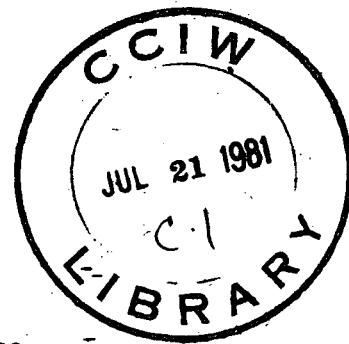


HYDRAULICS DIVISION
Technical Note



DATE: July 1981 **REPORT NO:** 81-20

TITLE: Calculation of Bearing Capacity for Proposed Installation of Vertical Automatic Profiler in Hamilton Harbour Basin

AUTHOR: A. J. Zeman, Shore Processes Section

REASON FOR REPORT: This technical note has been written in response to a request by Mr. F. Roy, Mechanical Engineering Unit, Hydraulics Division, National Water Research Institute.

CORRESPONDENCE FILE NO:

5180

1.0 INTRODUCTION

On May 8, 1981, a request was received from Mr. F. E. Roy, Mechanical Engineering Unit, Hydraulics Division, to carry out geotechnical investigation of three sites in the Hamilton Harbour basin in connection with a proposed installation of an NWRI vertical automatic profiler GVAPS ES 1-32. Three Benthos core samples were obtained from locations shown in Figure 1 and they were received in the laboratory on May 15, 1981.

The results of investigation presented herein provide penetration estimates for the GVAPS profiling winch and anchor. In the investigation, the same theoretical approach was used as for the investigation in the central Lake Erie basin described in Technical Note 78-17 (Zeman, 1978). The dimensions and weights of the anchor and profiling winch are the same as in TN78-17. The laboratory tests were done by K. Salisbury and the results checked by G. A. Duncan and A. J. Zeman.

2.0 LABORATORY METHODS

The cores were stored at 4°C prior to testing and the tests commenced on the same day when the cores were received in the laboratory. Each unextruded core was cut into 10-cm long sections and the bulk unit weight was determined by dividing the net sediment weight by the corresponding volume. The natural water content was measured at 10-cm intervals in accordance with the ASTM standard D2216. The undrained shear strength was measured, also at 10-cm intervals, using the fall-cone test in which a calibrated metal cone is dropped freely into the sediment and the depth of penetration is recorded (Hansbo, 1957). The Atterberg limits were determined on three representative samples from each core in accordance with the ASTM standards D423 and D424. Particle size analyses on three representative samples from each core were carried out using the Sieve and Short Pipette Method (Duncan and LaHaie, 1979), which provides gravel, sand, silt and clay percentages.

3.0 **RESULTS**

3.1 Natural Water Content

The range of natural water contents in the three cores (Figures 2, 3 and 4) lies above the liquid limit as would be expected for a post-glacial basin sediment. In Core 1 (Figure 2), the water content at the top of the core is close to 400% and it decreases to about 200% below the depth of 40 cm. The anomalously high value of 287% at the bottom of core reflects probable sample disturbance during coring. A similar trend of natural water contents was obtained for Core 2 (Figure 3), except for higher scatter of data points. In Core 3 (Figure 4), a desiccated, denser crust was found immediately below the water-sediment interface to the depth of about 10 cm. Below this depth, the water content decreases from about 300% at the depth of 20 cm to about 175% at the depth of 1 metre. The test results are presented in Table 1, Appendix 1.

3.2 Submerged Unit Weight

The vertical profiles of the submerged unit weight in the three cores are plotted in Figures 5, 6 and 7. In Core 1 (Figure 5), the values increase gradually with depth from about 1.0 kN/m^3 to about 4.4 kN/m^3 close to the bottom of the core. The sediment is less dense in Core 2 (Figure 6), reaching values of about 2.0 kN/m^3 below the depth of 1 metre. In Core 3 (Figure 7), no vertical trend has been obtained and widely-scattered data have an average of about 2.0 kN/m^3 . The test results are presented in Table 2, Appendix 1.

3.3 Undrained Shear Strength

All three profiles show gradual increase of shear strength values with depth. In Cores 1 and 2 (Figures 5 and 6), the values range between 0.1 kPa and 1.5 kPa, except for an anomalous value of 2.3 kPa in Core 1 at the depth of 80 cm below the lake bottom. In Core 3 (Figure 7), shear strength values increase with depth at a greater rate than in Cores 1 and 2. Values of about 3 kPa were measured at the bottom of Core 3. For all three cores, the consistency of the sediment is very soft for all samples tested. The test results are presented in Table 3, Appendix 1.

3.4 Atterberg Limits

Three samples from each core were tested. The variation of the liquid limit and the plastic limit with depth is shown in Figures 3, 4 and 5, and

the results are also summarized on the Casagrande plasticity chart in Figure 8. The liquid limit in all three cores ranges from about 125% to 180%, and the plastic limit from about 60% to 80%. According to the Unified Soil Classification System (Casagrande, 1948), all samples tested fall-within the region of organic silts and clays of high plasticity (OH). The test results are presented in Table 4, Appendix 1.

3.5 Particle Size Analysis

The results of nine particle size analyses are plotted on a ternary diagram in Figure 9. According to Shepard's ternary classification, five samples tested are clayey sands, three are sandy silty clay, and one sample is sandy clay. According to Folk's ternary classification, six samples are sandy mud and three samples are muddy sand. The clay content increases with depth in all three cores and samples close to the bottom of the cores (1-10, 2-12 and 3-11) contain more than 40% of clay-sized particles. Computer printouts of test results are presented in Appendix 2.

4.0

PENETRATION ESTIMATE

The theoretical derivation of the method used is explained in Technical Note 78-17 (Zeman, 1978).

The method uses linear relationships between the undrained shear strength $C=S_u$ and the depth D , and the submerged unit weight γ' and the depth D . For the three cores analyzed, these relationships are approximated by empirical equations obtained from the results of laboratory tests (Sections 3.2 and 3.3).

