples recovered in the explorations in general accordance with ASTM D 2216 as soon as possible following their arrival in our laboratory. Water contents were not determined for very small samples. The results of these tests are plotted at the respective sample depth on the exploration logs. In addition, the water contents of samples subjected to other testing have been determined

and are presented on the exploration logs as well as with the various test results which follow in this appendix.

Atterberg Limits (AL)

Atterberg limits determinations were accomplished for three silt soil samples from boring SEB-1 (S-3, S-17, S-19). The liquid limit and plastic limit were determined in general accordance with ASTM D 423 and ASTM D 424, respectively. The results of these Atterberg limits analyses show the plastic limit to be the same as or higher than the liquid limit which indicates that these soils are non-plastic. The results of the Atterberg limits tests are therefore not shown graphically.

Grain Size Analysis (GS)

Grain size analyses were performed on representative samples in general accordance with ASTM D 422. The wet sieve analysis method was used for most samples and determines the size distribution greater than the U.S. No. 200 mesh sieve. The results of the tests are presented as curves on Figures B-2 through B-7 plotting percent finer by weight versus grain size.

200-Wash

Nineteen (19) samples were subjected to a modified grain size classification known as a 200-wash. The samples were "washed" through the No. 200 mesh sieve to determine the relative percentages of coarse and fine-grained material in the samples. The tests were performed in general accordance with ASTM D 1140. The results are presented as a single point plotted on the No. 200 sieve line on Figures B-2 through B-7. That point represents the percentage of the sample finer than the No. 200 sieve.

Pocket Penetrometer (PP) and Torvane (TV)

The pocket penetrometer and torvane procedures provide quick approximate tests of the consistency (undrained shear strength) of a cohesive soil

sample. The pocket penetrometer device consists of a calibrated spring mechanism which measures penetration resistance of a 1/4-inch-diameter steel tip over a given distance. The penetration resistance is correlated to the unconfined compressive strength of the soil, which is typically twice the undrained shear strength of a saturated, cohesive soil.

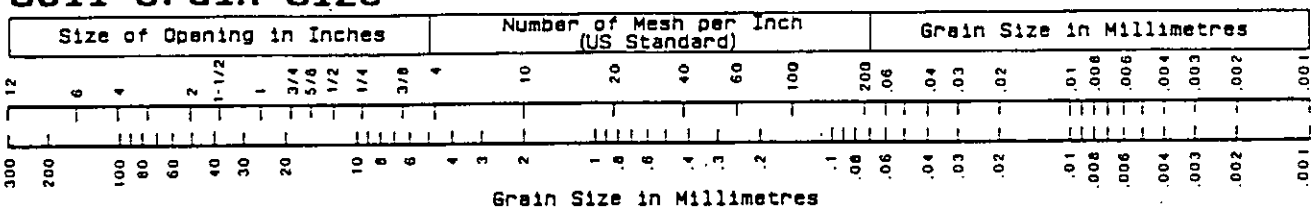
The torvane device consists of a 1-inch-diameter plate with eight equally spaced and radially arranged 1/4-inch vanes. The vanes are pressed into the soil and the device is rotated. The vanes force a shear failure to take place over the area of the face of the plate, and the resistance at failure as measured by a calibrated spring is correlative to the undrained shear strength of the sample tested. The results of the pocket penetrometer and torvane tests are presented on the exploration logs.

Triaxial Unconsolidated Undrained Compression Test (TUU)

The triaxial unconsolidated undrained compression test is a method used to estimate the undrained shear strength of the soil. The test was performed in general accordance with ASTM D 2850 on two samples. A relatively undisturbed fine-grained sample was trimmed to a length of about 5-1/2 to 6 inches, encased in a rubber membrane and placed in the triaxial cell. An all-around confining pressure was applied hydraulically, but the sample was not allowed to consolidate, and no back pressure was applied. An axial load was then applied at a constant strain rate to the sample without allowing drainage from the specimen. The stress-strain behavior was recorded until failure occurred. The failure stress was generally taken as the maximum load on the sample or the load recorded at 20 percent strain, whichever was greater. The test results plotted in terms of axial strain versus deviator stress are presented on Figure B-8. The shear strength is considered to be one-half the maximum stress difference.

Unified Soil Classification (USC) System

Soil Grain Size



COBBLES	GRAVEL	SAND	SILT and CLAY
Coarse-Grained Soils			Fine-Grained Soils

Coarse-Grained Soils

G W	G P	G M	G C	S W	S P	S M	S C
Clean GRAVEL <5% fines	*	GRAVEL with >12% fines		Clean SAND <5% fines	*	SAND with >12% fines	
GRAVEL >50% coarse fraction larger than No. 4				SAND >50% coarse fraction smaller than No. 4			
Coarse-Grained Soils >50% larger than No. 200 sieve							

G W and S W $\left(\frac{D_{60}}{D_{10}}\right) > 4$ for G W, > 6 for S W & $1 \leq \left(\frac{(D_{30})^2}{D_{10} \times D_{60}}\right) \leq 3$

G P and S P Clean GRAVEL or SAND not meeting requirements for G W and S W

G M and S M Atterberg limits below A Line with PI <4

G C and S C Atterberg limits above A Line with PI >7

* Coarse-grained soils with percentage of fines between 5 and 12 are considered borderline cases requiring use of dual symbols.

D_{10}, D_{30}, and D_{60} are the particle diameter of which 10, 30, and 60 percent, respectively, of the soil weight are finer.

Fine-Grained Soils

M L	C L	O L	M H	C H	O H	Pt
SILT	CLAY	Organic	SILT	CLAY	Organic	Highly Organic Soils
Soils with Liquid Limit <50%			Soils with Liquid Limit >50%			
Fine-Grained Soils >50% smaller than No. 200 sieve						

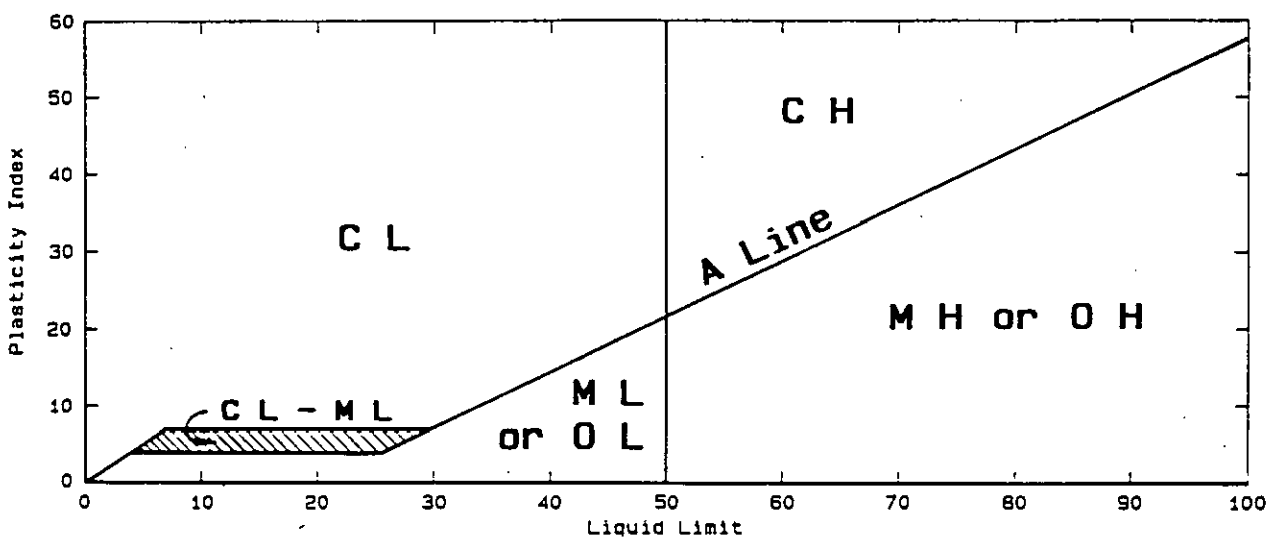


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Figure B-1

Boring Log SEB-1

SOIL DESCRIPTIONS

Approximate Mudline Elevation in Feet -25.0(MLLW)

