APPENDIX 2H

ROCK STRESS MEASUREMENTS IN BORING **OC1A**

The information contained in this appendix was not revised, but has been extracted from the original FSAR and is provided for historical information.

SEABROOK STATION

ROCK STRESS MEASUREMENTS
IN BORING OC1A

for

Yankee Atomic Electric Company
and
Public Service Company of New Hampshire

September 1973

by

Geotechnical Engineers, Inc.
934 Main Street
Winchester, Massachusetts 01890

SEABROOK STATION

ROCK STRESS MEASUREMENTS
IN BORING OC1A

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SUMMARY

Rock stress measurements were made in June and July 19'73 at depths of 33 ft to 42 ft in vertical Boring OC1A, which is about 34 ft from the center of proposed Reactor No. 1 of Seabrook Station.

The results of five measurements of compressive stresses in the horizontal plane were:

Largest stress:	1240 psi (150 to 2150 psi)
Smallest stress:	860 psi (50 to 1570 psi)

The vertical stress can be assumed equal to the overburden stress of about 50 psi. The average direction of the largest stress in the horizontal plane was N 40 E ($\pm$ 36°). These results compare well with other stress measurements in New England. (Fig. 18).

The rock at this location consists of a medium-grained, massive, quartz-diorite that contains pegmatitie dikes ranging in thickness from inches to two feet. See Figs. 2 and 3 for logs of Boring OC1A and El-l. The latter hole is NX-size and is located at the center of proposed Reactor No. 1.

The stress measurements were made by inserting a 6-arm borehole gage in a 1.5 in. diameter hole and overcoring with a bit that cuts a 4.31 in. diameter core around the inner hole. The rock modulus was measured by testing the annular core in a cell constructed to apply stress to the exterior of the annulus while making deformation measurements in the inner hole with the borehole gage.

SEA BROOK STATION

ROCK STRESS MEASUREMENTS
IN BORING OC1A

for

Yankee Atomic Electric Company

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Geotechnical Engineers, Inc. September 10, 1973

1. INTRODUCTION

1.1 Background

Measurements of seismic velocities in the bedrock at the plant site at Seabrook Station were made in the spring of 1969 by Weston Geophysical Research. These measurements indicated that the velocity in the Newburyport granodiorite ranged from 16500 fps to 18500 fps, whereas in the Kittery Schist the velocity was about 13000 fps. The velocities in the granodiorite were slightly on the high side, although not unusual in the area, and could be taken as a possible indication of in-situ stresses in the bedrock. Therefore, a modest program of stress measurement was undertaken in the zone where high velocities were measured at the location of one of the two proposed reactors. The measurements were made during June and July 1973.

1.2 Purpose

The purpose of this report is to present the results of measurements of in-situ stresses in the Newburyport granodiorite in vertical Boring OC1A at a depth of 31 to 43 ft using the overcoring technique. The coordinates of this hole are N20413, E796'71.

1.3 Scope

One hole was drilled near the center of proposed Reactor #1 at Seabrook Station for the purpose of measuring in-situ stresses. Eleven measurements

were made using the overcoring technique. Each measurement consisted of three deformation readings in the horizontal plane on axes oriented 120^{o} apart. Of the eleven attempts, the data from five of the measurements, at depths of 33 ft 9 in. to 41 ft 5 in., were deemed suitable for analysis and are reported herein. The other measurements gave poor or marginal information because of rock fracture and /or equipment breakdown during overcoring.

Moduli of elasticity of the rock were measured (a) on two annular cylinders of rock removed after overcoring, and (b) intact specimens oriented such that the load was' applied in the direction of the axis that was horizontal in-situ. These moduli were used with the measured deformations and published formulae to compute the magnitude and direction of the largest and smallest normal stresses in the horizontal plane. The vertical stress was assumed to be *equal* to the overburden *pressure.*

The test procedures used are described in detail in Appendix A and B.

The tests were carried out in the field by Pierre Le Francois under the direction of Geotechnical Engineers Inc. The drilling was performed by the American Drilling and Boring Company.

2. METHOD OF MEASUREMENT

2.1 General

The overcoring technique consists of three phases:

1. Measurement of borehole expansion during overcoring.

2. Determination of the modulus of elasticity of the rock, for rebound to zero stress, preferably at the point of measurement, and

3. Computation of stresses using the theory of linear elasticity and the measured deformations and moduli.

Each of the above steps are described briefly in subsequent subsections.

2.2 The Overcoring Technique

Fig. 1 is a sketch of the appearance of the hole during overcoring. A PX hole, 5. O-in. diameter, was first drilled with a single-tube core barrel to the desired depth. In this case, this depth was the shallowest at which the rock was continuous enough to be tested, which turned out to be 31 to 43 ft below ground surface. Logs of Boring OC1A and Boring E1-1 (NX-size), which are about 14 ft apart, are shown in Figs. 2 and 3, respectively.

An EX single-tube core barrel, 1.5 in, 0. D. , was then carefully centered in the bottom of the PX hole and drilled to a depth of about 2 ft. The recovered EX core was examined to determine whether the rock was sufficiently continuous to attempt a measurement. If the core was unbroken, or only jointed once or twice, then an attempt was made.

The borehole gage, which is described in Subsection 2.3, was then lowered into the hole using orientation rods. These rods were used to preserve the orientation of the measuring points and for measuring depths accurately when the borehole gage was lowered into the hole. The measuring points on the borehole gage were at least 3.5 in. below the bottom of the PX core barrel (Fig. 1) so that a minimum depth of overcoring would be needed for a measurement, and to allow two measurements for each EX run if the rock did not break.

Overcoring with the PX single-tube core barrel was then carried out. Readings of deformation on three axes 120^{o} apart in the horizontal plane were taken continuously until the PX core barrel was about 5 in. below the measuring points, or until the readings stopped changing rapidly.

The procedure for carrying out each measurement is described in detail in Appendix A.

2.3 The Borehole Gage

A photograph of the instrument, the hose, the readout, and the pressure application system is shown in Fig. 4. The instrument, without its vinyl sheath, is shown in Fig. 5. The deformation is measured by bending of the cantilevers that are seen at the left in Fig. 5. The readout of the strain gages on the cantilever arms is proportional to the movement of the tips of the cantilevers. In this instrument three pairs of cantilevers were installed 120° apart. In principle only three cantilevers are needed, but a fourth is necessary to be able to compute body movement of the instrument within the hole. To eliminate this computation, the cantilevers were installed in pairs such that body movements cause zero output on the readout device. The instrument was designed and constructed by Pierre Le Francois.

The tips of the cantilevers are attached to the vinyl sheath, Fig. 4, such that when air pressure (or bottlednitrogen pressure) is applied inside, the cantilevers are forced against the side of the hole. Hence the hose serves the dual purpose of protecting the strain gage leads and passing air to the instrument. The readout is made on a conventional strain gage indicator.

2.4 Measurement of Modulus of Rock

To obtain the best value of the modulus of elasticity of the rock in the zone tested, it is necessary to remove the overcored annular cylinder of rock from the hole and test it in a rock modulus cell. In Fig. 6 an annular core is shown in the cell with the borehole gage in the central hole of the core. To determine the modulus one applies pressure to the outside of the core, up to about 3000 psi, and then removes it in increments, measuring the deformation of the central hole for each pressure decrement. In this way one reproduces reasonably well in the core the stresses that it underwent during overcoring. The details of the measurement procedure are given in Appendix B.

In the present case the rock in Boring OC1A, at the measuring points, was so broken up that only two satisfactory annular cores of sufficient length (16 in.) were recovered. They both contained slightly healed joints that broke during testing, although satisfactory results were obtained from both.

'To supplement the measurement of modulus on the annular cores, intact specimens of rock from Boring OC1A, from depths where stress measurements were made, were tested in unconfined compression. The specimens were loaded in the direction of the axis that was horizontal in-situ so that the load was in the same direction as in situ. The rebound modulus of these specimens was measured with the aid of strain gages glued on the sides of the specimens.

2.5 Computation of Stresses

The major and minor stresses in the horizontal plane were computed from the measurements using the following formulae from Obert (1 966):

$$p = \frac{Ek}{6d} (R_1 + R_2 + R_3) \qquad (1)$$

$$q = \frac{\sqrt{2}\,Ek}{12d} \sqrt{(R_1 - R_2)^2 + (R_2 - R_3)^2 + (R_3 - R_1)^2} \qquad (2)$$

where:

p = Stress at center of Mohr circles of stress, psi
q = Radius of Mohr circle of stress , psi
E= Modulus of elasticity measured for same stress changes as occurred in situ, psi
d = Diameter of central hole in which instrument is placed, in.
kR = Horizontal expansion of the diameter of the borehole during overcoring. The subscripts refer to axes that are 120° apart in the plane perpendicular to the axis of the borehole gage - in this case horizontal. R is the reading in microinches/inch ($\mu\epsilon$) and k is the instrument calibration in in. /$\mu\epsilon$

From the values p and q one can compute the largest and smallest stresses in the plane perpendicular to the axis of the borehole gage from:

$$\sigma_I = p + q \qquad (3)$$

$$p_I = p - q \qquad (4)$$

The direction of stress σ_I is obtained from the formula: 1):

$$\alpha = 1/2 \tan^{-1} \frac{\sqrt{3}\,(R_2 - R_3)}{2R_1 - (R_2 + R_3)} \qquad (5)$$

where: α = angle measured from the direction of R_1 to the direction of σ_I in the counterclockwise direction.

Reference (1) Obert, Leonard (1966) "Determination of the Stress in Rock - A State of the Art Report," Presented at the 69th Annual Meeting of the ASTM, Atlantic City.

1) Eq. (5) contains $\sqrt{3}$ in the argument rather than 3, which was shown in the Reference (1) by error, but was correct in an earlier reference.

Equation (5) is subject to the following restrictions:

If $R_2 > R_3$ and $R_2 + R_3 < 2R_1$, then $0 < \alpha < 45^\circ$

and $R_2 + R_3 > 2R_1$, then $45^\circ < \alpha < 90^\circ$

If $R_2 < R_3$ and $R_2 + R_3 > 2R_1$, then $90^\circ < \alpha < 135^\circ$

and $R_2 + R_3 < 2R_1$, then $135^\circ < \alpha < 180^\circ$

All but Eq. (5) above are based on the assumption that a plane stress condition exists at the measuring point in situ, i.e. that the vertical stress is zero. Since the vertical stress is very close to the overburden stress of about. 50 psi, which is small compared to the magnitude of horizontal stresses of interest, the plane stress assumption is appropriate in this case. Hence the computed stresses are dependent only on the modulus of elasticity and not on Poisson's ratio of the rock.

3. TEST DATA AND RESULTS

3.1 Calibrations

The results of calibrations of the instrument and measurements of rock modulus are shown in Table 1. Direct calibration of Instrument, No, 2 with a micrometer yielded k = 10 μ in. /$\mu\epsilon$. Since 5$\mu\epsilon$ can be read, the instrument can be used to discern movements in the borehole as small as 5 x 10^{-5}in. Instrument, No. 1 was not calibrated directly, but it is capable of discerning movements of 2 x 10^{-5}in. in the borehole.

The borehole gages were calibrated under conditions similar to in-situ conditions by using an annular aluminum cylinder of known modulus (10 x 10^6 psi) as a standard. Table 1 shows that Instrument No. 2 yielded k = 8.6 μ in./$\mu\epsilon$, as compared with 10 μ in./$\mu\epsilon$ for the direct calibration above. Since the calibration in the rock modulus cell models very closely the in-situ testing conditions and since the modulus of aluminum is well known, the value of k = 8.6 μ in. /$\mu\epsilon$ for Instrument No. 2 is the better value and was used herein. * Similarly k = 4.4 μ in./$\mu\epsilon$ was used for Instrument No. 1.

Two annular cores of granodiorite were retrieved that could be tested in the rock modulus cell. The second of these, near tests OC1A-8/9, broke and had to be glued with epoxy to complete the test, The results in Table 1 show that the moduli of the two cores were 4.1 and 3.0 x 10^6 psi. The modulus for the pegmatite (Test OC1A-2) was assumed to be 4.1 x 10^6 psi also since it was harder but seemed to contain a greater number of healed joints than the granodiorite.