These equations are as follows:

Core 1

$$\begin{aligned} C &= 0.087 + 1.521 D \\ r^2 &= 0.621 \end{aligned} \quad (1a)$$

$$\begin{aligned} \gamma' &= 0.183 + 0.031 D \\ r^2 &= 0.721 \end{aligned} \quad (1b)$$

Core 2

$$\begin{aligned} C &= -0.062 + 0.175 D \\ r^2 &= 0.929 \end{aligned} \quad (2a)$$

$$\begin{aligned} \gamma' &= 1.447 + 0.003 D \\ r^2 &= 0.027 \end{aligned} \quad (2b)$$

Core 3

$$\begin{aligned} C &= -0.232 + 2.510 D \\ r^2 &= 0.903 \end{aligned} \quad (3a)$$

$$\begin{aligned} \gamma' &= 1.936 + 0.001 D \\ r^2 &= 0.003 \end{aligned} \quad (3b)$$

where r^2 is the coefficient of determination. The regression lines are also shown in Figure 5, 6 and 7.

4.1 Penetration of Anchor

The dimensions and weight of the anchor are as given in TN78-17 (Zeman, 1978).

The effective cohesion, C_D , is the one measured at the depth $B/2$ below the anchor base, where B is the diameter of the anchor. In this case, $B=0.9$ m.

The effective unit weight, γ'_D , is the average submerged unit weight above the anchor base. Therefore, at an arbitrary penetration depth D of the anchor, the following equations are used.

Core 1

$$C_D = 0.779 + 1.521 D \quad (4a)$$

$$\gamma'_D = 0.183 + 0.016 D \quad (4b)$$

Core 2

$$C_D = 0.473 + 1.175 D \quad (5a)$$

$$\gamma'_D = 1.477 + 0.002 D \quad (5b)$$

Core 3

$$C_D = 0.910 + 2.510 D \quad (6a)$$

$$\gamma'_D = 1.936 + 0.001 D \quad (6b)$$

The relationship between the ultimate bearing capacity q_{uc} and the depth of penetration D is

$$q_{uc} = 7.4 C_D + \gamma'_D D \quad (7)$$

Substituting from Equations 4 to 6 yields

Core 1

$$q_{uc} = 0.016 D^2 + 11.438 D + 5.765 \quad (8a)$$

Core 2

$$q_{uc} = 0.002 D^2 + 10.172 D + 3.500 \quad (8b)$$

Core 3

$$q_{uc} = 0.001 D^2 + 20.510 D + 6.734 \quad (8c)$$

Since q_{uc} for $D=0$ exceeds the footing pressure of 4.415 kPa in Equations 8a and 8c, no penetration is expected at the sites of Cores 1 and 3.

At the site of Core 2, the penetration is estimated from Equation 8b for $q_{uc}=4.415$ and the positive root is

$$D = 0.09 \text{ m.}$$

The results obtained are compared with the estimated penetration in the central Lake Erie basin in Figure 10. The conclusion is that at all three sites in the Hamilton Harbour basin the penetration should be less than in the central Lake Erie basin. Out of the three sites investigated, the site of Core 3 is the most favourable and the site of Core 2 is the least favourable. The results probably reflect the fact that the basin sediment in Hamilton Harbour is significantly coarser (Figure 9) than in the Erie basin.

4.2 Penetration of Profiling Winch

The computation is quite analogous to the one presented in 4.1, except for the use of a bearing-capacity equation applicable to rectangular, rather than circular, footings. In this case,

$$q_{ur} = 5.7 C_D \left(1 + 0.3 \frac{B}{L}\right) + \gamma' D \quad (9)$$

where q_{ur} is the ultimate bearing capacity, B is the width of the footing and L is the length of the footing. In the present case, $B=1.20 \text{ m}$ and $L=1.80 \text{ m}$.

The equations for C_D and $\gamma' D$ are as follows:

Core 1

$$C_D = 1.000 + 1.521 D \quad (10)$$

$$\gamma'_D = 0.183 + 0.016 D \quad (4b)$$

Core 2

$$C_D = 0.643 + 1.175 D \quad (11)$$

$$\gamma'_D = 1.477 + 0.002 D \quad (5b)$$

Core 3

$$C_D = 1.274 + 2.510 D \quad (12)$$

$$\gamma'_D = 1.936 + 0.001 D \quad (6b)$$

Substituting these equations into Equation 9 yields:

Core 1

$$q_{ur} = 0.016 D^2 + 10.857 D + 6.840 \quad (13)$$

Core 2

$$q_{ur} = 0.002 D^2 + 9.514 D + 4.398 \quad (14)$$

Core 3

$$q_{ur} = 0.001 D^2 + 19.104 D + 8.714 \quad (15)$$

In all three cases, q_{ur} for $D=0$ exceeds the footing pressure of 0.513 kPa and no penetration is expected. The results are compared with the calculation for the central Lake Erie basin in Figure 11. Out of the three sites investigated, the site of Core 3 is the most favourable and the site of Core 2 is the least favourable.

5.0 DISCUSSION

Empirical data are required to evaluate potential deviations between theoretical and observed penetrations. For the site in the central Lake Erie basin, the penetration estimates were 21 cm for the anchor (Figure 10) and no penetration for the profiling winch (Figure 11). Diver's observations after the installation indicated approximately 2 m penetration for the anchor and approximately 10 cm for the profiling winch. It has to be realized, however, that data used for the estimate came from Core 13163, which was obtained some 40 km from the proposed installation site. The present study indicates significant differences in resistance to penetration among sites that are only several hundred metres apart (Figures 10 and 11).

Gemenhardt and Focht (1970), who used a similar theoretical approach, reported a good agreement between predicted and observed penetrations in the Gulf of Mexico for penetration depths ranging from 0.75 m to 25 m, i.e. on the average for penetrations much greater than those considered in the present study. In particular, it remains uncertain whether the assumed mode of bearing failure is applicable to very shallow (and critical) penetrations of the profiling winch.

For future investigations of this type, it is therefore important to obtain accurate and reliable measurements of actual penetrations in the Hamilton Harbour basin where the geotechnical conditions are known at, or very close to, the selected installation site.