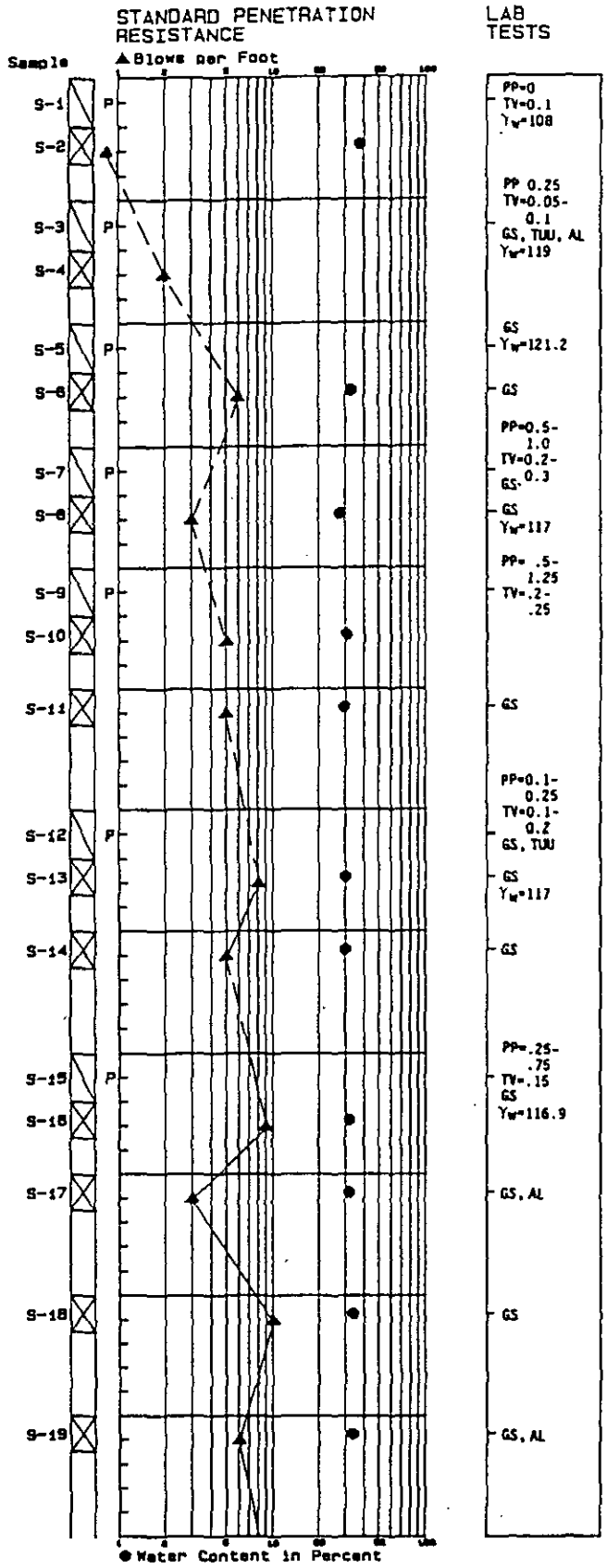
Depth in Feet

Very loose, wet, black, very silty SAND with sandy silt seams.

Loose to medium dense, wet, gray, very silty, fine SAND to very sandy SILT.

Medium stiff, wet, gray, very sandy SILT.

Medium stiff, wet, gray, sandy SILT.



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Sheet 1 of 3 Figure A-3

Boring Log SEB-1

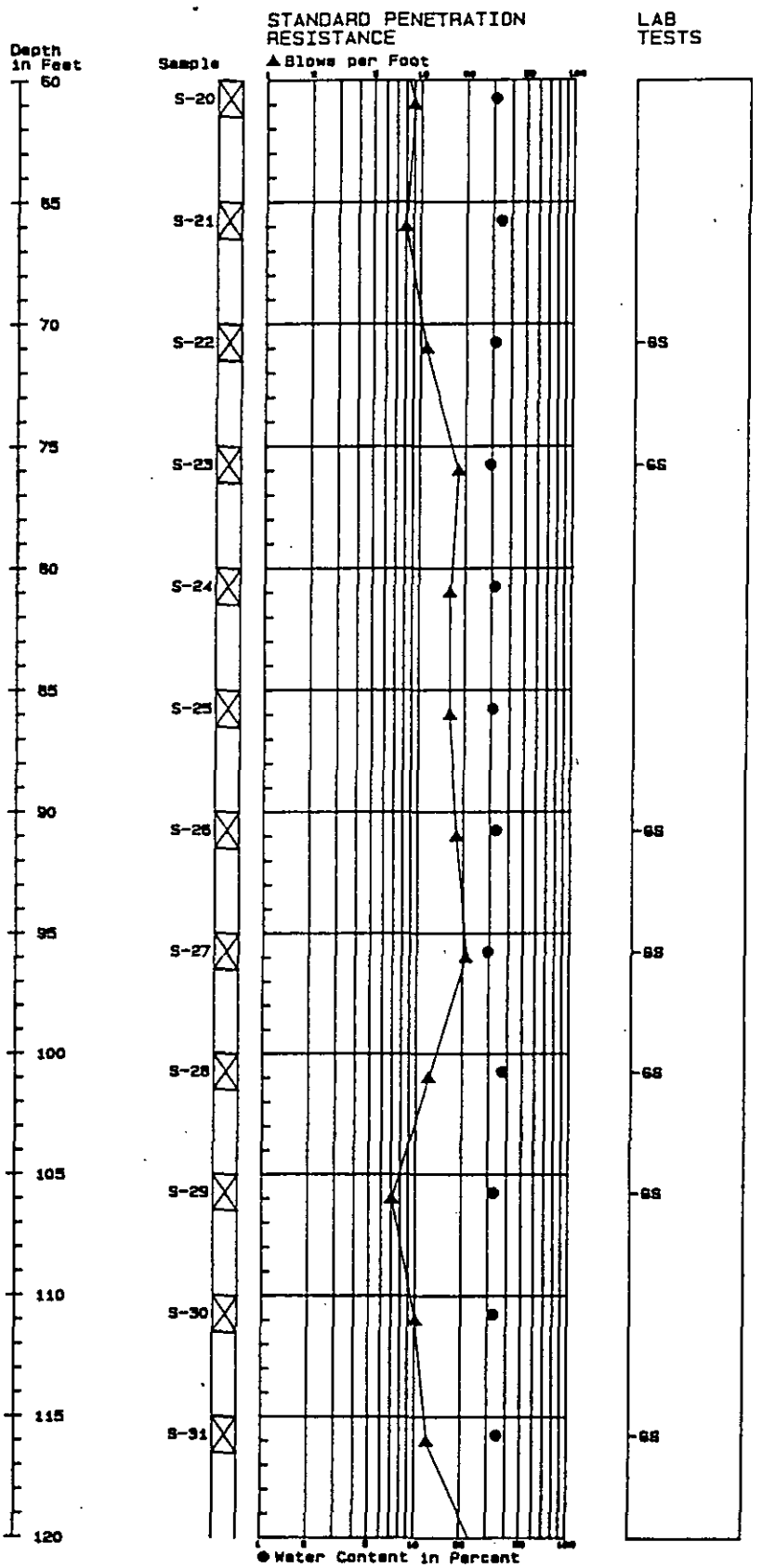
SOIL DESCRIPTIONS

Approximate Mudline Elevation in Feet -25.0(MLLW)

Stiff, wet, gray, very sandy SILT.

Medium dense, wet, gray, very silty SAND.

Medium to very stiff, wet, gray, slightly sandy SILT.