As a check on the modulus values obtained for the annular cores of granodiorite, additional tests were made by cutting 1.2 in. cube samples from some of the broken cores, gluing on strain gages, and loading them horizontally . The moduli were:

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*The direct calibration was made without the vinyl sheath in place. The cantilevers were therefore unstressed. When the gage is in the borehole, the cantilevers are stressed to half their elastic limit. Hence, the direct calibration is not as appropriate as the calibration which makes use of a standard annular cylinder.

From Test	Rock*	Rebound Modulus 10^6 psi
OC1A-2	Granodiorite	12
OC1A-2	Pegmatite	12
OC1A-3	Granodiorite	5
OC1A-7	Granodiorite	11

* Specimens were cubes 1.2 in. on a side.

The range of possible moduli of the granodiorite is from about 3 to 12×10^6 psi. The larger values were measured on small intact specimens using strain gages, whereas the smaller values were measured on the annular *cores* using a loading sys tern and measuring device which were identical for practical purposes to in situ conditions. Hence the moduli used in the computations were those measured on the annular cores. The fact that one intact specimen of granodiorite had a modulus of only 5×10^6 psi gives some confidence in the use of a still lower modulus for the large annular cores, because they can be expected to contain more defects than the smaller specimens.

3.2 In Situ Stresses and Directions

Table 2 shows the test conditions and the computed calibrations and moduli. Table 3 shows the readings selected from the data in Figs. 7 to 11 together with the stresses and directions computed from Eys. (3), (4), and (5). The dimensions of the overcored hole for each test are shown in Figs. 12-16, and photographs of the annular cores recovered, including the ones for which moduli were measured, are shown in Fig. 17.

Fig. 18 shows to scale the computed stresses and directions for the best estimated values. Table 3 shows the numerical values for these best estimates as well as other possible values for Tests OC1A-2, 7, and 9. These additional values arise from alternate selections of the changes in reading from Figs. 7, 10, and 11.

The largest normal stress in the horizontal plane (σ_I) is compressive, ranges from 150 to 2150 psi, and averages 1240 psi. The smallest normal stress in the horizontal plane (σ_{II}) is also compressive, ranges from 50 to 1570 psi, and averages 860 psi. The direction of σ_I is N 40 E $\pm$, 36°. In giving this direction,the direction for Test OC1A-5 is neglected because the stress was so small in that test that the computed direction is not meaningful.

4. DISCUSSION OF RESULTS

The stresses and directions in Fig. 18 show that the direction of the major stress in the horizontal plane is generally NE-SW. The magnitude of this stress is best taken as the average of the five satisfactory measurements, since inherent variations in the stress and direction can occur within any given block of rock in situ, particularly near surface. This average is 1240 psi (87 bars) for the major stress and 860 psi (61 bars) for the minor stress in the horizontal plane. The vertical stress is assumed equal to the overburden pressure of about. 50 psi,

At the bottom of Fig. 18 is a tabulation of some known previous stress measurements in New England (Sbar and Sykes, 1973). The general agreement. between the stresses at Seabrook and those elsewhere in New England is clear. The direction of the major stress is also in reasonable agreement. The range of error in the computed direction, simply due to alternate selections of the changes that occurred during overcoring, is such as to place all of the earlier values essentially within the possible total range for the present case.

It should be noted that the technique used herein for modulus measurement is really nothingmore than a method for reapplying the in-situ stresses under laboratory conditions. Hence the computed stresses are in fact independent of the absolute values of the modulus and the instrument calibration constant. If the researchers who made the previous measurements did not use a similar approach, then the agreement of all the data may be fortuitous.

By measuring the deformation of an annular specimen of rock in the laboratory one eliminates many potential sources of error. However, the damage done to the core during drilling is not taken into account. If the rock in-situ contains microfractures, they may be opened during drilling of the EX and the PX holes. When this annulus is brought to the laboratory, its modulus is likely to be lower than in situ. Previous work by Obert (1962) indicates that until the stress levels reach about 50% of the crushing strength of the intact rock, the effect of stress relief is likely to be low. The effect in the present case is probably low because the crushing strength is more than four times the highest stress that was measured.

Reference (2) Sbar, M. L. and Sykes, L. R. (1973) "Contemporary Compressive Stress and Seismicity in Eastern North America: An Example of Intra-Plate Tectonics," Geological Society of America Bulletin, Volume 84, No. 6, p. 1871.

Reference (3) Obert, Leonard (1962) "Effects of Stress Relief and Other Changes in Stress on the Physical Properties of Rock," Bureau of Mines, RI 6053.

TABLES

TABLE 1 CALIBRATIONS

A. DIRECT CALIBRATION WITH MICROMETER

Inst No.	Change in Reading per 10^{-3} in. for each Channel, $\mu\epsilon$				Instrument Calibration k μ in. /$\mu\epsilon$
	R_1	R_2	R_3	Avg	
2	100	100	103	101	10

B. CALIBRATIONS USING ANNULAR CORES IN ROCK MODULUS CELL

Inst No.	Change in Reading per 10^3 psi for each Channel, $\mu\epsilon$				k	E	Medium
	R_1	R_2	R_3	R_{Avg}	μ in. /$\mu\epsilon$	10^6 psi	--
1	76	78	76	77	4.4	10	Al
2	40	41	39	40	8.6	10	Al
	41	39	39	40	8.6	10	Al
1	200	173	192	188	4.4	4.1	OC1A-4 diorite
2	135	140	130	135	8.6	3.0	OC1A-8/9 diorite

Underlined values computed using equation for thick-walled cylinder under external pressure for OD = 4.31 in, ID = 1.50 in.: $kR = 3.43\frac{p}{E}$. The quantity kR is equal to the diametral deformation. Al = Aluminum.

TABLE 2 TEST CONDITIONS FOR STRESS MEASUREMENTS

Test No.	Depth ft-in.	Inst. No.	Inst. Calib. k μin./$\mu\epsilon$	Modulus E 10^6 psi	True Azimuth Channel #1 deg.	Rock Type
OC1A-2	33 - 9½	2	8.6	4.1	285	Pegmatite
OC1A-5	36 - 9	1	4.4	4.1	165	Granodiorite
OC1A-6	38 - 3	2	8.6	4.1	285	Granodiorite
OC1A-7	39 - 3	2	8.6	3.0	255	Granodiorite
OC1A-9	41 - 5	2	8.6	3.0	240	Granodiorite

μ in. = microinches

$\mu\epsilon$ = microstrain

k = instrument calibration

E = modulus of elasticity used for computation of stresses (see Table 3)

All tests performed in vertical Boring OC1A. Coordinates 20413N; 79671E. Ground El. 28.0. Hole diameter = 5.0 in. Core O.D. = 4.3 in. Hole 0. D. in which instrument placed = 1.5 in. Of eleven attempts made to measure stresses, five were successful.

TABLE 3 DATA AND RESULTS OF STRESS MEASUREMENTS

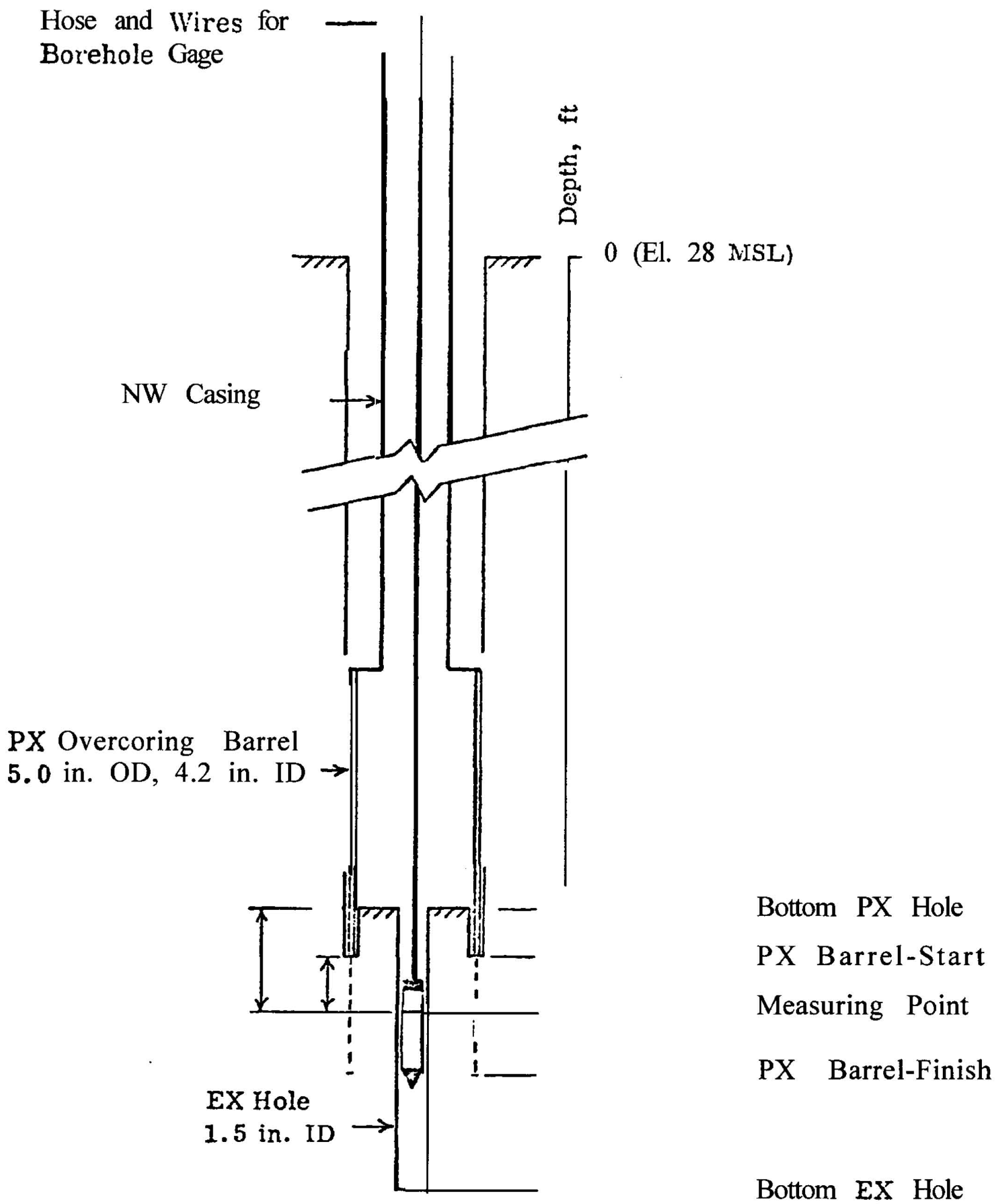
Test No.	Depth	Reading Change during Overcoring 1) 3)			Compressive Stress in Horizontal Plane 2)		True Bearing of σ_I
		R_1	R_2	R_3	σ_I	σ_{II}	
	ft-in.	$\mu\epsilon$	$\mu\epsilon$	$\mu\epsilon$	psi	psi	
OC1A-2	33 - 9½	80	95	125	1335	1025	N 38 E
		80	95	(90)	(1090)	(990)	(N 5 E)
OC1A-5	36 - 9	20	30	0	150	50	N 55 W
OC1A-6	38 - 3	60	110	90	1190	850	N 3 E
OC1A-7	39 - 3	250	150	250	2150	1570	N 45 E
		250	(200)	(200)	(2010)	(1710)	(N 75 E)
		250	150	(200)	(1970)	(1470)	(N 60 E)
OC1A-9	41 - 5	90	195	100	1400	800	N 48 E
	'	(130)	195	100	(1470)	(970)	(N 36 E)

1) Readings are shown for data from Channels 1, 2, and 3 on instrument. For all tests except OC1A-5, the numbering of the channels, each 120° apart, was counterclockwise. For OC1A-5 it was clockwise. In the equations for computation of the angle between the σ_I and the Channel 1 directions, the numbering is assumed to be clockwise. Hence for all but Test OC1A-5, R_2 and R_3 should be exchanged when computing this angle. See text for equations used for computations.

2) The vertical stress is assumed to be equal to the overburden, i.e. about 50 psi. Hence the stresses shown for the horizontal plane are close to the major and the intermediate principal stresses at each point tested.

3) Numbers in parentheses are alternate possible selections of reading changes during each test from the plots in Figs. 7, 10, and 11. These alternates are not considered quite as probable as the ones without parentheses, but they are included, together with the resulting stresses and stress directions to provide insight into the significance and dependability of the results as they are affected by this one source of error.