6.0 REFERENCES

- Casagrande, A., 1948. "Classification and Identification of Soils." Trans. ASCE, 113: 901-992.
- Duncan, G. A. and LaHaie, G. G., 1979. "Size Analysis Procedure Used in the Sedimentology Laboratory, NWRI." Hydraulics Division Manual, September 1979.
- Gemenhardt, J. P. and Focht, J. A., Jr., 1970. "Theoretical and Observed Performance of Mobile Rig Footings on Clay." 2nd Annual Offshore Technology Conf., Houston, Paper No. OTC 1201, 10 p.
- Hansbo, S., 1957. "A New Approach to the Determination of the Shear Strength of Clay by the Fall-Cone Test." Royal Swedish Geotechnical Institute Proceedings No. 14, 46 p.
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APPENDIX I
Results of Geotechnical Tests

TABLE I Natural Water Content - Core 1

Depth cm	1	2	3	w, %	\bar{x}
0	384.60			-	384.60
10	305.87	345.70		-	325.79
20	322.14	234.23	218.27	-	258.21
30	208.00	204.53		-	206.27
40	202.38	190.26		-	196.32
50	198.06	194.07	196.66	-	196.26
60	223.78	173.56		-	198.67
70	182.25	187.88		-	185.07
80	69.03	124.82		-	96.93
90	204.86	190.20		-	197.53
100	173.49	219.53		-	196.51
112	278.53	296.27		-	287.40

Natural Water Content - Core 2

0	472.18			472.18
10	301.18	298.30		299.74
20	293.39	300.40		276.90
30	247.22	184.51	157.43	196.39
40	190.59	202.09		196.34
50	237.72	270.59		254.16
60	169.92	174.72		172.32
70	196.19	173.43	209.08	192.90
80	195.11	143.56		169.34
90	243.81	214.04		228.93
100	218.00	188.67	196.38	201.02
110	171.28	181.14		176.21
120	230.87	279.26		255.07
125	291.02			291.02

Natural Water Content - Core 3

0	69.06			69.06
10	62.13	293.31		177.72
20	306.57	455.75	164.60	308.97
30	323.90	167.22		245.56
40	167.28	102.67		134.98
50	264.08	235.15		249.62
60	167.19	155.66	174.15	165.67
70	188.54	188.00		188.27
80	182.25	197.57		189.91
90	130.77	182.37		156.57
100	198.74	154.67	179.29	177.57
110	154.06	220.27		187.17
112	238.41			238.41

TABLE 2

Submerged Unit Weight

	Depth, cm	γ' , kN/m ³
Core 1	5	0.96
	25	-1.14
	35	1.41
	45	1.32
	55	1.13
	65	1.70
	75	2.84
	85	1.84
	95	3.71
	106	4.34
Core 2	5	3.35
	25	0.36
	35	0.94
	45	1.28
	65	1.37
	75	1.56
	85	2.00
	95	1.66
	105	1.98
	115	2.00
	122	2.31
Core 3	5	2.91
	15	0.14
	25	3.31
	35	1.92
	45	1.01
	55	1.72
	65	3.08
	75	1.84
	85	2.30
	95	1.82
	105	2.20
	111	2.01

TABLE 3

Undrained Shear Strength - Core 1

Depth, cm	S_u , Pa		
	1	2	\bar{x}
0	<62		<62
10	98	167	133
20	167	235	201
30	500	785	643
40	677	1177	927
50	785	677	731
60	431	1569	1000
70	637	902	770
80	2059	3040	2550
90	637	1471	1054
100	1471	1471	1471
112	1569		1569

Undrained Shear Strength - Core 2

0	<62		<62
10	<62	98	~80
20	98	127	113
30	186	196	191
40	981	402	692
50	363	294	329
60	637	981	809
70	569	637	603
80	637	981	809
90	706	1373	1040
100	686	1765	1226
110	794	1373	1084
120	1471	1471	1471
125	1471		1471

Undrained Shear Strength - Core 3

0	<62		62
10	127	235	181
20	108	500	304
30	902	559	731
40	431	637	534
50	373	637	505
60	804	1765	1285
70	843	1471	1157
80	834	2256	1545
90	1373	2452	1913
100	1471	3825	2648
110	2452	2256	2354
112	3138		3138

TABLE 4

Atterberg Limits

Depth cm	Liquid Limit W_L , %	Plastic Limit W_P , %	Plasticity Index PI, %	Natural Water Content W_N , %	Liquidity Index
Core 1					
25	126.74	58.56	68.18	158.77	1.47
55	155.14	80.71	74.44	192.02	1.50
105	163.84	71.07	92.77	171.25	1.08
Core 2					
15	178.69	78.79	99.90	274.93	1.96
65	124.58	64.37	60.21	167.75	1.72
115	167.63	75.97	91.66	169.84	1.02
Core 2					
15	160.10	64.37	95.72	326.72	2.74
55	137.21	68.37	68.84	175.97	1.56
105	174.00	81.77	92.23	178.06	1.04

APPENDIX 2
Results of Particle Size Analysis

1-1-BOTTOM PCT. GRAVEL 0.00 SAND 0.30681 SIEVE AND PIPELINE(2) SAMPLE WT.= 19.9652
46.56 SILT (PIPELINE) 21.26 CLAY (PIPELINE) 32.18
(SEDIGRAPH) 0.00 (SEDIGRAPH) 0.00
GRAVEL+SAND 46.56 SILT/(SILT+CLAY) 39.79PCT. GRAV+SAND/SILT+CLAY .87
LABELS SHEPARD -SAN SIL CLY FOLK(GMS)-SANDY MUD

1-6-BOTTOM PCT. GRAVEL 0.00 SAND 0.30681 SIEVE AND PIPELINE(2) SAMPLE WT.= 20.7314
58.78 SILT (PIPELINE) 13.36 CLAY (PIPELINE) 27.85
(SEDIGRAPH) 0.00 (SEDIGRAPH) 0.00
GRAVEL+SAND 58.78 SILT/(SILT+CLAY) 32.41PCT. GRAV+SAND/SILT+CLAY 1.43
LABELS SHEPARD -CLAYEY SAND FOLK(GMS)-MUDY SAND - (SCSI)-CLAYEY SAND

1-10-BOTTOM PCT. GRAVEL 0.00 SAND 0.30681 SIEVE AND PIPELINE(2) SAMPLE WT.= 19.5625
43.55 SILT (PIPELINE) 12.26 CLAY (PIPELINE) 44.19
(SEDIGRAPH) 0.00 (SEDIGRAPH) 0.00
GRAVEL+SAND 43.55 SILT/(SILT+CLAY) 21.72PCT. GRAV+SAND/SILT+CLAY .77
LABELS SHEPARD -SANDY CLAY FOLK(GMS)-SANDY MUD
(SCSI)-SANDY CLAY