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Sheet 2 of 3 Figure A-3

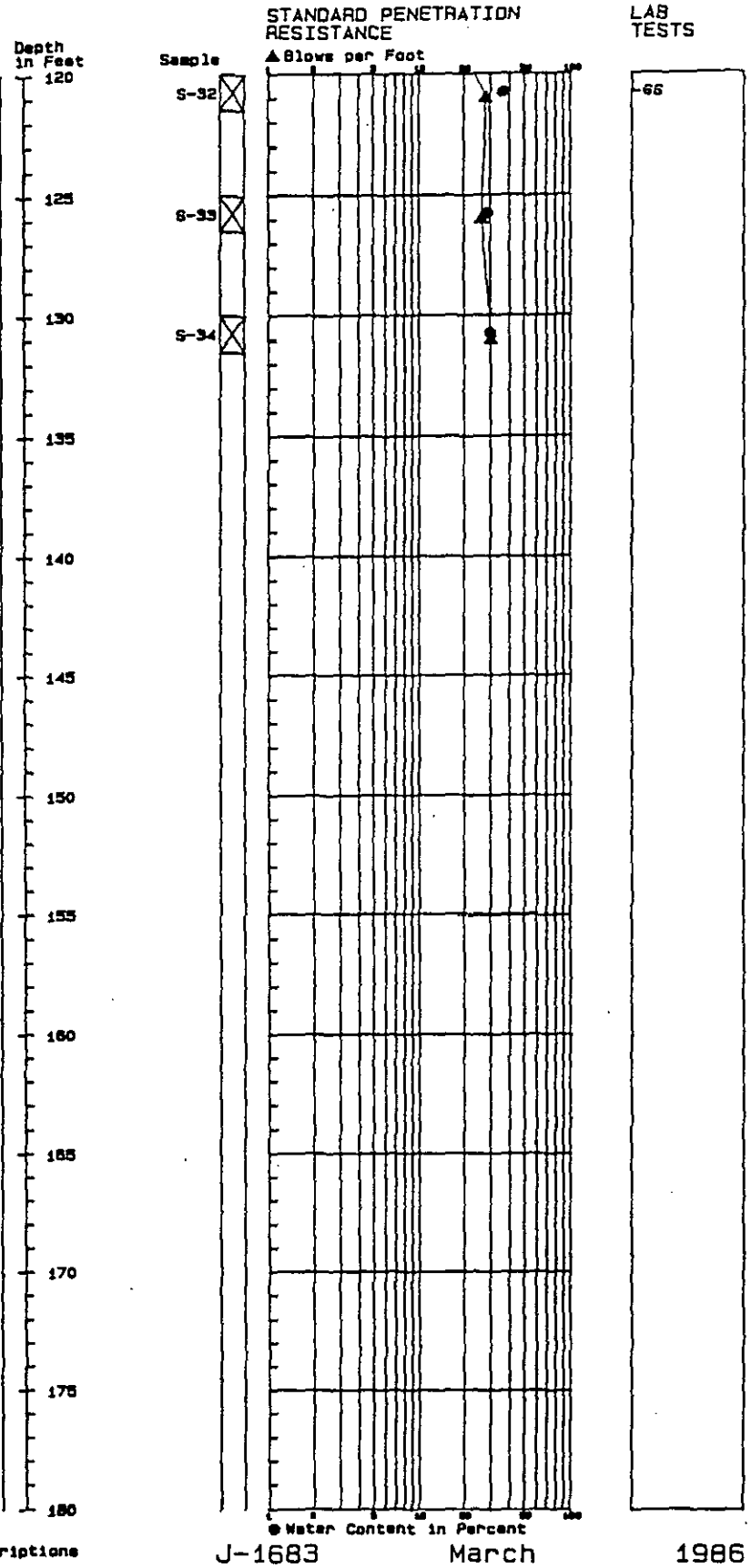
Boring Log SEB-1

SOIL DESCRIPTIONS

Approximate Mudline Elevation in Feet -25.0(MLLW)

Medium dense, wet, gray, silty fine SAND.

Bottom of Boring at 131.5 Feet.
Completed 3/22/86.



1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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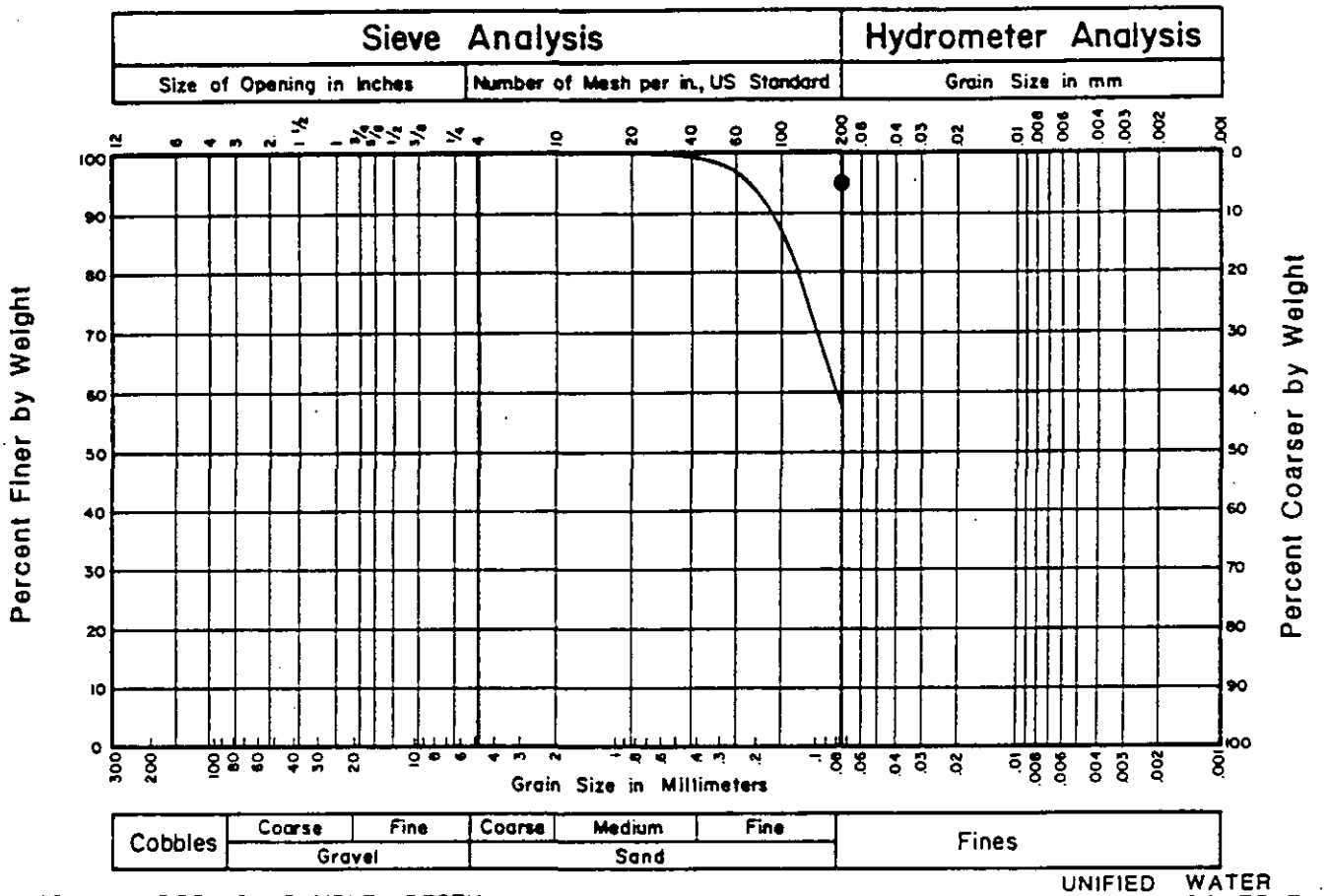
Sheet 3 of 3 Figure A-3

Grain Size Classification



LINE SYMBOL	BORING NUMBER	SAMPLE NUMBER	DEPTH IN FEET	CLASSIFICATION	UNIFIED SOIL CLASS.	WATER CONTENT PERCENT
●	SEB-1	S-28	100.0-101.5	SILT		37
———	SEB-1	S-3	6.3-6.9	Very sandy SILT		33