FIGURES



Yankee Atomic Electric Company	SEABROOK STATION	SKETCH OF HOLE DURING OVERCORING
Geotechnical Engineers, Inc. Winchester, Massachusetts	Project 7286	Sept. 10. 1973 FIG. 1

GEOTECHNICAL ENGINEERS INC

SEABROOK STATION
LOG OF BORING OC1A

Coordinates: N 20413; E 79671 | Logged by: P. LeFrancois

Top El. (MSL): 28.0 | Date Logged: August 1973

Depth (ft)	BREAKS	DIP	CONDITION OF CORE	GRAPHIC LOG	DESCRIPTIVE NOTES
30	Multiple drilling breaks		60° Joint rusty		
			30° Joint slightly rusty		Pegmatite dike, coarse grained.
			①		
					Contact: 60° dip
32			Joint set intersecting at. 30°		Quartz diorite. Dark gray, medium grain, massive texture. Quartz ~ 15%, Feldspar- 35%, Ferromag-nesium ~ 40%, Biotite ~ 10%
			Multiple joints, with pieces from 1/4" to 3" long. Dip from 20 to 70° ②		
34					Pegmatite dike, coarse grained. Contact 45° dip
			③		
					Quartz diorite as above.
36			55° Tight joint broken by drilling ④		
			⑤		
	Drilling break		35°		
38			70° Tight joint ⑥		Pegmatite dike, 2" wide, at about 40° dip.
			40° Rusted joint		
			40° Two tight joints, rusty		
			⑦		Quartz diorite as above.
40			60° Rusty joint		
			20° Rusty joint		
			40° Two tight joints ⑧		
	Drilling break		0° ⑨		
42			6 0° Tight joint		
			60° Tight joint		
	Drilling breaks		⑩		
44			⑪		

REMARKS - Log is shown, to a large scale, only for range of depth where stress measurements were attempted. Photographs of cores from tested depths are shown in Fig. 17. Log of Boring El-1, 14 ft away, shown in Fig. 3. Depth of stress measurements are shown above by: ① = OC1A-1.

FIG. 2

GEOTECHNICAL ENGINEERS INC

SEABROOK STATION
LOG OF BORING El-1

Coordinates: N 20400; E 79675 | Logged by J. R. Rand

Top El. (MSL): 25.9 | Date Logged Dec. 26, 1972

Depth (ft)	BREAKS	DIP	CONDITION OF CORE	GRAPHIC LOG	DESCRIPTIVE NOTES
0–20	Core Breaks on low angle (30°) joints @ Chips to 1' intervals	Rusty; 70° joint even; Chips-Rusty; 70° joint; Chips, rusty; moderate weathering minor vugging	Rock is fresh. Locally affected by slight to moderate weathering on joints as shown. Most joints dip about 30° at .3' to 1' intervals.		Quartz diorite, medium fine grained medium grey. Massive texture (not notably foliated. Locally intruded by pegmatite veinlets as shown. Pegmatite Veinlet, 65° Dip; Pegmatite Veinlet, 75° Dip
20–30	Breaks on low angle joints @ .5' to 1.5' intervals	Chips, rusty; 60° joint minor rust; 65° joint slight weathering	Rock is fresh. Slight weathering to minor rusty coatings on some joints.		Pegmatite Veinlet. Quartz diorite, as above, Massive, medium fine grained, medium grey.
30–60	Breaks @ .5' to 2' pieces	65° joint clean, minor rust; 70° joint minor rust; 70° joint rough slight weathering; moderately weathered; slight weathering	Joints are normally clean. Not rusty. Rock is fresh. Low-angle joints @ 30° to 35° dips. Joints not rusty except as shown.		Quartz diorite as above. Mostly medium fine grained medium grey low angle (30° to 35") joints @ .5' to 2 ' intervals.
60–70	Breaks @ .3' to 3' pieces	slightly weathered rusty	Rock is fresh. Slight to moderate weathering, rust on occasional joints as shown.		Rock becomes coarse-grained Quartz diorite @ 72.6' depth. 50° dip on intrusive, welded contact. Reactor excavation

REMARKS - The total depth of this boring is 150 ft, as shown in the log submitted by J. R. Rand for the PSAR for Seabrook Station. This partial log is taken from the original and is included to cover the rock above and immediately below the zone where stres measurements were made, i.e. from 33 - 44 ft.

FIG. 3

GEOTECHNICAL ENGINEERS INC

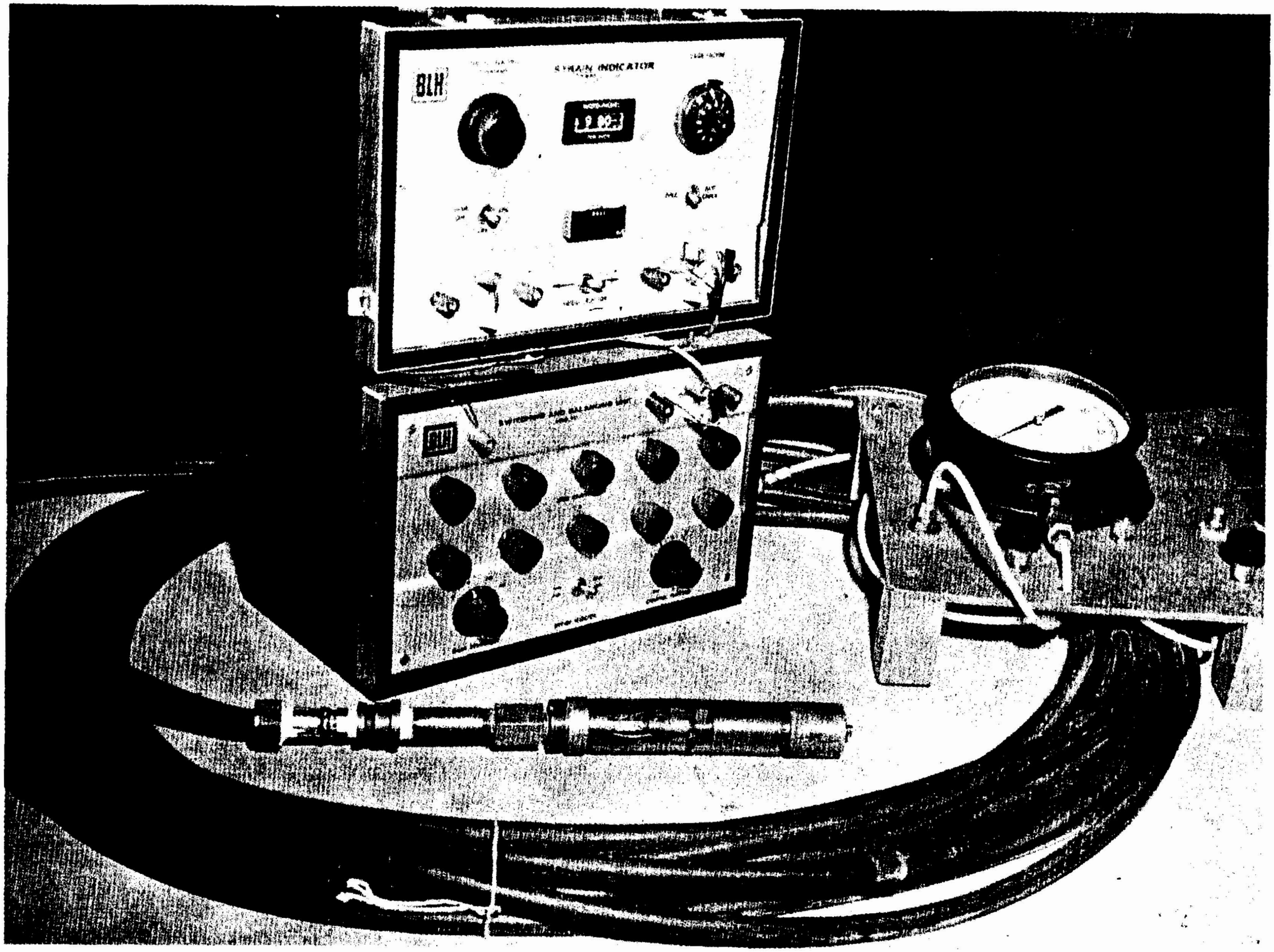
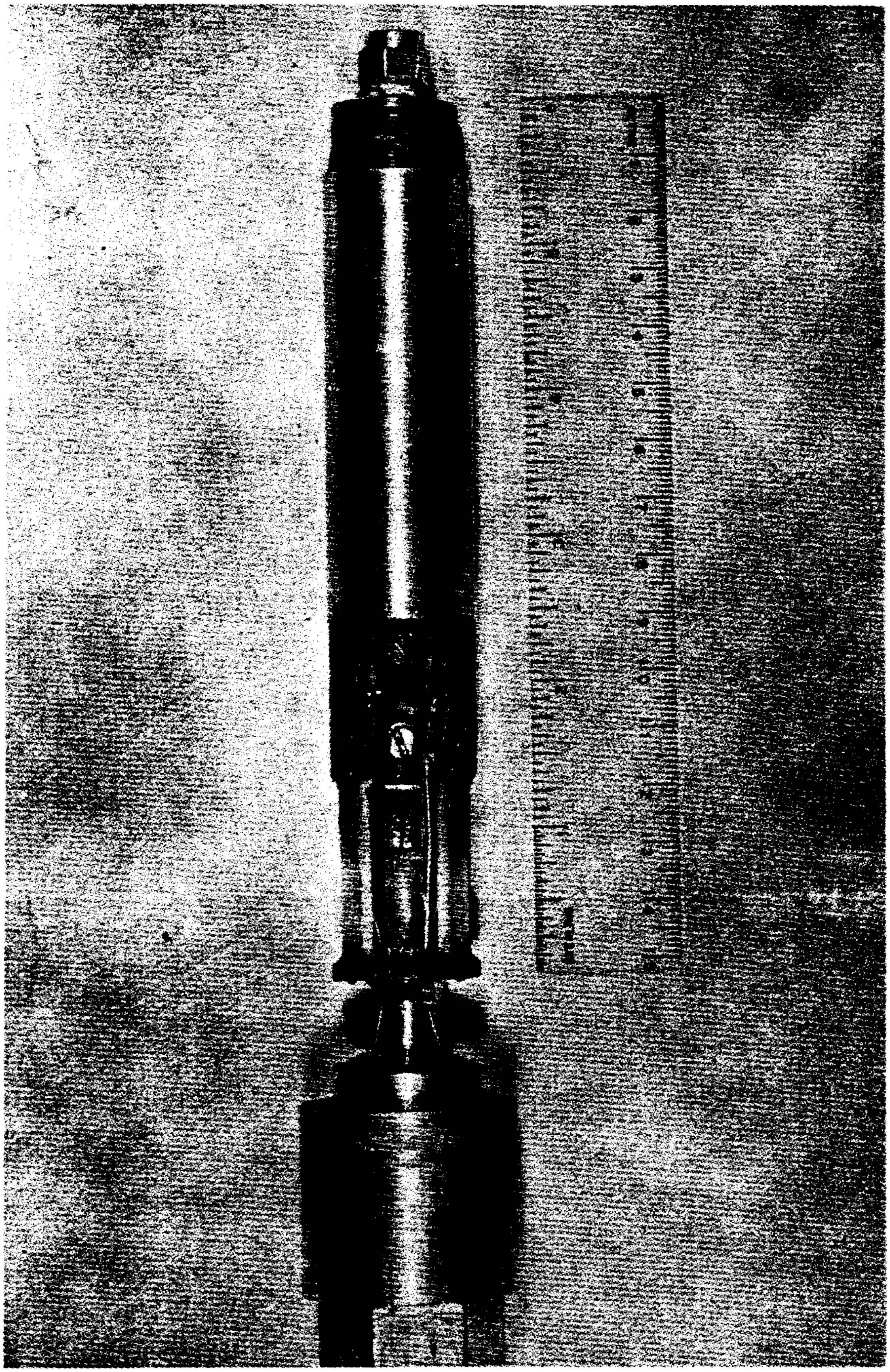
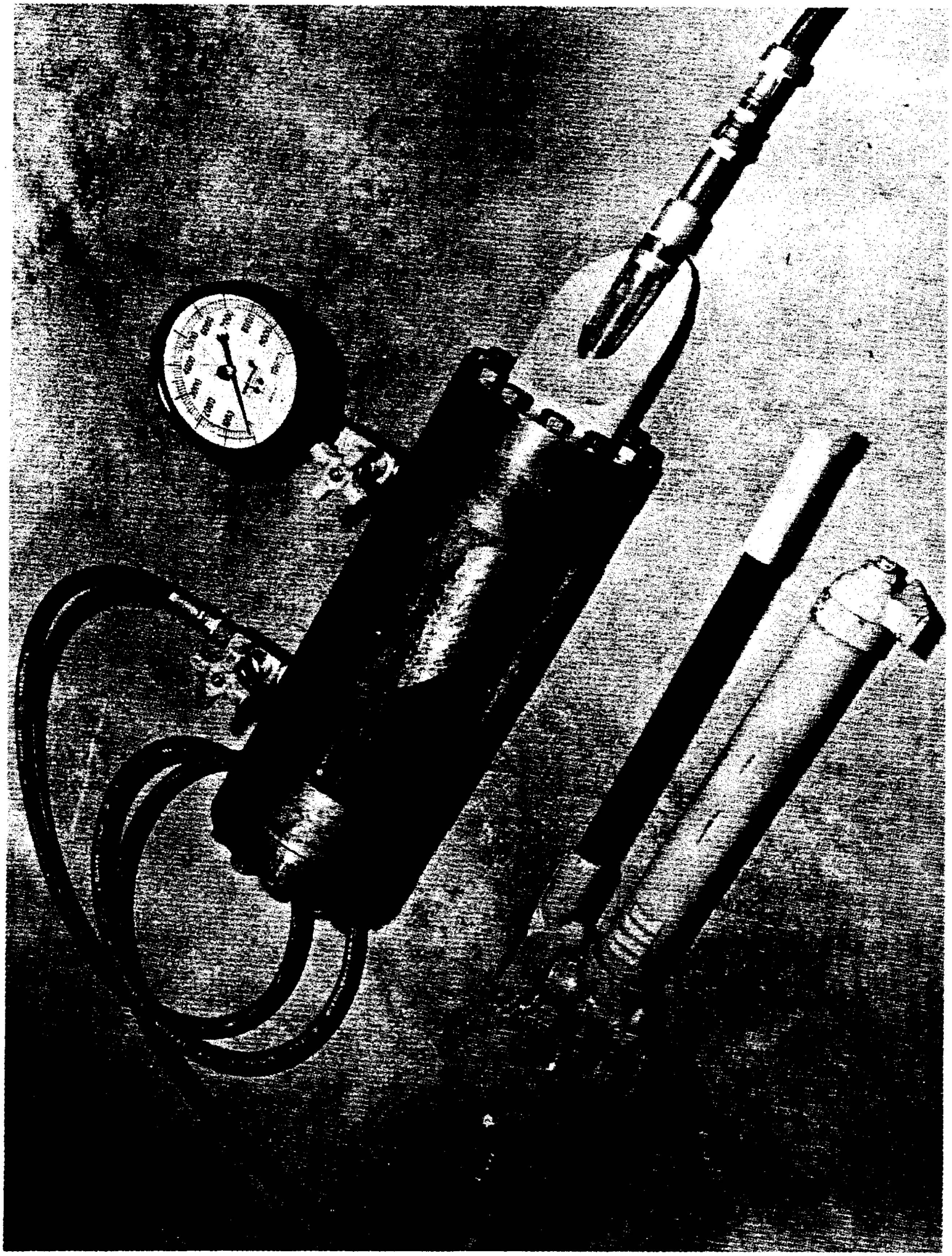