2-2-BOTTOM
PCT. GRAVEL C.00 030681 SIEVE AND PIPETTE(2) SAMPLE WT.=18.5169 CLAY (PIPETTE) 26.41
(SEDIGRAPH) 0.00 (SEDIGRAPH) 0.00
GRAVEL+SAND 58.86 SILT/(SILT+CLAY) 35.81PCT.GRAV+SAND+SILT+CLAY 1.43
LABELS SHEPARD -CLAYEY SAND FOLK(GMS)-MUDDY SAND (SCS)-MUDDY SAND

2-7-BOTTOM
PCT. GRAVEL C.00 030681 SIEVE AND PIPETTE(2) SAMPLE WT.=23.3192 CLAY (PIPETTE) 15.021
(SEDIGRAPH) C.00 (SEDIGRAPH) 0.00
GRAVEL+SAND 44.72 SILT/(SILT+CLAY) 27.51PCT.GRAV+SAND/SILT+CLAY .81
LABELS SHEPARD -CLAYEY SAND FOLK(GMS)-SANDY MUDDY CLAY (SCS)-SANDY CLAY

2-12-BOTTOM
PCT. GRAVEL C.00 030681 SIEVE AND PIPETTE(2) SAMPLE WT.=18.8014 CLAY (PIPETTE) 42.95
(SEDIGRAPH) C.00 (SEDIGRAPH) 0.00
GRAVEL+SAND 26.95 SILT/(SILT+CLAY) 41.21PCT.GRAV+SAND/SILT+CLAY .37
LABELS SHEPARD -SAN SIL CLY FOLK(GMS)-SAVVY MUDDY (SCS)-SANDY MUDDY

3-2-BOTTOM PCT. GRAVEL 1 0.00 SAND 59.12 SILT (PIPETTE) 15.20 CLAY. (PIPETTE) 3544
SIEVE AND PIPETTE (2) SAMPLE WT.=²⁶₂₁ 3544
(SEDIGRAPH) 0.00 (SEDIGRAPH) 0.00
GRAVEL+SAND 59.12 SILT/(SILT+CLAY) 36.33PCT.GRAV+SAND/SILT+CLAY .39
LABELS SHEPARD -CLAYEY SAND FOLK(GMS)-MUDY SAND

3-6-BOTTOM PCT. GRAVEL 1 0.00 SAND 42.53 SIEVE AND PIPETTE (2) SAMPLE WT.=²¹₁₉ 3394
SILT (PIPETTE) 19.32 CLAY (PIPETTE) 38.15
(SEDIGRAPH) 0.00 (SEDIGRAPH) 0.00
GRAVEL+SAND 42.53 SILT/(SILT+CLAY) 33.61PCT.GRAV+SAND/SILT+CLAY .74
LABELS SHEPARD -CLAYEY SAND FOLK(GMS)-SANDY MUD

3-11-BOTTOM PCT. GRAVEL 1 0.00 SAND 20.64 SIEVE AND PIPETTE (2) SAMPLE WT.=²³₂₇ 3840
SILT (PIPETTE) 27.29 CLAY (PIPETTE) 52.07
(SEDIGRAPH) 0.00 (SEDIGRAPH) 0.00
GRAVEL+SAND 20.64 SILT/(SILT+CLAY) 34.39PCT.GRAV+SAND/SILT+CLAY .26
LABELS SHEPARD -SAN SIL CLY FOLK(GMS)-SANDY MUD