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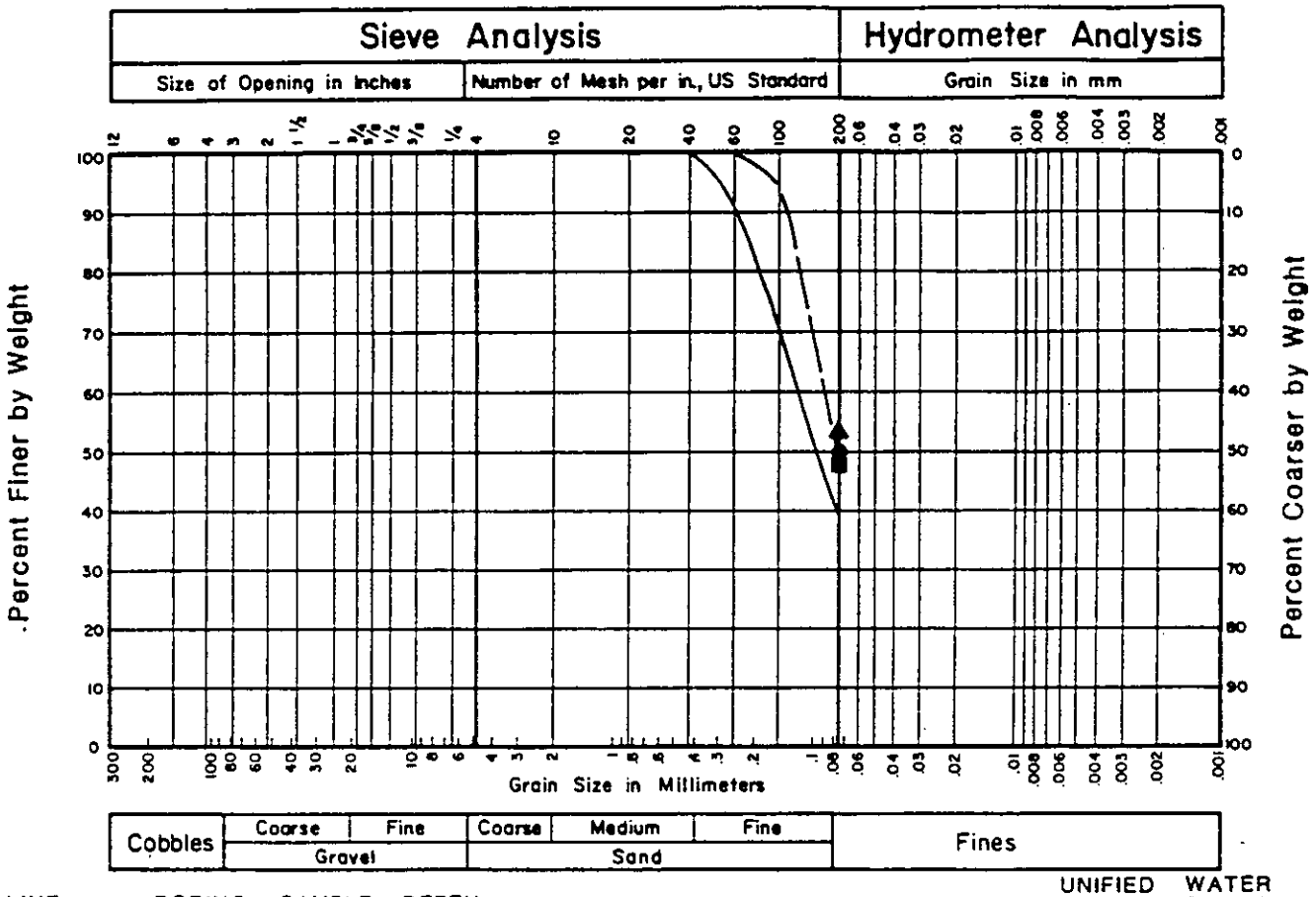
Figure B-2

Grain Size Classification



LINE SYMBOL	BORING NUMBER	SAMPLE NUMBER	DEPTH IN FEET	CLASSIFICATION	UNIFIED SOIL CLASS.	WATER CONTENT PERCENT
●	SEB-1	S-5	10.0-12.0	Very silty SAND		32
———	SEB-1	S-6	12.0-13.5	Very silty, fine SAND	SM	32
▲	SEB-1	S-7	15.5-15.7	Very sandy SILT		32
—— —	SEB-1	S-7	16.0-16.5	Very silty, fine SAND	SM	34
■	SEB-1	S-8	17.0-18.5	Very silty SAND		31

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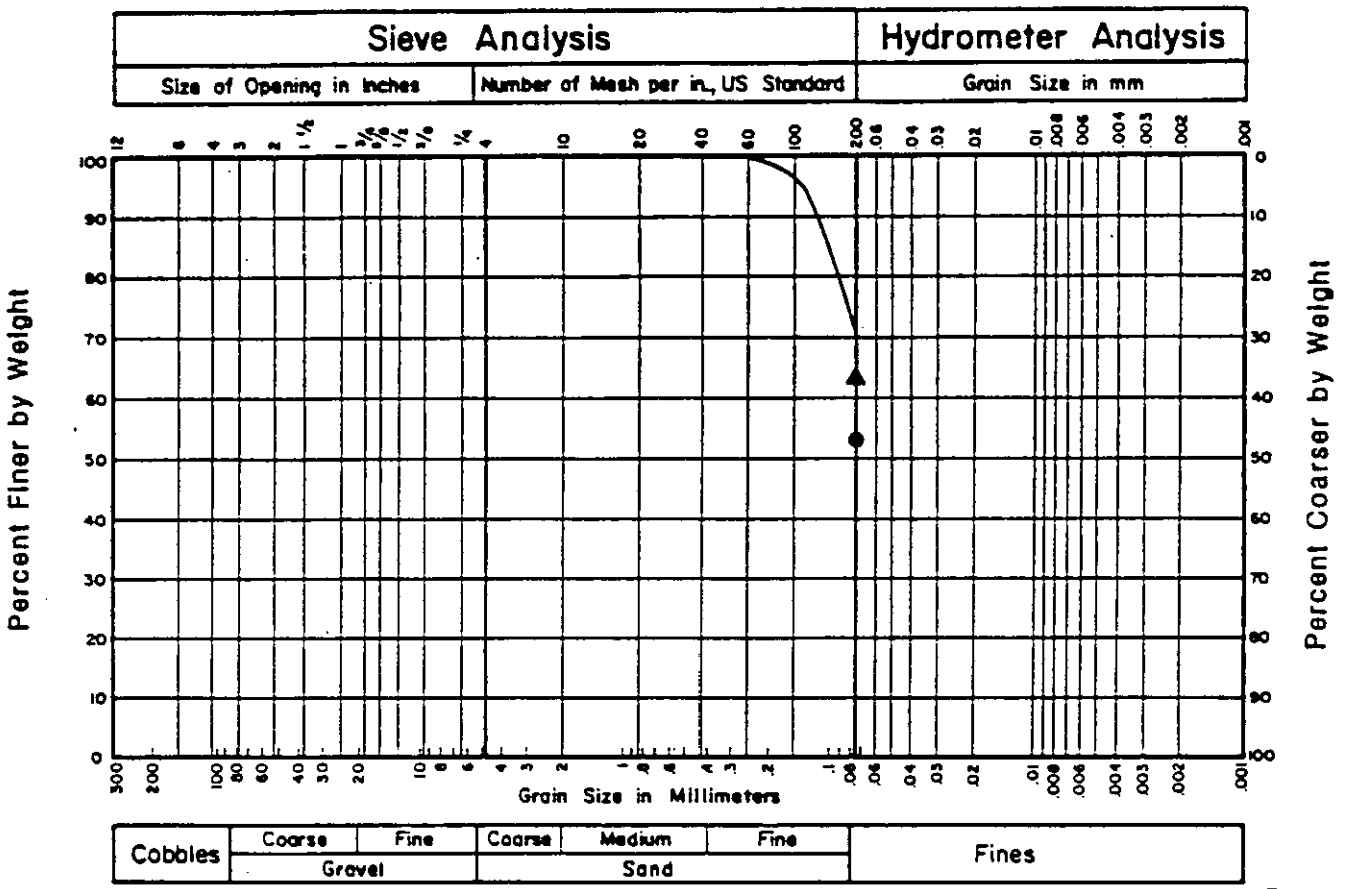
Figure B-3

Grain Size Classification



LINE SYMBOL	BORING NUMBER	SAMPLE NUMBER	DEPTH IN FEET	CLASSIFICATION	UNIFIED SOIL CLASS.	WATER CONTENT PERCENT
●	SEB-1	S-9	21.3-21.4	Very sandy SILT		33
▲	SEB-1	S-11	25.0-26.5	Very sandy SILT		36
———	SEB-1	S-12	31.3-31.8	Sandy SILT	ML	32