FIG. 4

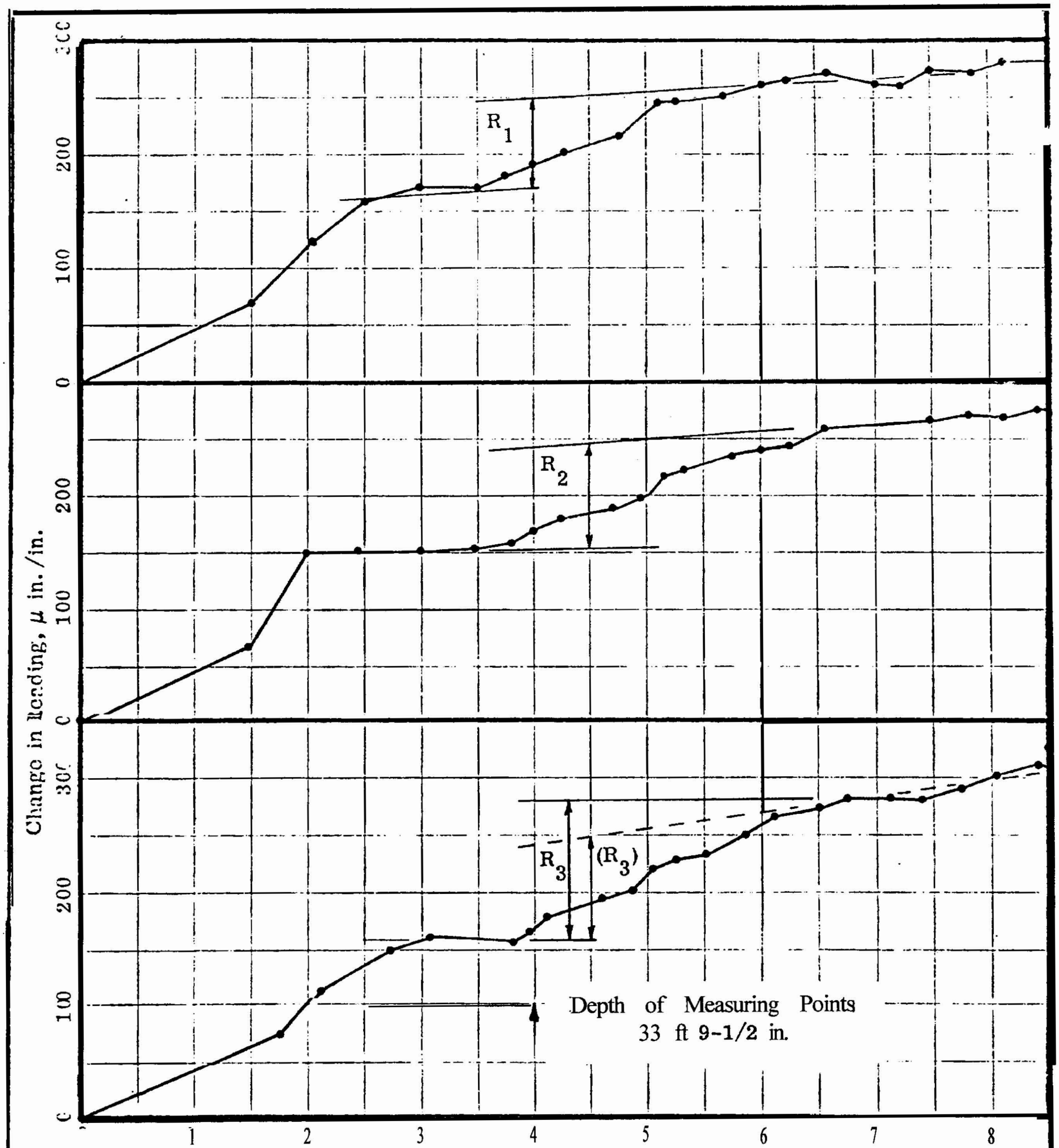
BOREHOLE GAGE SYSTEM



BOREHOLEGAGE
(vinyl sheath removed)



ROCK MODULUS CELL



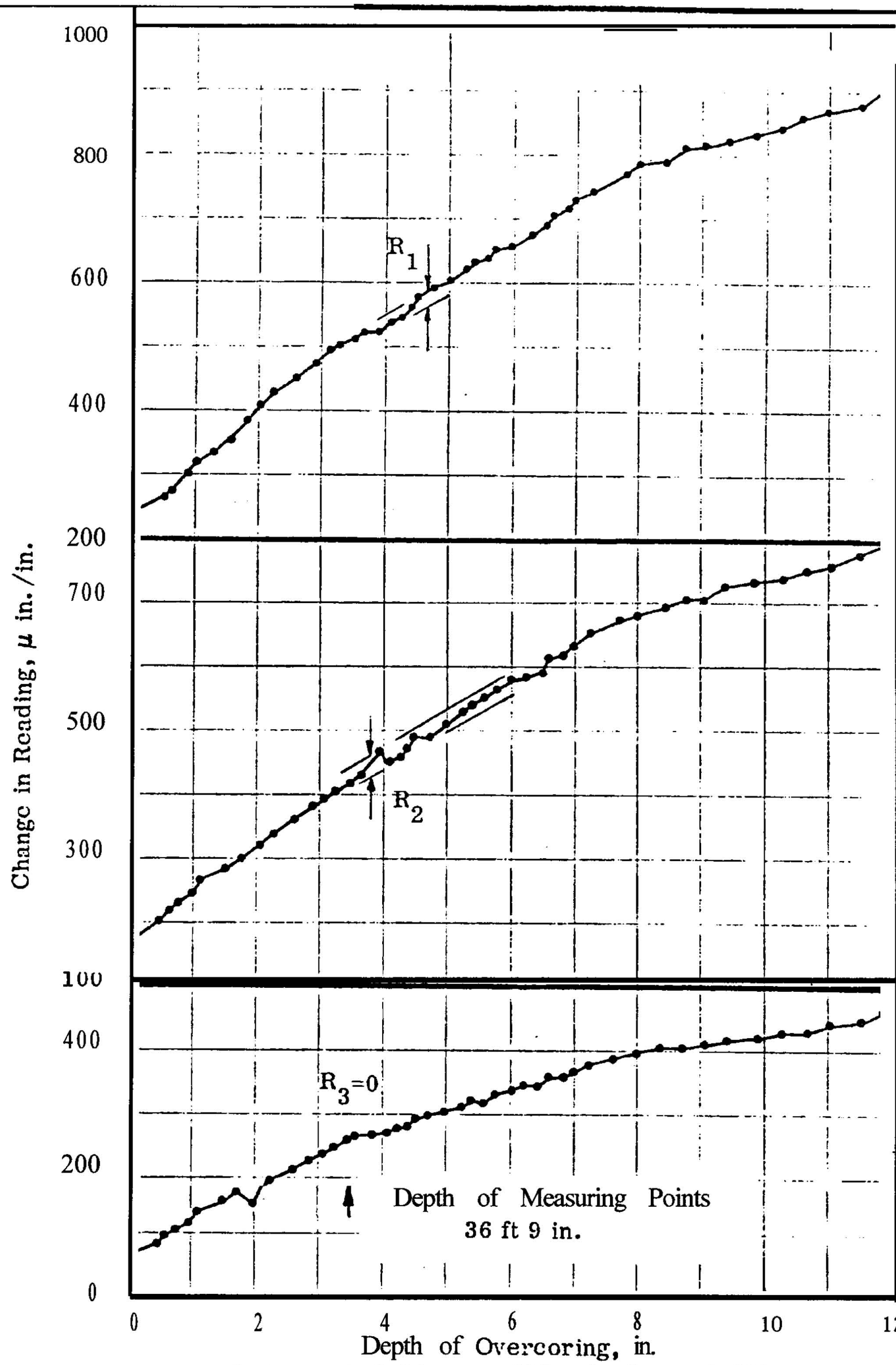
Depth of Overcoring, in.

Instrument Calibration 116 μ in. /in. = 0.001 in.

Note: Hole I.D. = 1.495 in.