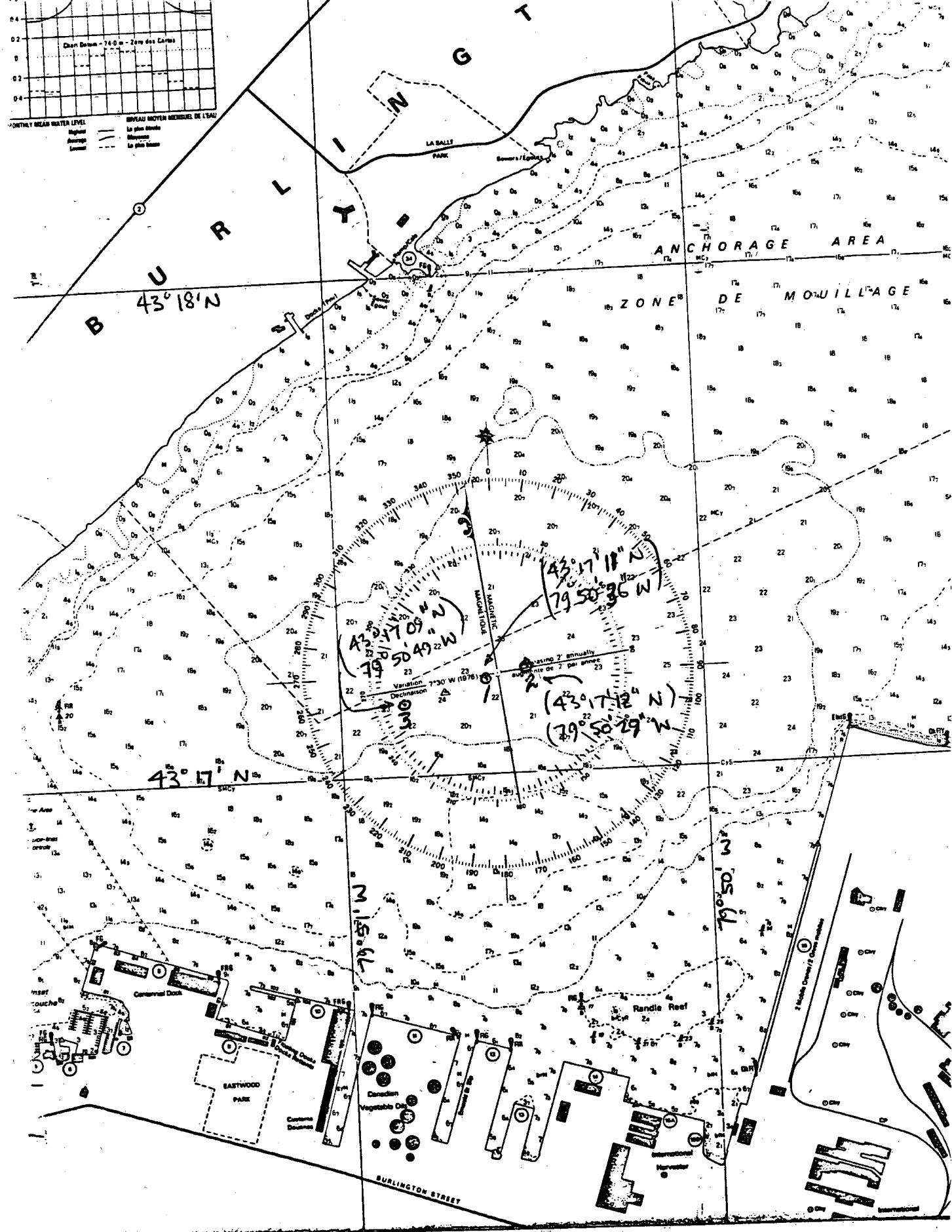


FIGURE 1. CORE LOCATIONS

CORE NO. 1

Hawthor Harbour Basin

NATURAL WATER CONTENT