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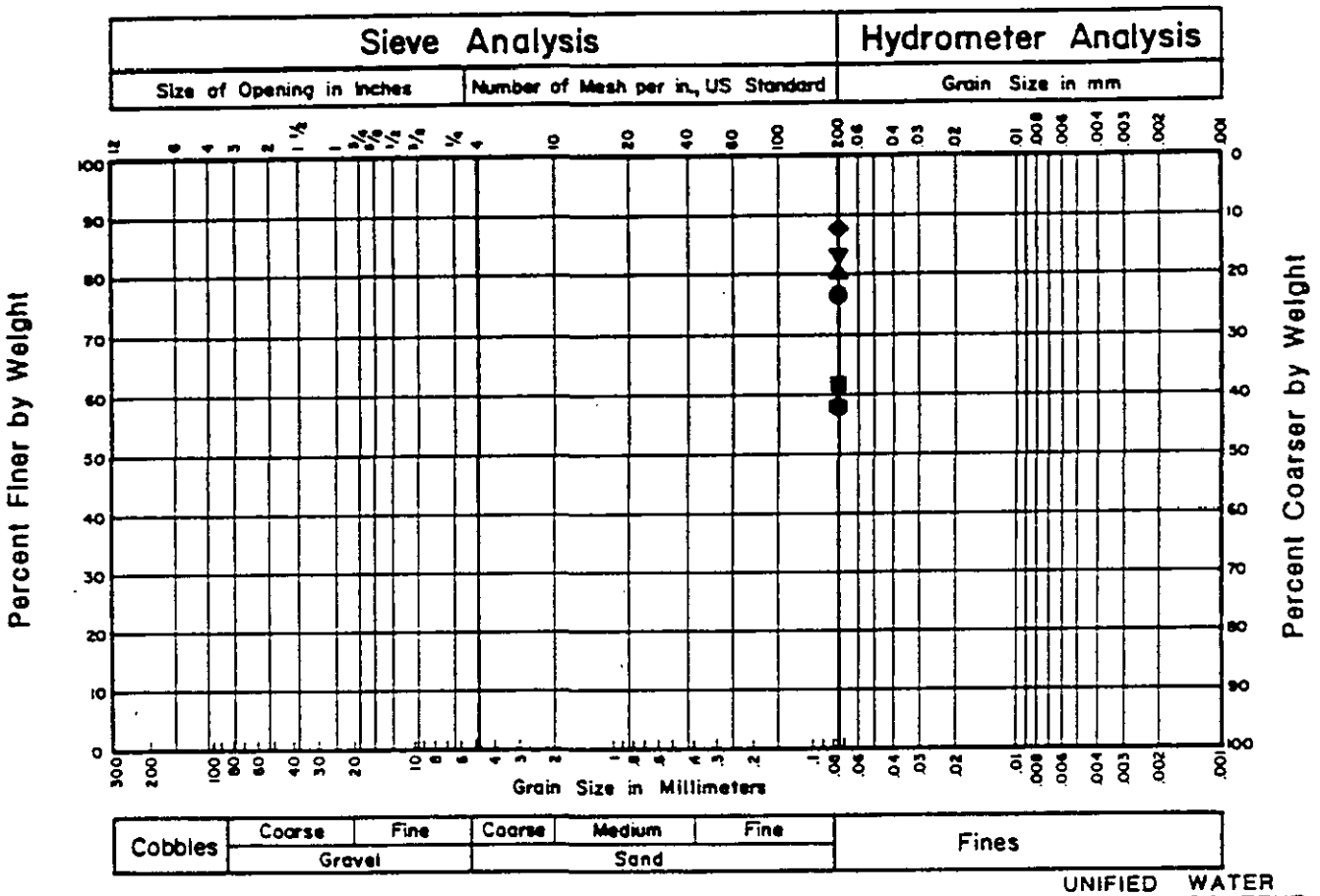
Figure B-4

Grain Size Classification



LINE SYMBOL	BORING NUMBER	SAMPLE NUMBER	DEPTH IN FEET	CLASSIFICATION	UNIFIED SOIL CLASS.	WATER CONTENT PERCENT
●	SEB-1	S-13	32.0-33.5	Sandy SILT		35
▲	SEB-1	S-14	35.0-36.5	Sandy SILT		35
■	SEB-1	S-15	41.3-41.4	Very sandy SILT		35
▼	SEB-1	S-17	45.0-46.5	Sandy SILT		32
◆	SEB-1	S-19	55.0-56.5	Sandy SILT		34
⬢	SEB-1	S-22	70.0 71.5	Very sandy SILT		31

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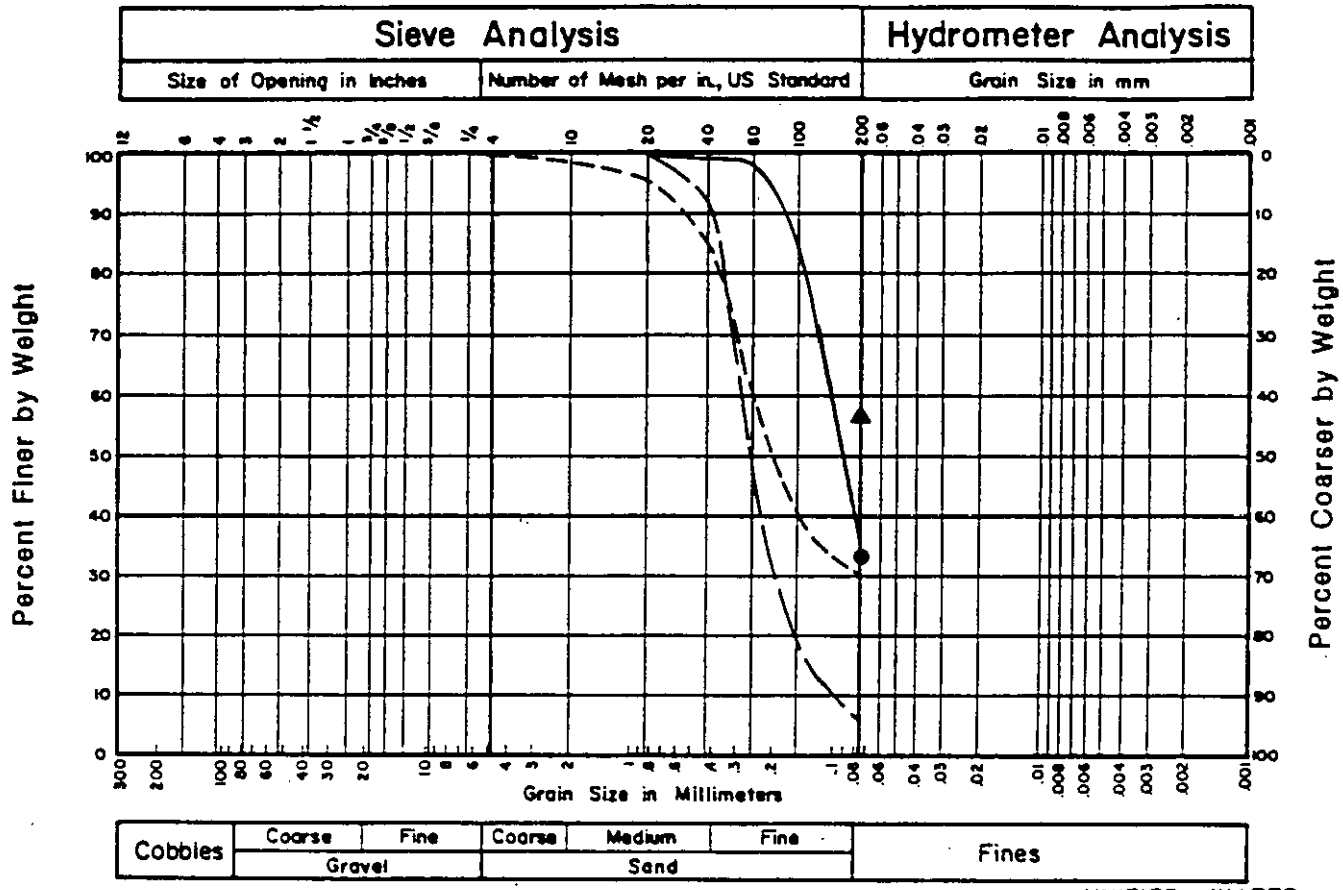
Figure B-5