0. D. = 4.31 in.

Yankee Atomic Electric Company	SEABROOK STATION	DATA FROM STRESS MEASUREMENTS 'TEST OC1A-2
Geotechnical Engineers, Inc. Winchester, Massachusetts	Project 7286	Aug. 8, 1973 FIG. 7

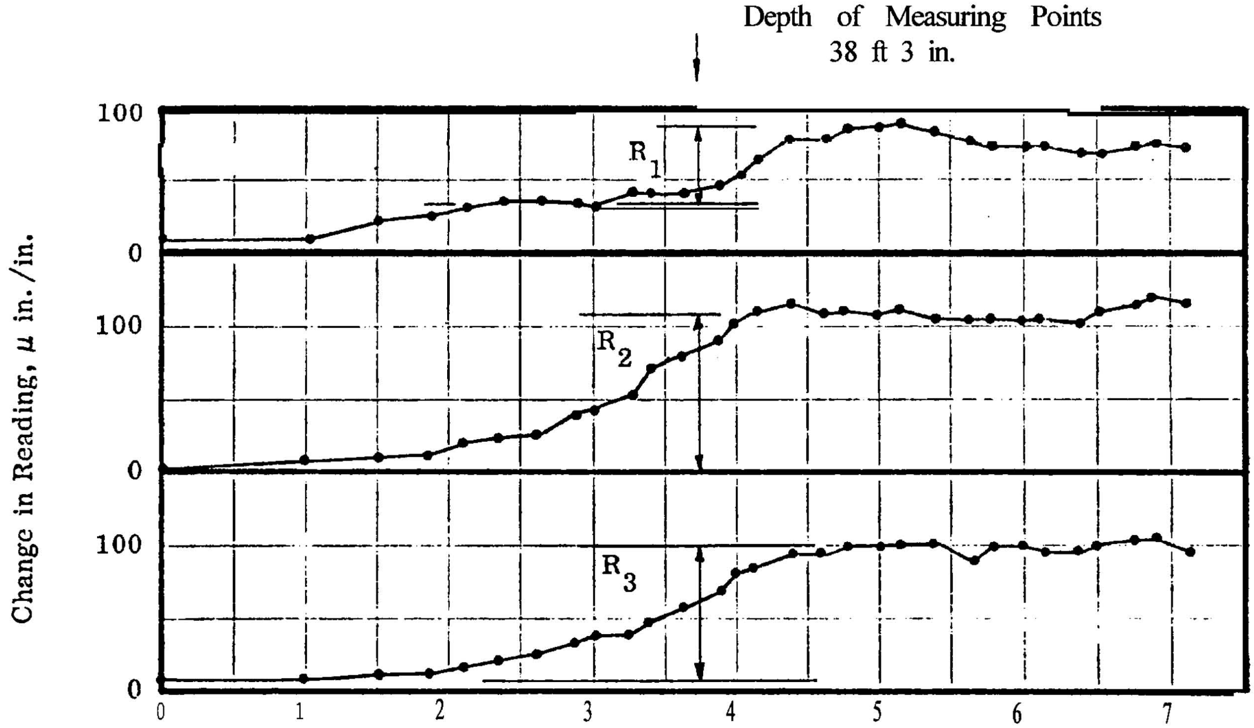


Instrument Calibration 230 μ in./in. = 0.001 in.

Note: Hole I.D. = 1.495 in O.D. -4.31 in.

Yankee Atomic Electric Company	SEABROOK STATION	DATA FROM STRESS MEASUREMENTS TEST OC1A-5
Geotechnical Engineers, Inc. Winchester, Massachusetts	Project 7286	Aug. s, 1973 FIG. 8

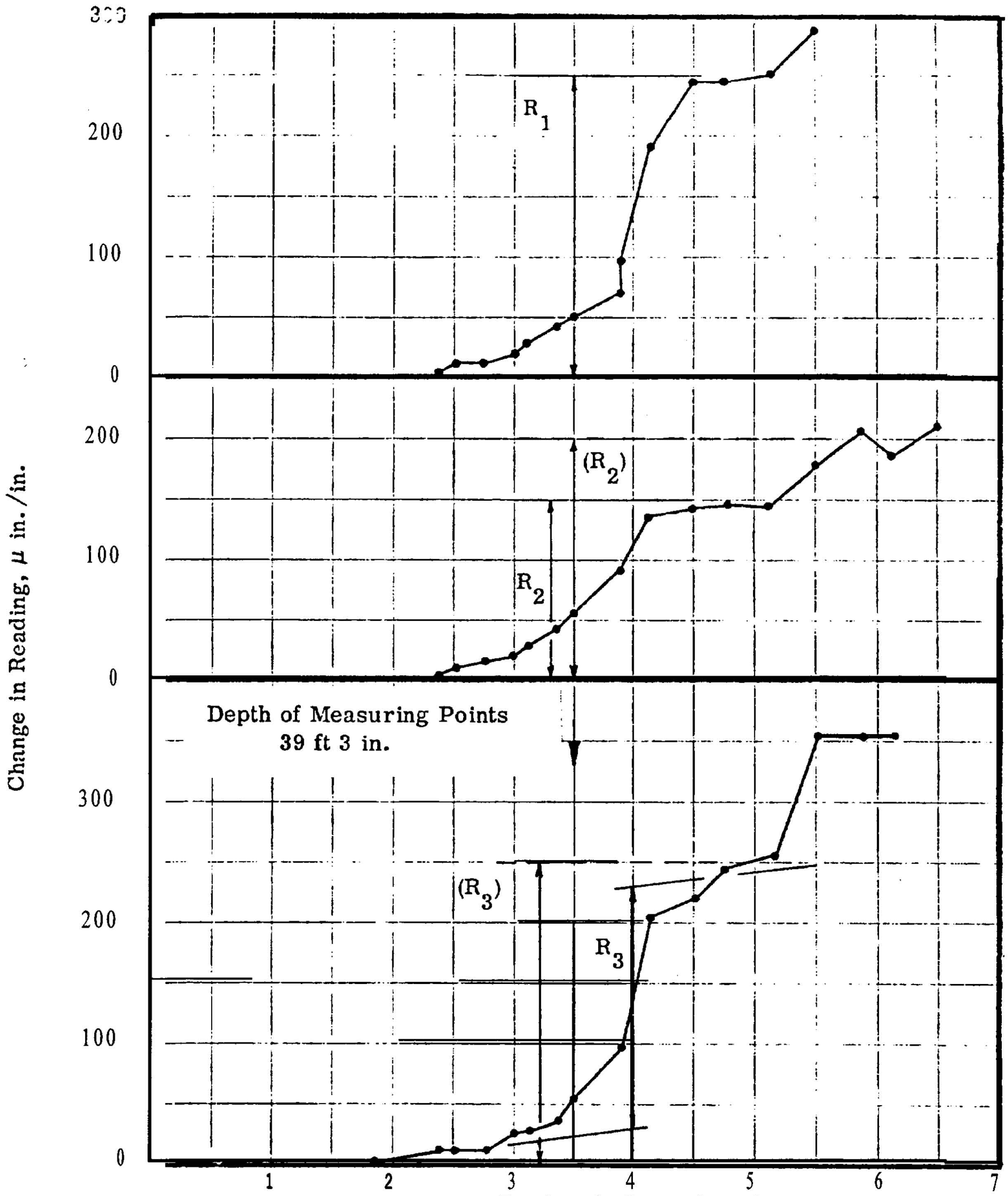
Depth of Measuring Points
38 ft 3 in.



Depth of Overcoring, in.
Instrument Calibration 116 μ in. /in. = 0.001 in.

Note: Hole I.D. = 1.495 in.
O.D. = 4.31 in.

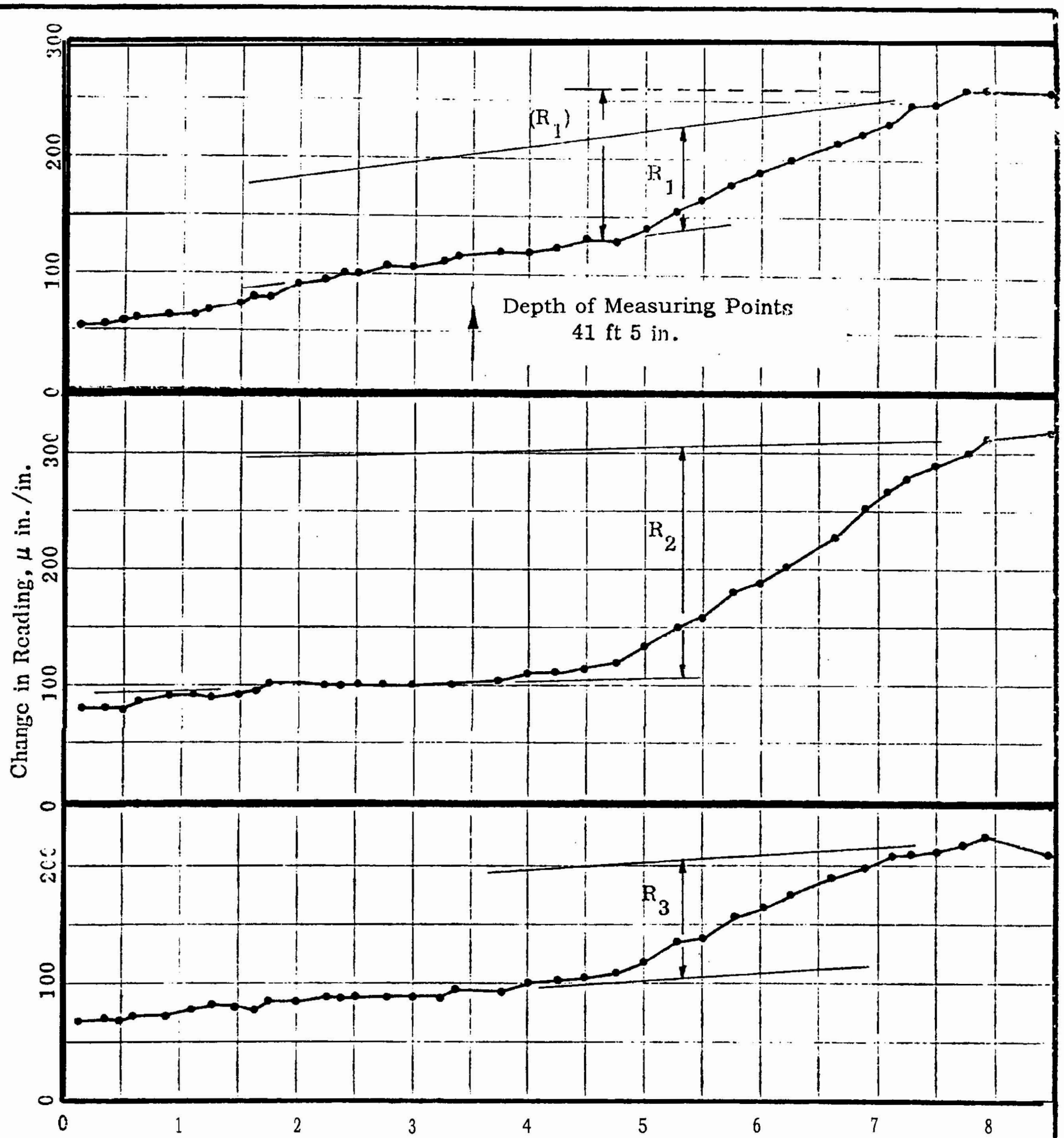
Yankee Atomic Electric Company Geotechnical Engineers, Inc. Winchester, Massachusetts	SEABROOK STATION Project 7256	DATA FROM STRESS MEASUREMENTS TEST OC1A-6 Aug. 8, 1973 FIG. 9



Instrument Calibration 116 μ in./in. = 0.001 in.

Note: Hole I.D. = 1.495 in.
O.D. = 4.31 in.