AND ATTERBERG LIMITS

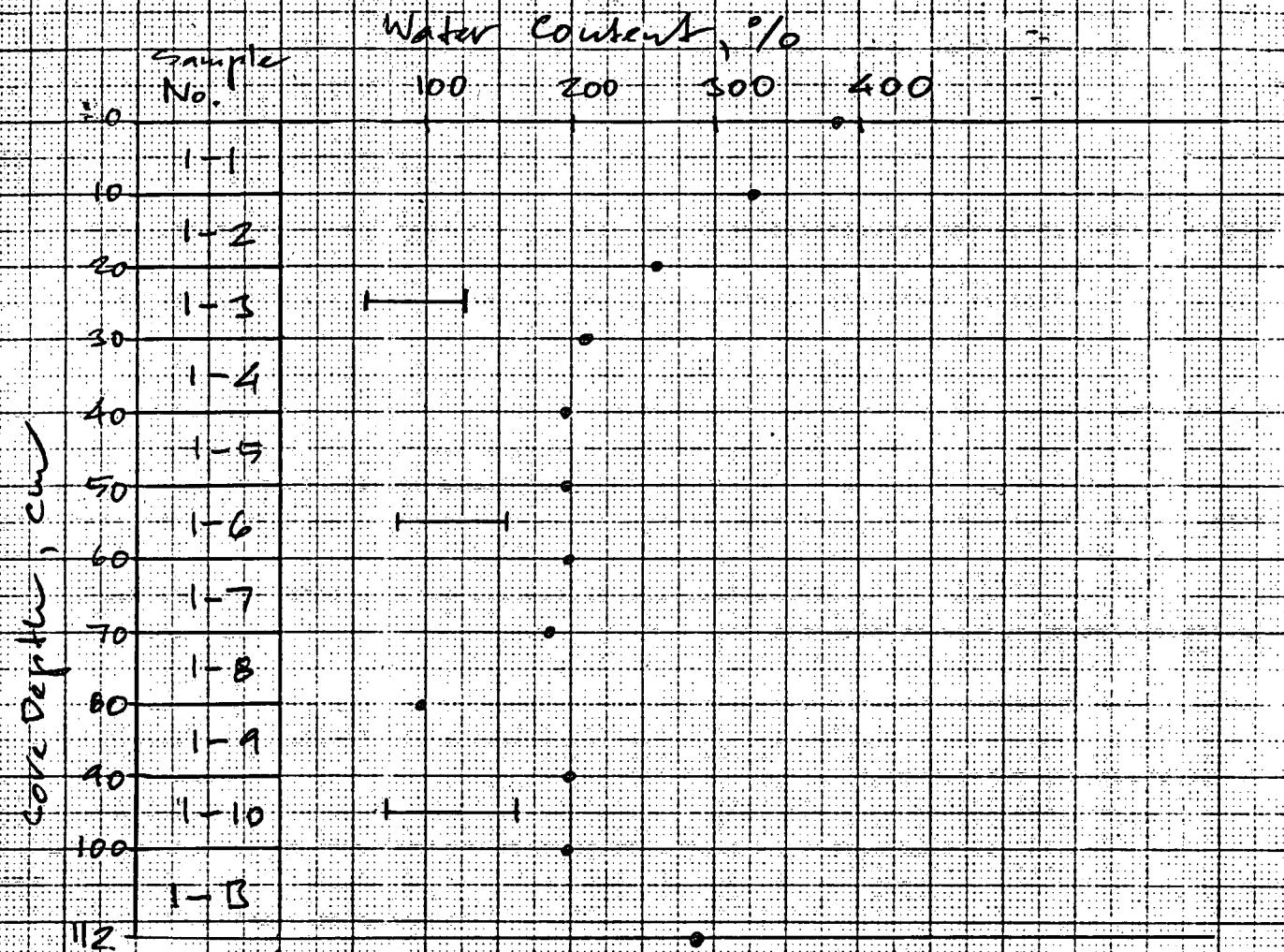
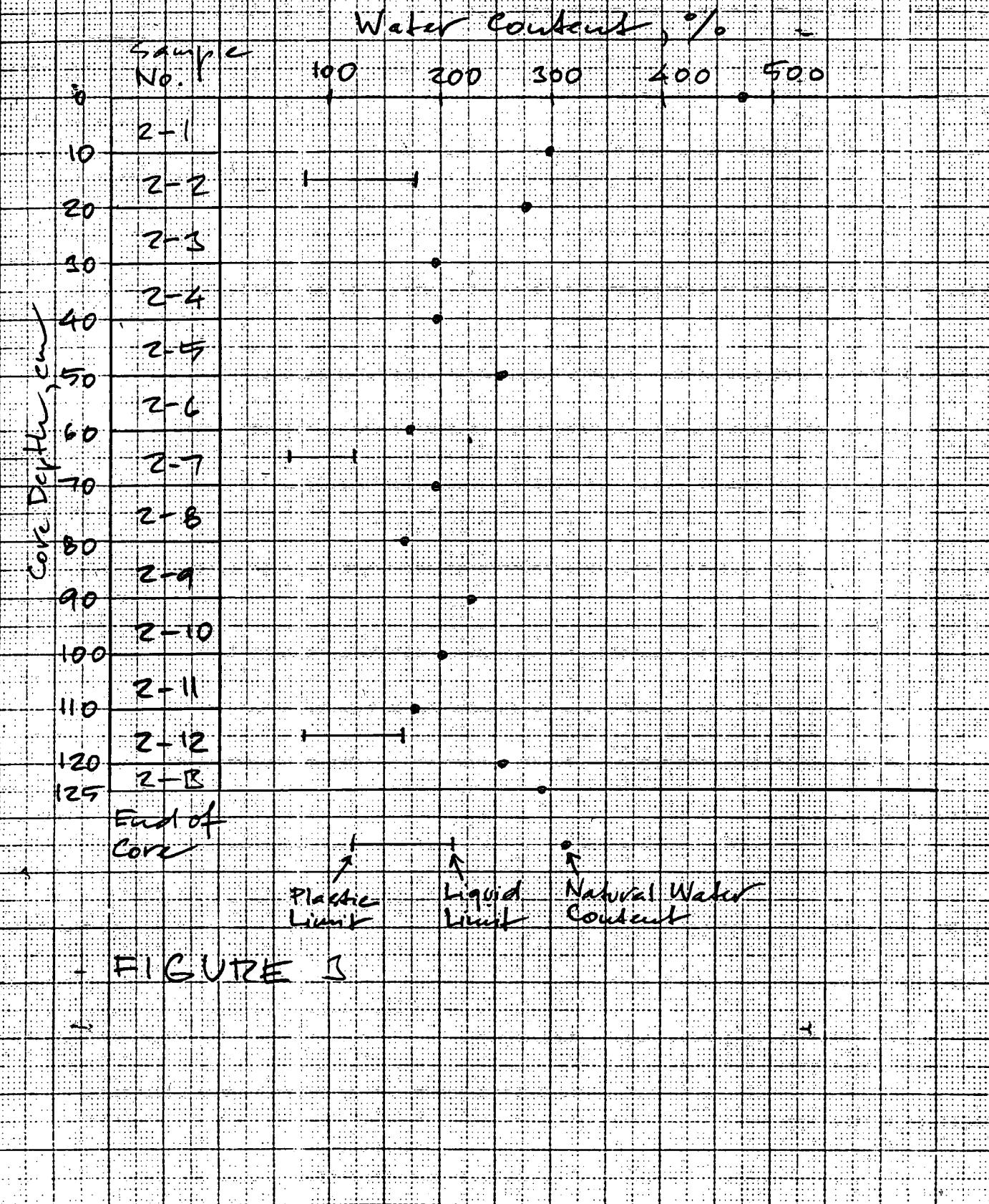