Grain Size Classification



LINE SYMBOL	BORING NUMBER	SAMPLE NUMBER	DEPTH IN FEET	CLASSIFICATION	UNIFIED SOIL CLASS.	WATER CONTENT PERCENT
———	SEB-1	S-23	75.0-76.5	Very silty, fine SAND	SM	30
●	SEB-1	S-26	90.0-91.5	Very silty SAND		33
▲	SEB-1	S-27	95.0-96.5	Very sandy SILT		32
— —	SEPB-1	S-1	90.0 - 91.5	Slightly silty, medium to fine SAND	SP-SM	30
- - - - -	SEPB-1	S-2	95.0-96.5	Silty, medium to fine SAND	SM	27

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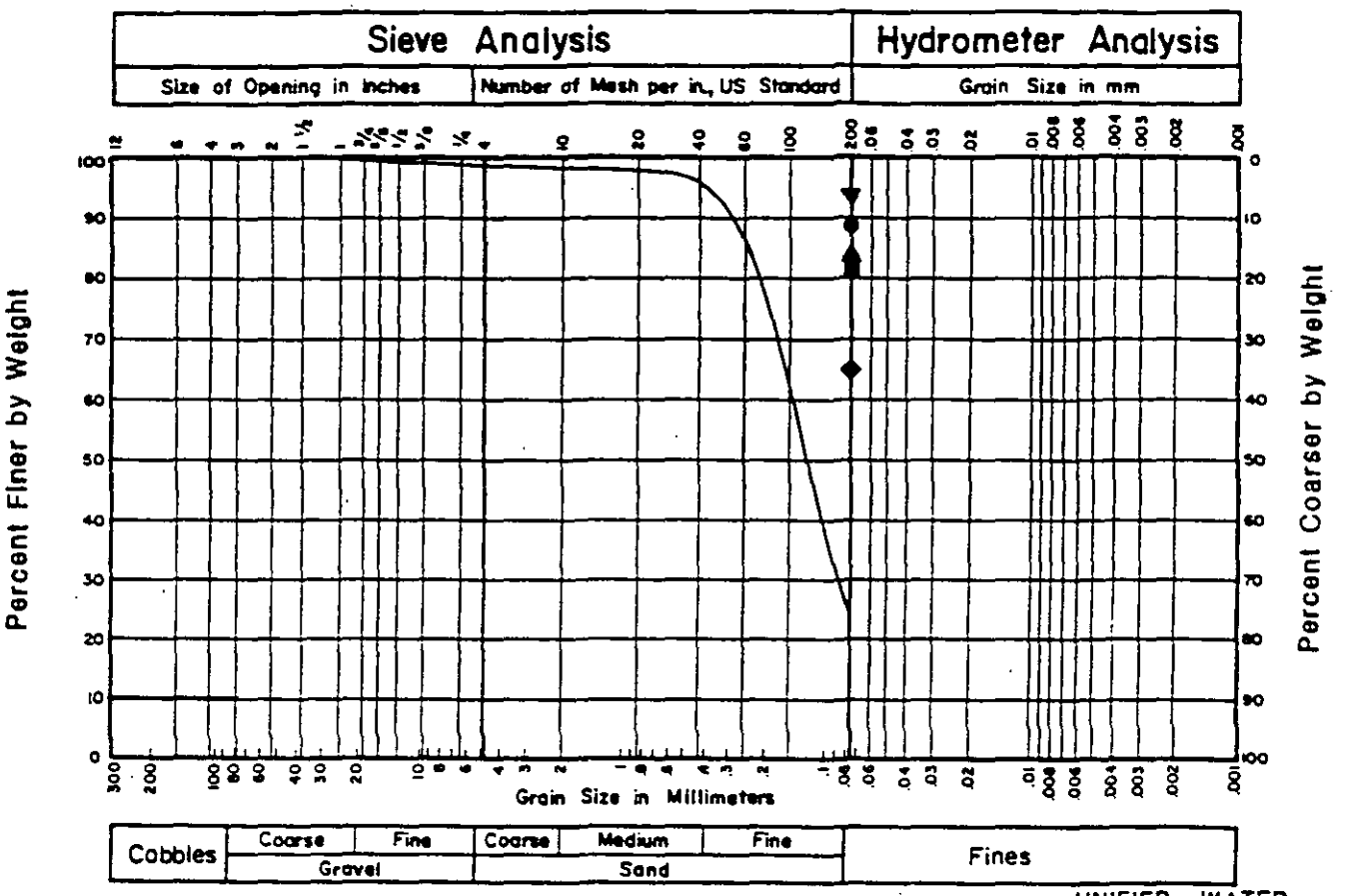
Figure B-6

Grain Size Classification



LINE SYMBOL	BORING NUMBER	SAMPLE NUMBER	DEPTH IN FEET	CLASSIFICATION	UNIFIED SOIL CLASS.	WATER CONTENT PERCENT
●	SEB-1	S-29	105.0-106.5	Slightly sandy SILT		35
———	SEB-1	S-32	120.0-121.5	Silty, fine SAND	SM	35
▲	SEPB-1	S-3	100.0-101.5	Sandy SILT		36
■	SEPB-1	S-4	105.0-106.5	Sandy SILT		33
▼	SEPB-1	S-6	115.0-116.5	Slightly sandy SILT		33
◆	SEPB-1	S-8	125.0-126.5	Very sandy SILT		31

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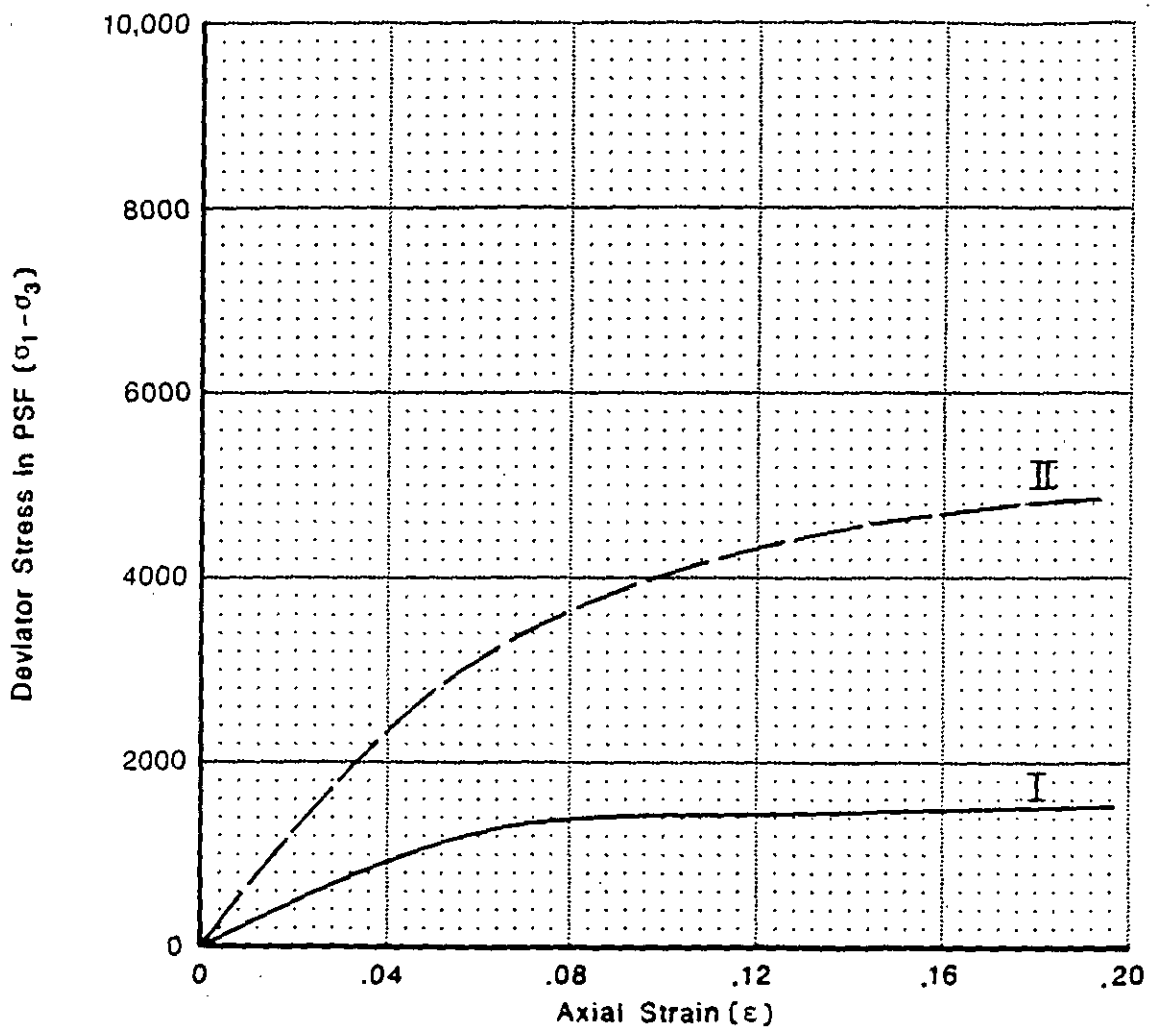
Figure B-7