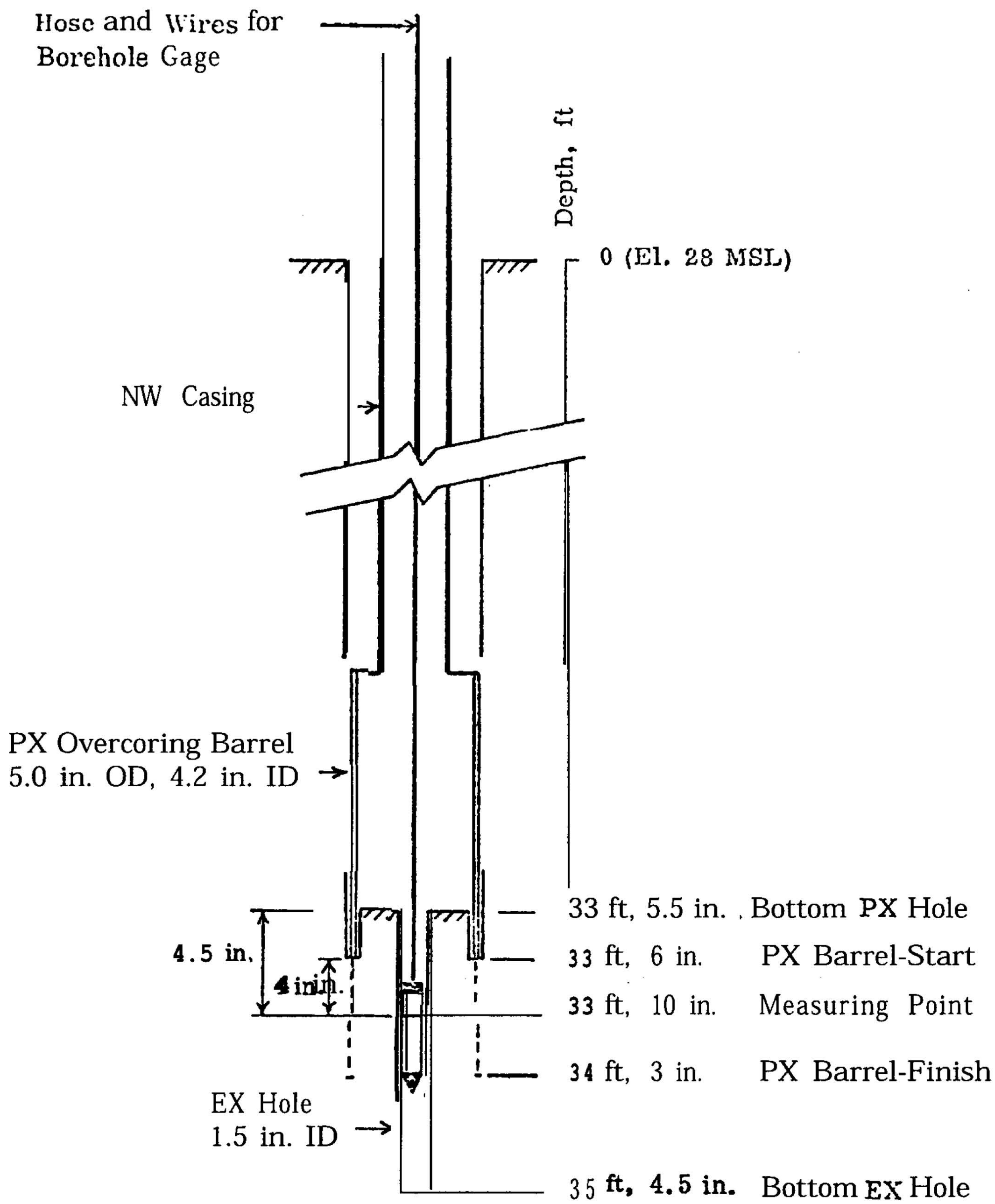
Yankee Atomic Electric Company	SEABROOK STATION	DATA FROM STRESS MEASUREMENTS TEST OC1A-7
Geotechnical Engineers, Inc. Winchester, Massachusetts	Project 7286	Aug. 8, 1973 FIG. 10



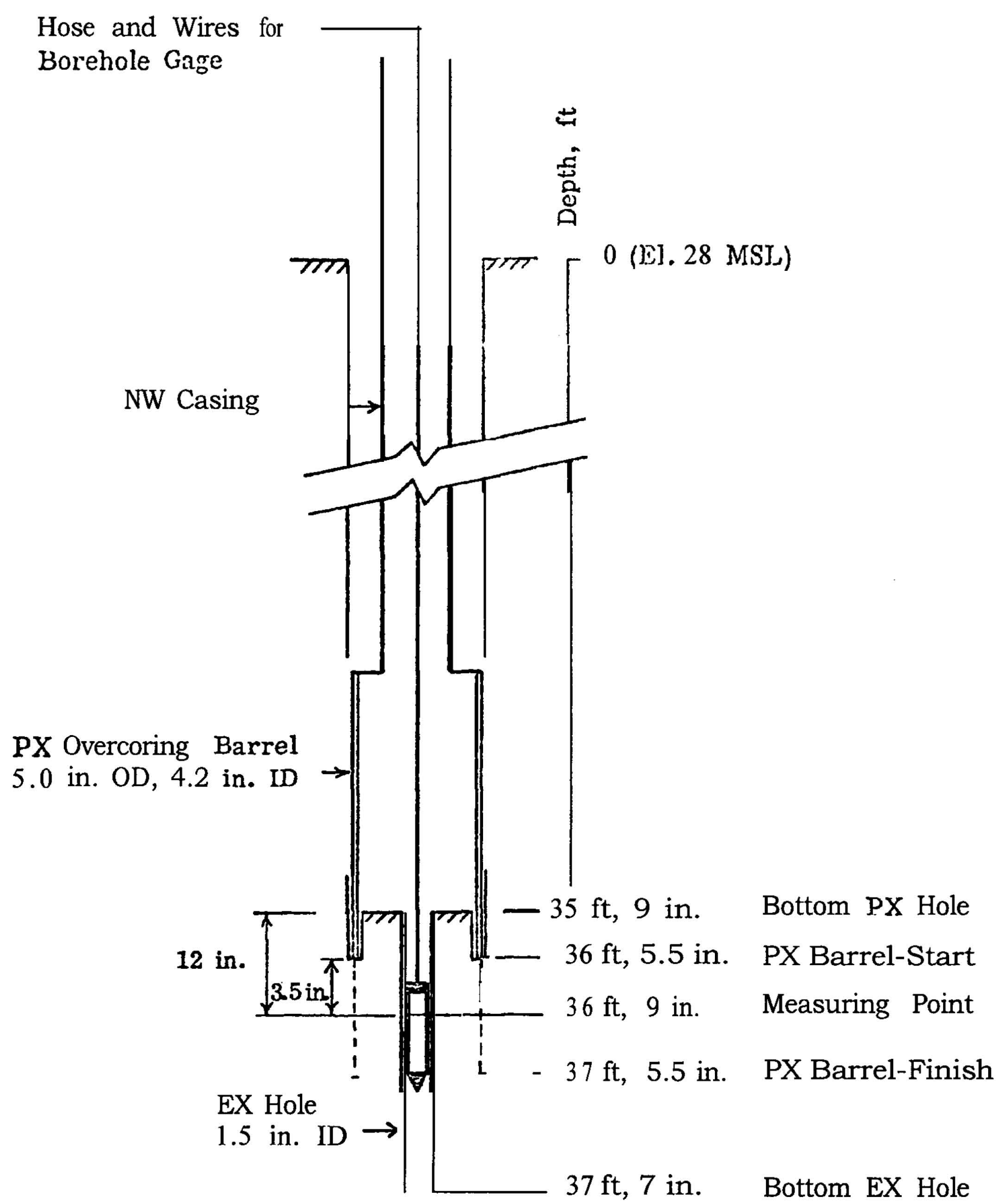
Instrument Calibration 116 μ in. /in. = 0.001 in.

Note: Hole I.D. = 1.495 in.
O. D. = 4.31 in.

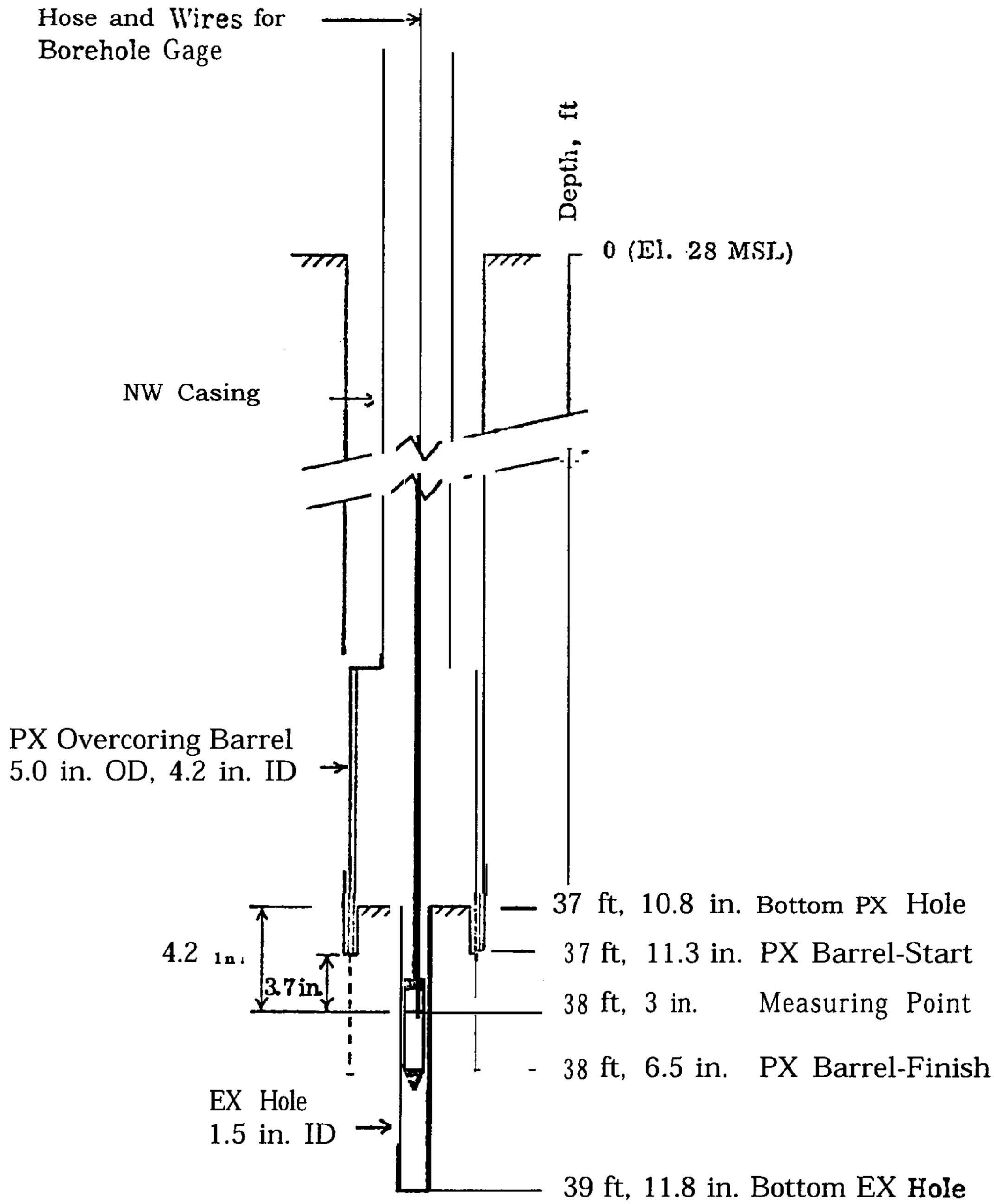
Yankee Atomic Electric Company	SEABROOK STATION	DATA FROM STRESS MEASUREMENTS TEST OC1A-9
Geotechnical Engineers, Inc. Winchester, Massachusetts	Project 7286	Aug. 8, 1973 FIG. 11



Yankee Atomic Electric Company	SEABROOK STATION	TEST OC1A-2 HOLE DIMENSIONS
Gcotechnical Engineers, Inc. Winchester, Massachusetts	Project 7236	June 20, 1973 FIG. 12