FIGURE 2

CORE NO. 2

Hamilton Harbour Basin

NATURAL WATER CONTENT
AND ATTERBERG LIMITS

CORE NO. 3

Hamilton Harbour Basin

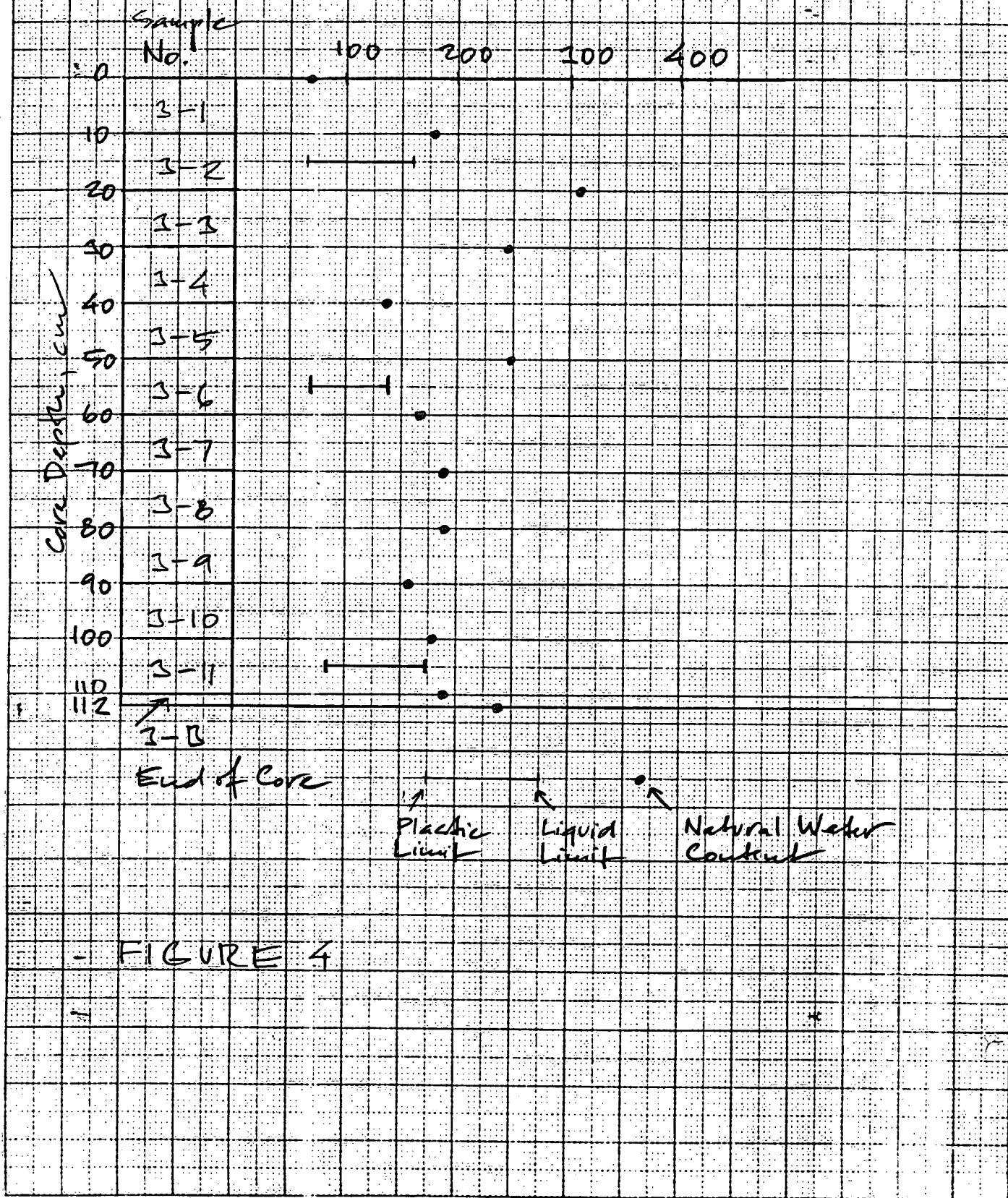
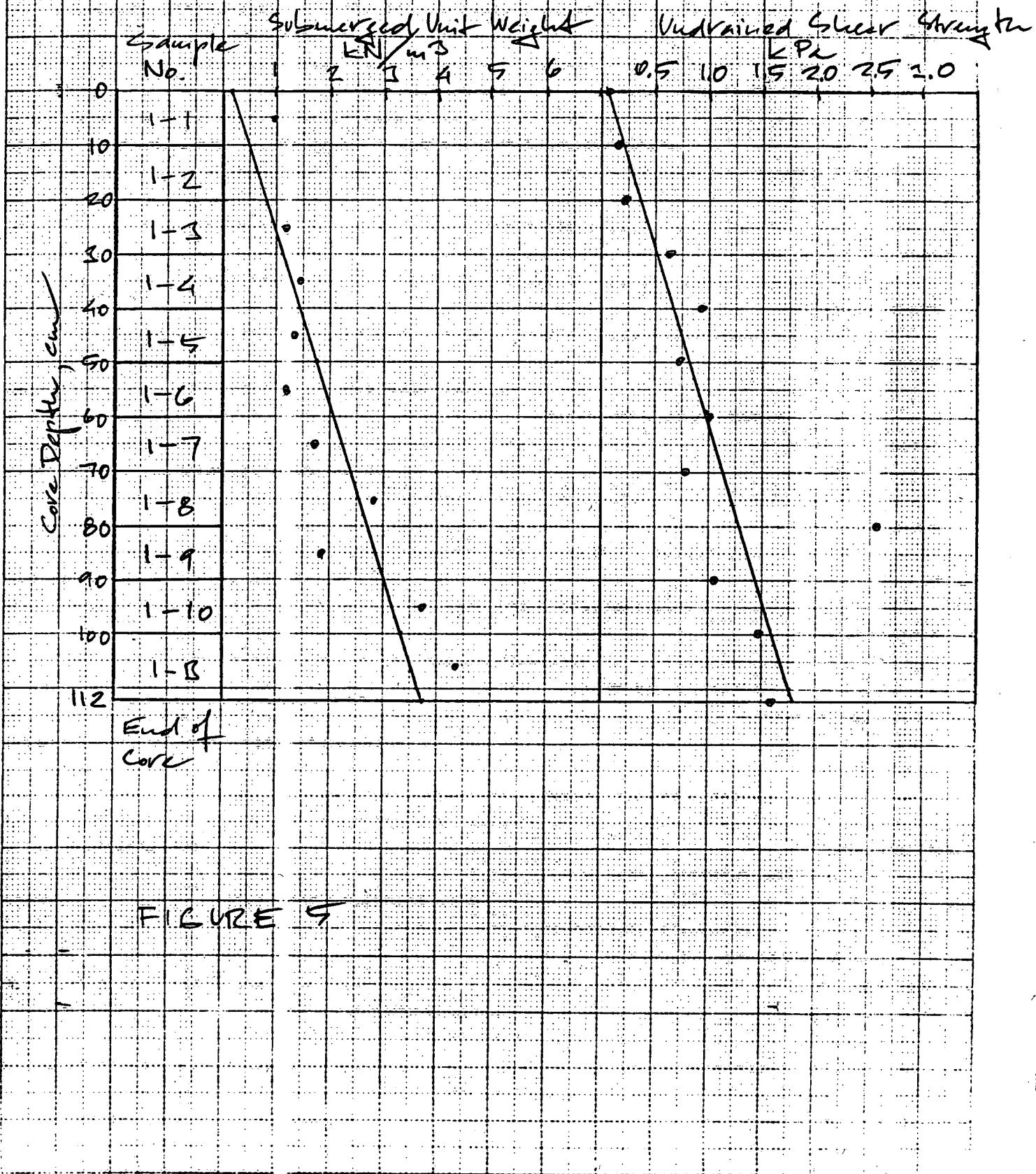
NATURAL WATER CONTENT
AND ATTERBERG LIMITS