Triaxial Compression Tests
Unconsolidated, Undrained



TEST NUMBER	EXPLOR NUMBER	SAMPLE NUMBER	DEPTH IN FEET	U.S.C.	DESCRIPTION
I	SEB-1	S-3	6.3- 6.8	ML	Very sandy SILT
II	SEB-1	S-12	31.3-31.8	ML	Sandy SILT

TEST NUMBER	WATER CONTENT IN PERCENT NAT.	L.L.	P.L.	P.I.	WET UNIT WEIGHT IN PCF	PRESSURE IN PSI CELL	BACK	SHEAR STRENGTH (S_u) IN PSF	STRAIN AT FAILURE (ε_f)
I	35	Non-Plastic			119	5		760	.20
II	32	Non-Plastic			121	20	0	2440	.20

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Figure B-8

Boring Log SEPB-1

SOIL DESCRIPTIONS

Approximate Mudline Elevation in Feet -35.0(MLLW)

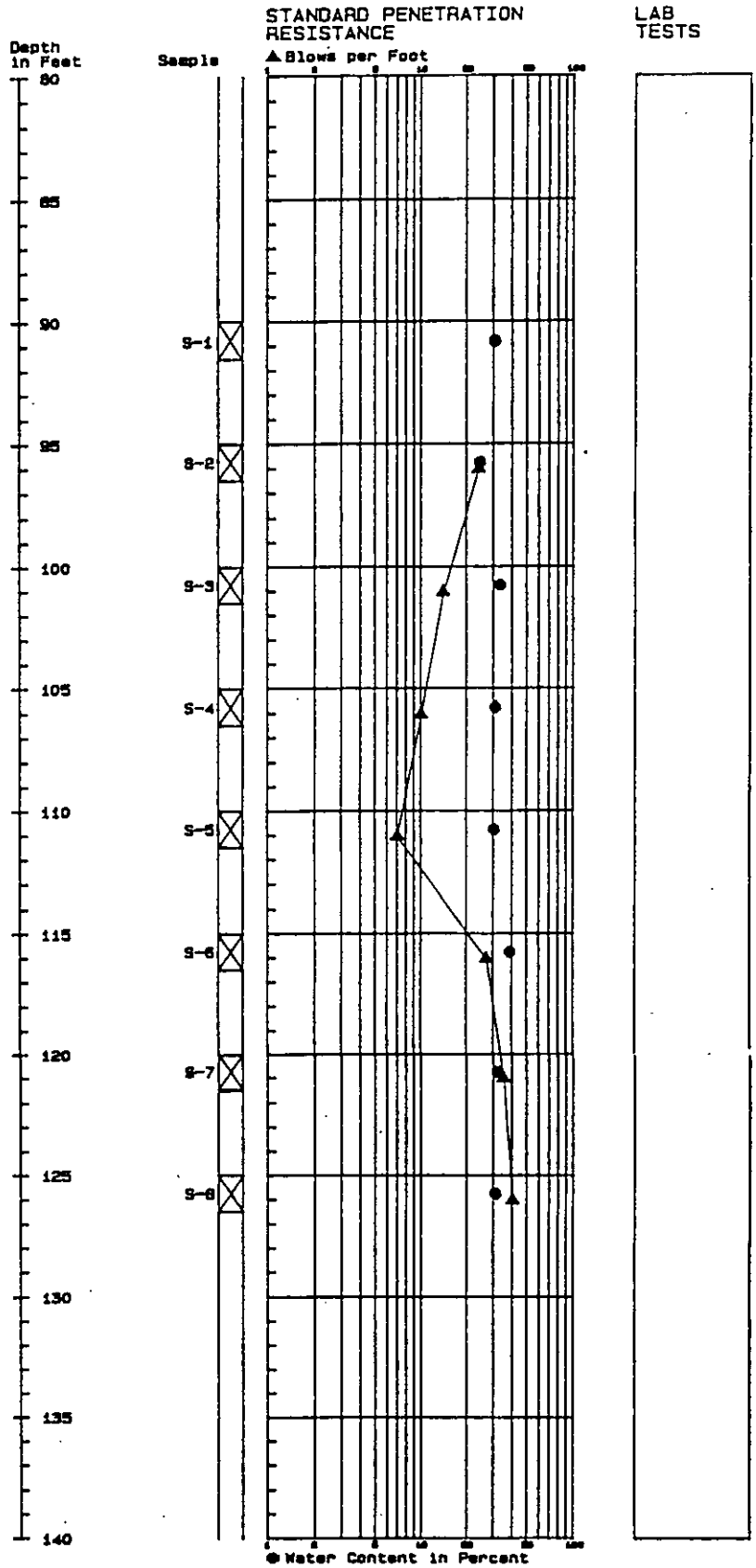
Drilled, unsampled to 90 feet adjacent to Probe location.
(See sheet 1 of 2)

Medium dense, wet, gray, slightly silty to silty, medium to fine SAND.

Medium stiff to hard, wet, gray, slightly sandy to sandy SILT.

Hard, wet, gray, sandy SILT.

Bottom of Boring at 126.5 Feet.
Completed 3/23/86.



1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Soil descriptions and stratum lines are interpretive and actual changes may be gradual.
3. Ground water level, if indicated, is at time of drilling (ATD) or for date specified. Level may vary with time.

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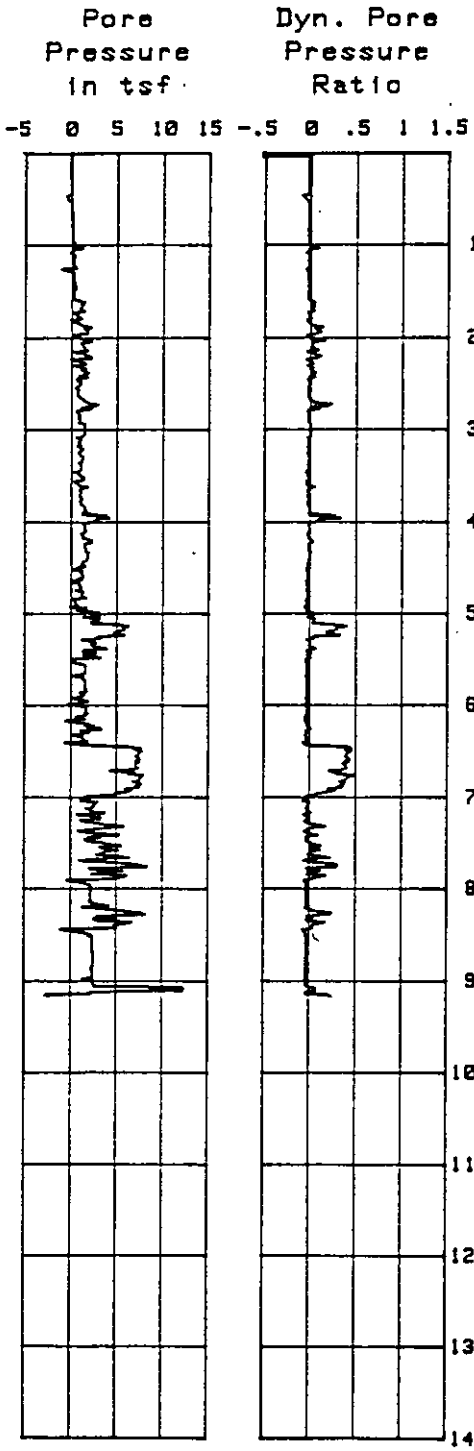
Sheet 2 of 2 Figure A-4

Probe Log SEBP-1



Soil Interpretation

Loose to medium dense, silty SAND and sandy SILT.