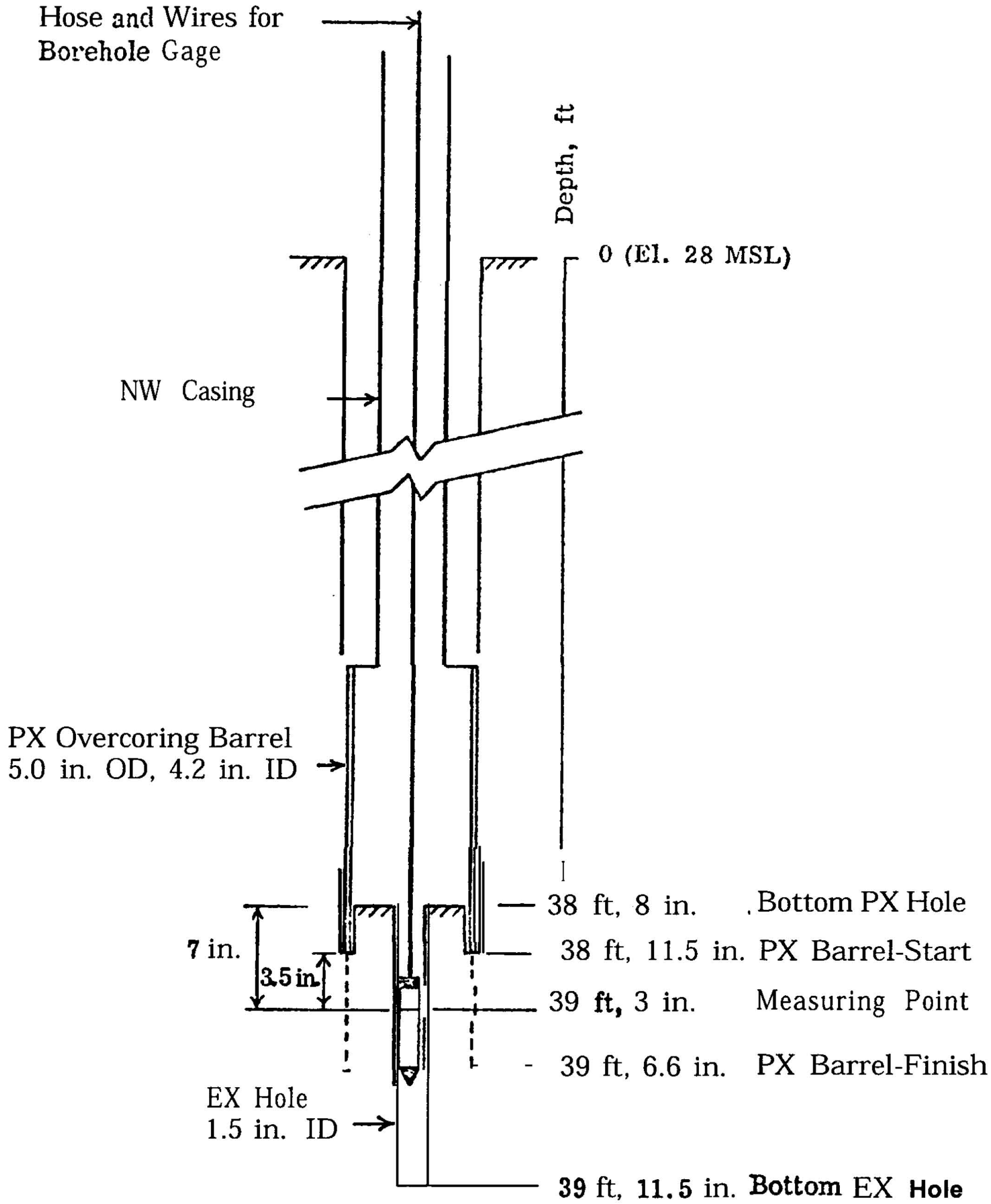


Yankee Atomic Electric Company	SEABROOK STATION	TEST OC1A-5 HOLE DIMENSIONS
Geotechnicsl Engineers, Inc. Winchester, Massachusetts	Project 7286	June 27, 1973 FIG. 13



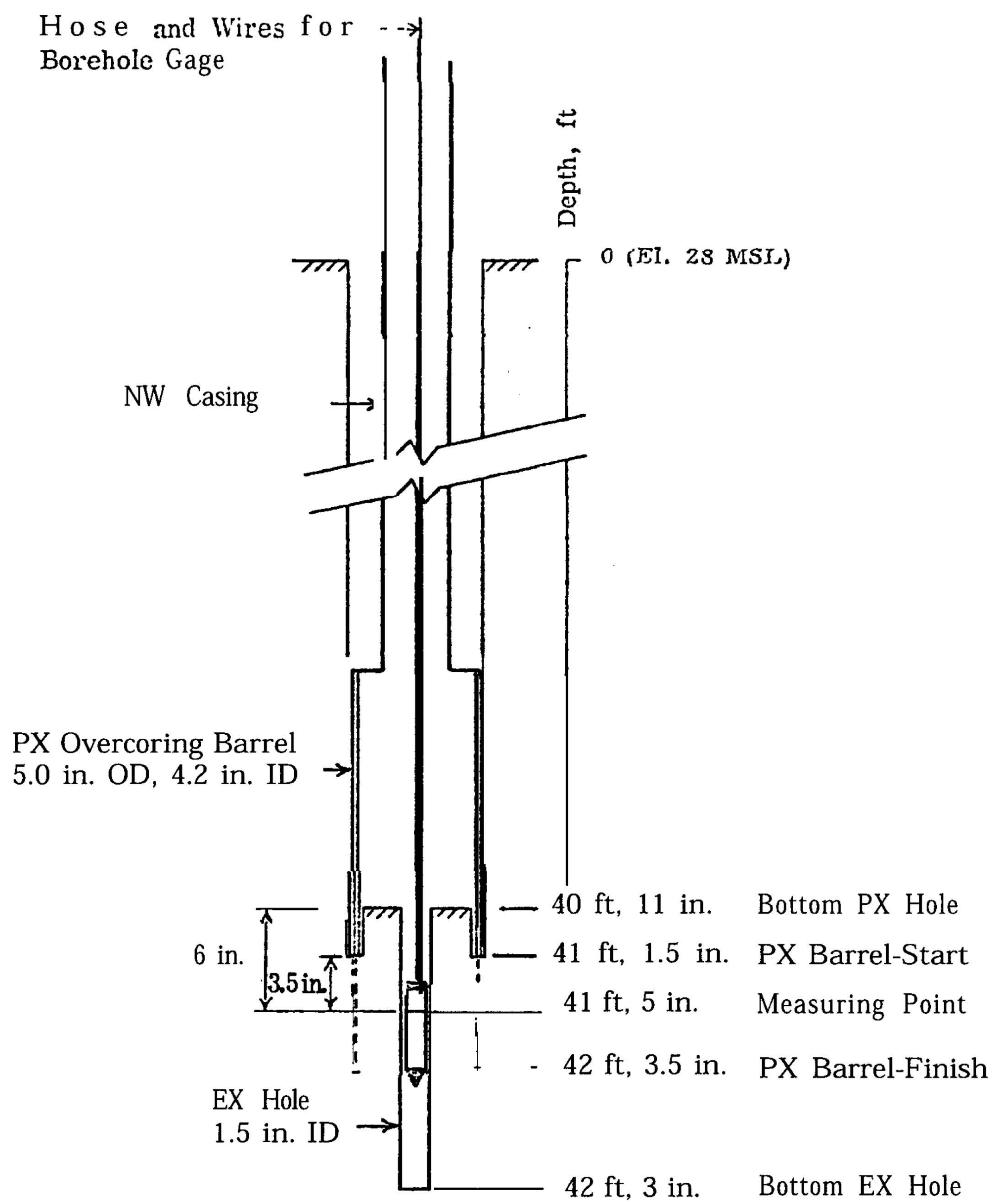
Yankee Atomic Electric Company / Geotechnical Engineers, Inc. Winchester, Massachusetts	SEABROOK STATION / Project 7236	TEST OCIA-6 HOLE DIMENSIONS / June 28, 1973 FIG. 14

GEOTECHNICAL ENGINEERS INC.



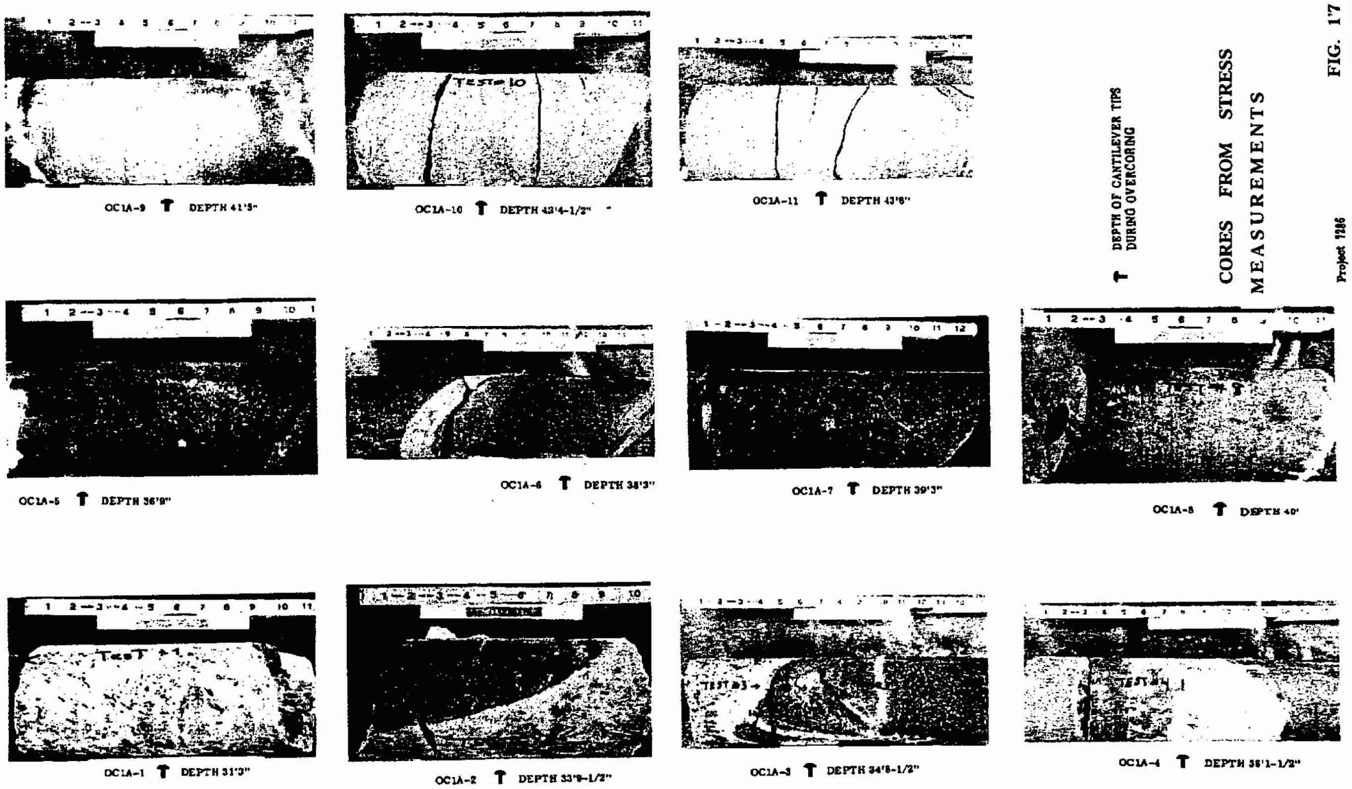
Yankee Atomic Electric Company	SEABROOK STATION	TEST OC 1A-7 HOLE DIMENSIONS
Geotechnical Engineers, Inc. U-inches ter, Massachusetts	Project 7286	June 28, 1973 FIG. 15

Φ GEOTECHNICAL ENGINEERS INC.



Yankee Atomic Electric Company	SEABROOK STATION	TEST OC1A-9 HOLE DIMENSIONS
Geotechnical Engineers, Inc. Winchester, Massachusetts	Project 7256	June 29, 1973 FIG. 16

GEOTECHNICAL ENGINEERS INC.

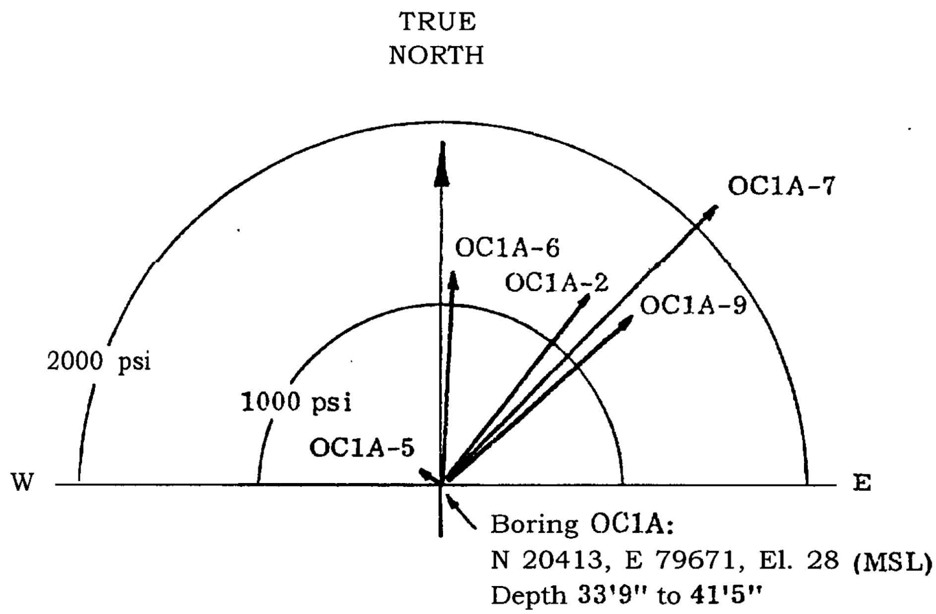


T DEPTH OF CANTILEVER TIPS DURING OVERCORING

CORES FROM STRESS MEASUREMENTS

Project 1286

FIG. 17



MAXIMUM IN-SITU COMPRESSIVE STRESSES ON HORIZONTAL PLANE
Seabrook Nuclear Station, New Hampshire
June - July, 1973

PREVIOUS STRESS MEASUREMENTS IN NEW ENGLAND *

Location	σ_I bars	σ_{II} bars	Bearing	Rock Type
Barre, Vt.	118	54	N 14 E	Granite
Proctor, Vt.	90	35	N 4 W	Dolomite
Tewksbury, Mass.	81	45	N 2 W	Paragneiss
W. Chelmsford, Mass.	145	76	N 56 E	Granite
Seabrook, N. H.	85	59	N 40 E	Granodiorite
Range	(8 - 145)	(3 - 106)	(± 36°)	

All stresses measured at depths less than 50 m (160 ft)
Stresses are compressive
One bar is 14.5 psi

*Sbar, M. L. and Sykes, L. R. (1973) "Contomporary Compressive Stress and Seismicity in Eastern North America: An Example of Intra-Plate Tectonics," Geological Society of America Bulletin, Volume 84, No. 6, p. 1871.

Yankee Atomic Electric Company	SEABROOK STATION	SUMMARY OF STRESS MEASUREMENTS
Geotechnical Engineers, Inc. Winchester, Massachusetts	Project 7286	Sept. 7, 1973 — Fig. 18

APPENDIX A

APPENDIX A

Test Procedure For

MEASUREMENT OF STRESSES IN ROCK
BY OVERCORING TECHNIQUE
IN VERTICAL HOLE

Geotechnical Engineers, Inc. September 1973

NOTE: HANDLE THE INSTRUMENT, HOSE, ORIENTATION RODS AND ALL ASSOCIATED EQUIPMENT VERY CAREFULLY TO PREVENT KINKING HOSE, LEAKS, AND INSTRUMENT DAMAGE.

1. Drill a pilot NX hole to examine the type and quality of rock. Make measurements only in zones where NX cores are primarily longer than 10 in.

2. In a hole about 5-10 ft from pilot hole, drill through poor zones with large diameter double-tube core barrel to reach measuring zone as quickly as possible. Then continue with PX overcore barrel to desired depth in three to five foot runs, each time examining the core to determine whether the rock is suitable for a measurement.

3. If the last run of PX core was suitable to try a measurement, attach the EX core barrel to the rods at the bottom end of the PX barrel with an adapter specially designed for that purpose. The adapter ensures that the EX core barrel is centered in the PX hole.

4. Drill the EX hole about 2 ft beneath the bottom of the previous bottom elevation of the PX bit and then withdraw the EX core.

5. Examine the EX core carefully to determine whether the rock is good enough for a stress measurement. The core pieces preferably should contain only drilling breaks and no natural fractures. If a natural fracture is more than 10 in. below the top, then a measurement near the top of the hole can be attempted.

6. Return the PX overcore bit to the bottom of the hole.

7. Wash through the BW casing rods and out the bottom of the PX bit for 15 minutes to remove all cuttings.

8. Measure accurately (to 1/8 in.) the depth from the surface reference point to the top of the rock at the bottom of the PX (not EX) hole. Enter the measurement on a sketch of the hole.

9. Measure and mark the required length on the orientation rods, so that measuring points will be at the proper depth.

10. Thread the instrument hose through the swivel at the top of the drive rod, attach gasket and reducing coupling, then attach to swivel. Do not over-tighten as this action may damage the instrument hose.

11. Attachinstrument leads to readout device and check readout to ensure that the strain gages can be read, that nothing is wrong with the instrument, and record the direction of reading change that corresponds to expansion of hole. Record instrument number. Record arrangement of leads on readout device.

12. Select desired orientation of measuring points on instrument. If possible, orient one axis in direction of anticipated major stress. Record orientation.

13. Lower the instrument in the hole after attaching it to the orientation rod with the special fitting for the instrument. The orientation of the cantilevers in the instrument relative to the orientation line on the rods must be recorded on the data sheet. Lower the instrument slowly and carefully, pulling up with slight pressure on the instrument hose so that the instrument is held in the orientation device. When the instrument goes below water, apply pressure inside the vinyl sheath to ensure that no water can enter. Use 2 psi pressure per foot of depth (or 1 kg/cm^2 per 30 ft of depth) as a minimum, but do not apply so much that the instrument will be over inflated and cannot be inserted into the EX hole.

14. Insert the instrument into the EX hole very carefully and without banging it on the lip of the EX hole. It helps to use a tapered point on the lower end of the instrument so that the EX hole can be found easily. Lower to the desired elevation and make sure that this elevation is accurate. Record the depth to the measurement point on the instrument from the surface reference point to the nearest 1/8 in.

15. Before inflating, make sure that the orientation of the measuring points relative to the line on the orientation rods and relative to a fixed azimuth reference is correct and record the orientation.

16. Inflate the instrument to a pressure of about 4 kg/cm^2 greater than the water pressure at that depth, but not greater than about 6 kg/cm^2 above the water pressure.

17. Remove the orientation rods carefully, making sure that the orientation fitting at the bottom does not catch on the hose on the way up. The rods should be unhooked carefully so that the connectors will not be broken.

18. Screw the drive rod (to which the swivel is attached) to the top of the drill rods using the special adapter. During this process the instrument hose has to be pulled up slightly through the swivel until the hose is straight in the drill rods.

19. Pull the PX barrel off the bottom of the hole slightly and start the drilling fluid running through the system.

20. Take readings continuously on the instrument readout device until the readings have stabilized with the water running and the PX barrel turning without any downward pressure.

DO NOT START OVERCORING UNTIL THE READINGS HAVE STABILJZED

21. When a plot shows that the readings are stable, which may take about 20 minutes, then set the readout to a convenient starting point so that the subsequent readings can be taken easily.

22. Apply slight downward pressure on the PX bit to start the overcoring. Drill at a rate of about 1/2 in. per minute (24 min. per foot), A slightly faster rate could be used if the rock is particularly good. The core catcher should be in place during this operation to ensure that the annular core will be recovered later. The core catcher may cause some extraneous vibrations.

23. Take readings during overcoring in the following sequence:

TIME DEPTH GAGE 1 GAGE 2 GAGE 3

Take readings continuously during overcoring, so that as good a graph as possible can be prepared. The driller should call out the overcoring depth to the nearest 1/8 in. when requested by the recorder. Then the person making the strain gage readings should provide his readings. A third person records all readings given to him and the time to the nearest ten seconds.

BE READY TO STOP THE DRILL DURING OVERCORING ANYTTME THAT THE READINGS START TO FLUCTUATE RAPIDLY-HAVE A SIGNAL PREARRANGED. ROTATION OF INSTRUMENT IN HOLE MAY DAMAGE IT.

24. When the readings stop changing during overcoring, stop the downward pressure and rotation but continue water flow. Continue the recording until the readings have again stabilized. During this wait, plot the readings taken in Step 23.

25. Lower the orientation rods into the hole and attach to instrument after detaching the drive rod from the drill rod at the top. When lowering the orientation rods, be sure that the hose is not cut or damaged.

26. Release the pressure in the instrument to that required to keep the water out. Wait until the pressure down at the instrument is at this level.

27. At this stage the instrument may be lowered to make a second stress measurement (to Step 14) or the instrument may be removed. The orientation rods are desirable for removal because if they are not used the top of the instrument can get caught on the lower lip of the drill rods at the top of the PX barrel. Remove from hole carefully and slowly, reducing internal pressure gradually if necessary.

28. Loosen the reducing coupling at the swivel, detach instrument from readout device, unthread the instrument hose from the swivel carefully, and put the instrument in a safe place, Examine the instrument and the hose for damage. Recheck instrument readout.

29. Attach the drive rod to the drill rod.

30. Remove the annular core.

31, With a crayon mark the location where the measuring points were on the annular core.

32. Carefully and in detail describe the core, particularly within 3 in., on each side of the measurement point. Photograph the core wet and dry, making sure that the crayon mark shows up.

33. *To* determine the modulus of the rock for computation of stresses, it is necessary to have a core with a length of 12 in. or more. Save such a piece from the measurement elevation so that it may be tested in the laboratory or field.

CHECK THE DATA SHEET, SKETCHES AND DESCRIPTIONS TO ENSURE THAT ALL DATA NEEDED FOR UNDERSTANDING THE TEST HAVE BEEN RECORDED. LIST THE NAMES OF ALL PERSONNEL AT THE SITE.

APPARATUS

1. Borehole gage for EX hole (1.5-m. dia.) including hose containing lead wires and air tube.

2. Portable strain gage readout system, including strain indicator and switching and balancing unit for three strain gages.

3. Dry nitrogen supply system, pressure gage, and pressure regulator. Pressure required is 100 psi plus hydrostatic pressure at greatest depth below water level at which instrument will be used.

4. Drilling system for overcoring, including hydraulic drill rig, SW casing for seating to rock, NW casing for use as drill rod for overcoring bit, 5 in. by 4-3/16 in. (PX) overcoring bit 5 ft long, 2 and 5-ft-long EX core barrel (1.5 in. 0. D.) adaptor to attach EX core barrel to bottom of overcoring bit. Swivel to allow passage of instrument hose so that it will not twist during test but drill water will not leak appreciably.

5. Data sheets, form attached.

6. Orientation rods for setting the borehole gage elevation and for maintaining orientation of borehole gage.

7. Compass for determining orientation of borehole gage.

OVERCORING READINGS - SEABROOK II, NEW HAMPSHIRE

Hole No. ____________
Hole Location ____________
____
El. Top of Hole ____________
El. Datum ____________
Orientation of Gage ____________

Depths ____________
Bot. 5-in. Hole ____________
Rot. EX Hole ____________
Pins on Gage ____________
Dimensions in ____________

Project No. ______ Date ______ Test ______
Driller ____________
Engineer ____________
Weather ____________
____________ Page ______

	Time	Elapsed Time	Overcore Depth	Strain Gage Readings								
				1	2	3	4	5	6	7	8	9
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												

Remarks ____________

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APPENDIX B

APPENDIX B

MEASUREMENT OF MODULUS OF ANNULAR ROCK CORE

Geotechnical Engineers Inc. September 1973

1. Prepare rock modulus cell by inserting membrane, filling with hydraulic fluid (trapping as little air as possible) and securing end plates.

2. Break rock annulus that was removed from hole in field into sections not less than 12 in. long and such that points within EX hole at which borehole gage measurements were made in field can be close to center of rock modulus cell if possible.

3. Insert core in cell.

4. Insert borehole gage in cell, preferably at same location as in field.

5. Apply 100 psi nitrogen pressure to interior of gage to secure it in proper location. Preferably use same pressure as was used in-situ during overcoring (after subtracting in-situ water pressure).

6. Connect leads from borehole gage to strain gage readout device, using same wires, lengths, and hook-up as in-situ.

7. Take initial gage readings until readings are stable.

8. Apply pressure to exterior of rock annulus in increments of 500 psi until the compression of the diameters is equal to theirextension during overcoring but do not exceed 3000 psi unless an axial load is put on the core. Record all strain gage readings each time an increment is applied. Allow for equilibrium to be reached before adding each new increment.

9. Release the pressure in decrements of 500 psi, taking readings as before.

10. Reapply the maximum stress in 1000 psi increments. Repeat the loading and unloading until results are consistent.

11. Using the diameter changes measured in the field and in the laboratory, together with the stresses applied in the laboratory, compute the rock modulus and the stress in situ. For the rock modulus cell:

$$u = kR = \frac{2db^2}{(b^2 - d^2)} \quad \frac{P}{E}$$

where:

- u = diametral deformation
- k = instrument calibration
- R = instrument reading
- d = I.D. of core
- b = O. D. of core
- P = external pressure
- E = rock modulus