Medium dense, silty SAND with sandy SILT interbeds

Medium stiff, slightly clayey SILT.

Medium dense, silty, fine SAND.

Medium dense to dense, slightly silty SAND.

Bottom of Probe at 92.0 Feet.
Completed 3/20/86.

Note: Auger boring drilled from 90 to 126-1/2 feet. (See Sheet 2 of 2)

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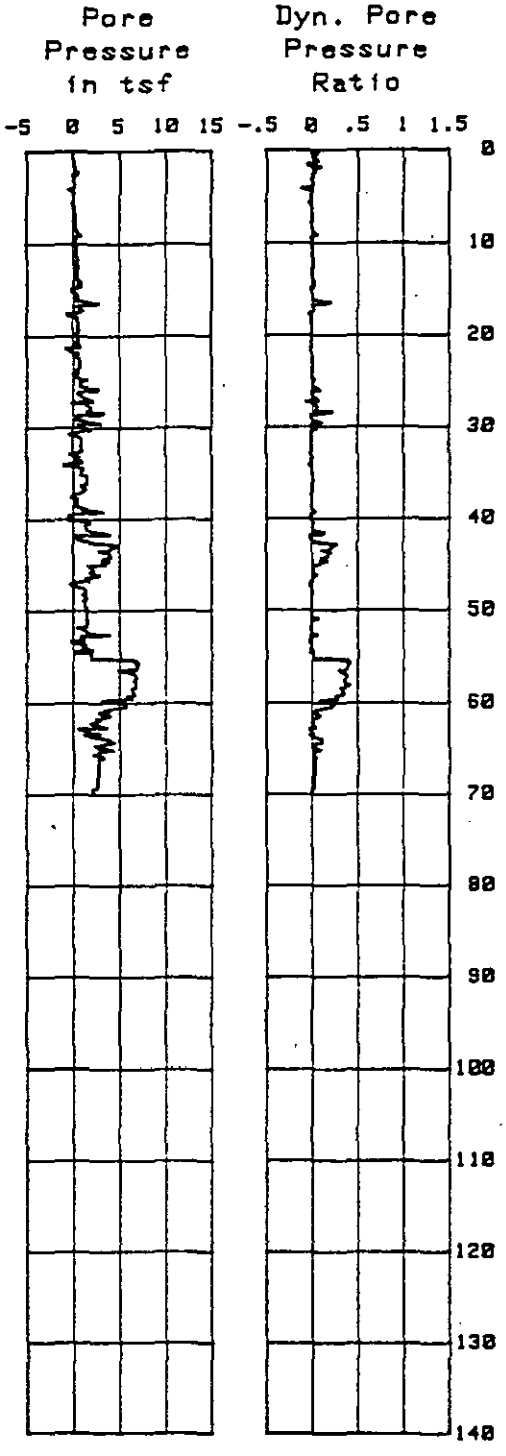
Sheet 1 of 2 Figure A-4

Probe Log SEP-1A



Soil Interpretation

Soft SILT.

Loose to medium dense, silty SAND.

Medium dense, silty SAND with sandy SILT interbeds.

Bottom of Probe at 70.0 Feet.
Completed 3/20/86.

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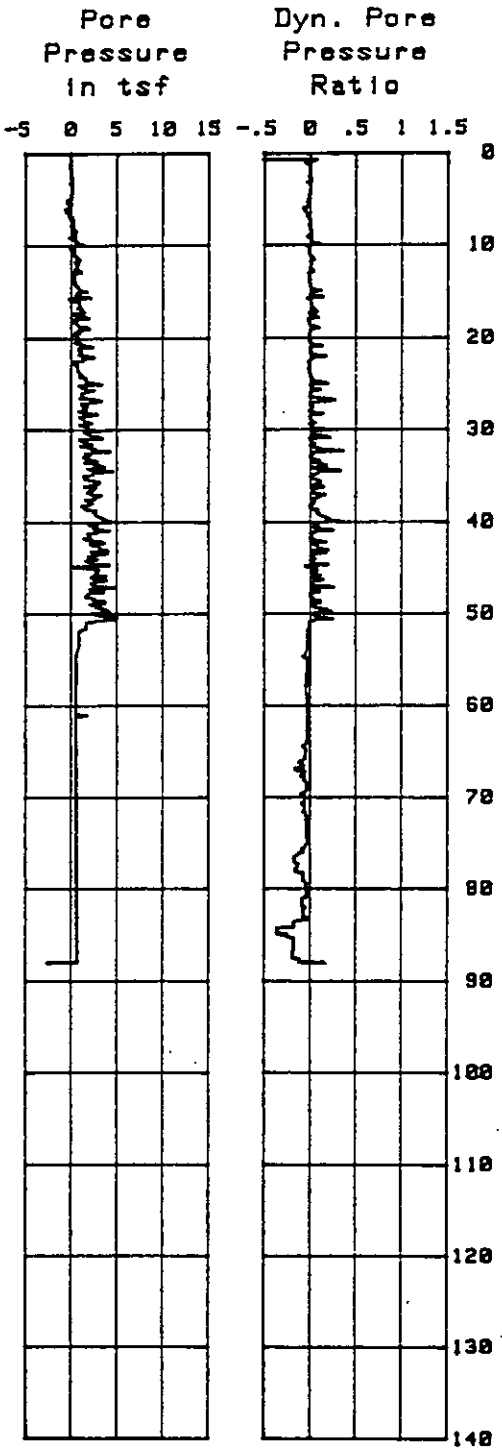
Figure A-5

Probe Log SEP-2



Soil Interpretation

Very soft to soft, sandy SILT.

Loose to medium dense, silty SAND and sandy SILT.

Medium dense to dense, silty SAND.

Bottom of Probe at 87.0 Feet.
Completed 3/21/86.

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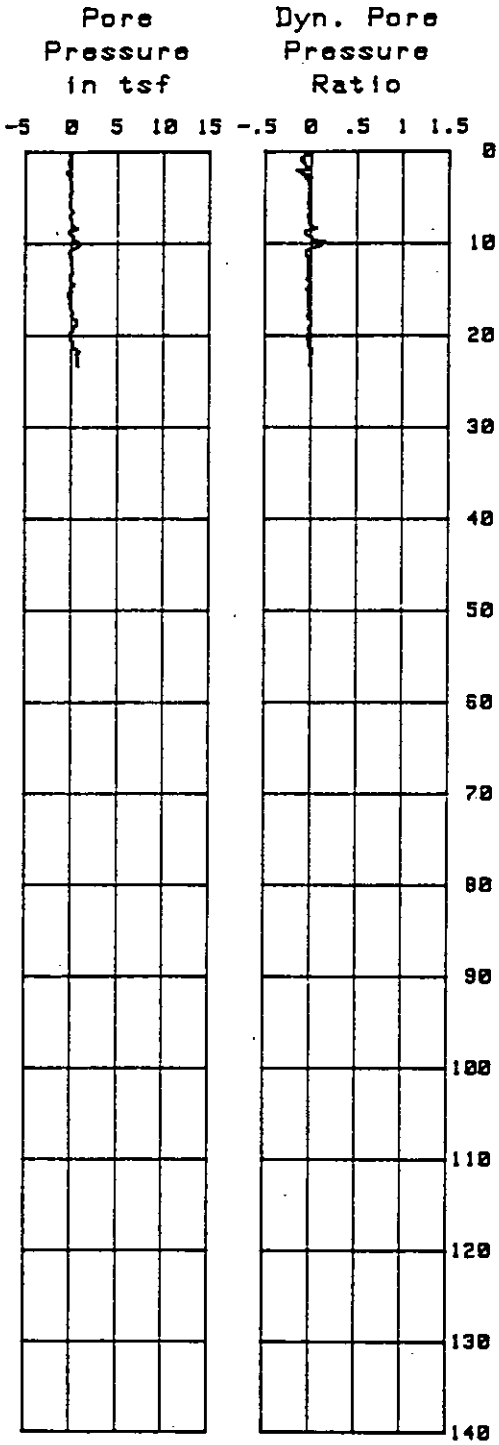
Figure A-6

Probe Log SEP-3



Soil Interpretation

0	Very soft to soft, sandy SILT grading sandier with depth.
10	Loose to medium dense, silty SAND.
20	
30	Bottom of Probe at 22.5 Feet. Completed 3/21/86.

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Figure A-7