FIGURE 4

CORE NO. 1

SUBMERGED UNIT WEIGHT

AND UNDRAINED SHEAR STRENGTH

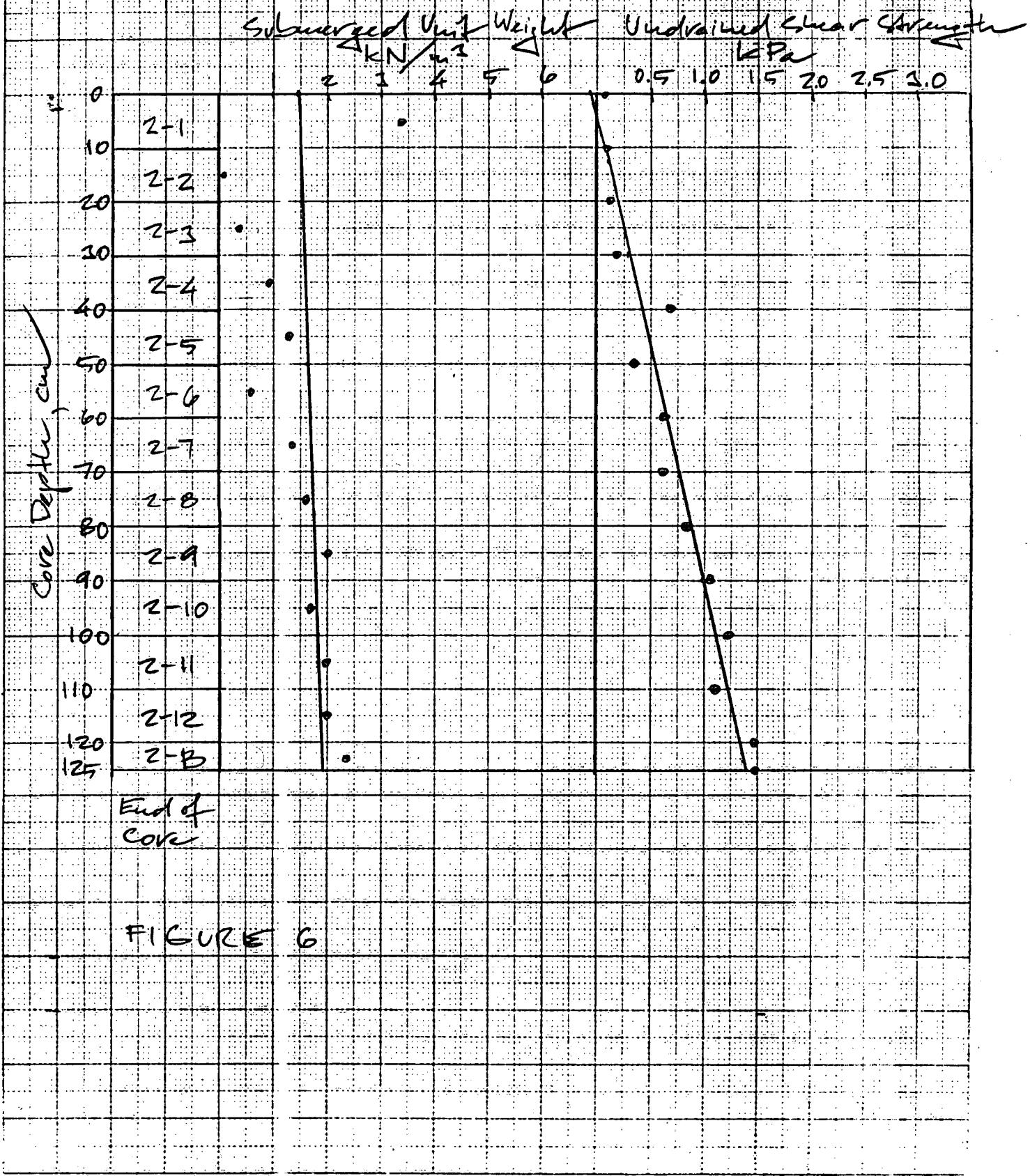


CORE NO. 2

Hamilton Harbour Basin

SUBMERGED UNIT WEIGHT

AND UNDRAINED SHEAR STRENGTH



CORE NO. 3

Hamilton Harbour Basin

SUBMERGED UNIT WEIGHT

AND UNDRAINED SHEAR STRENGTH

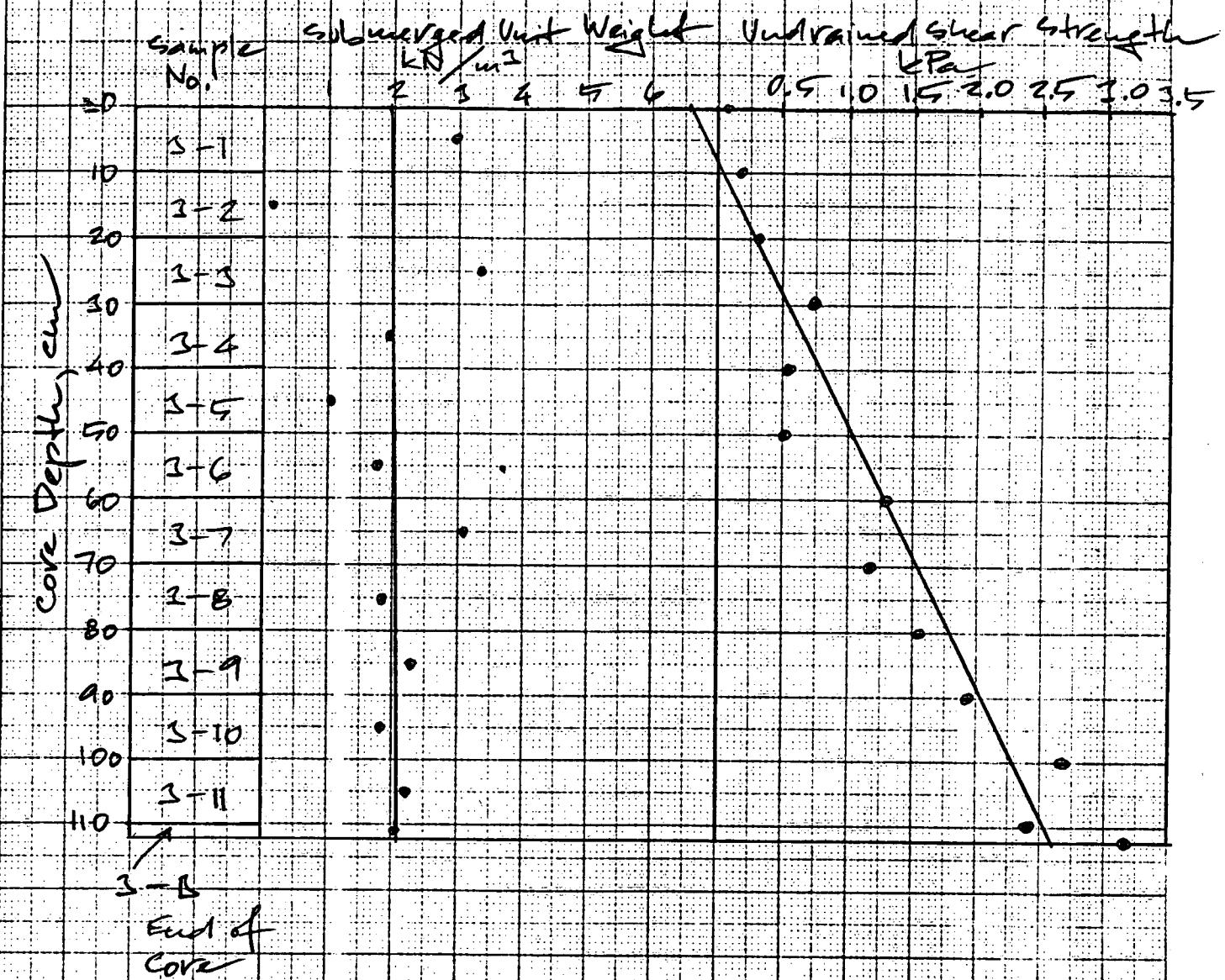


FIGURE 7

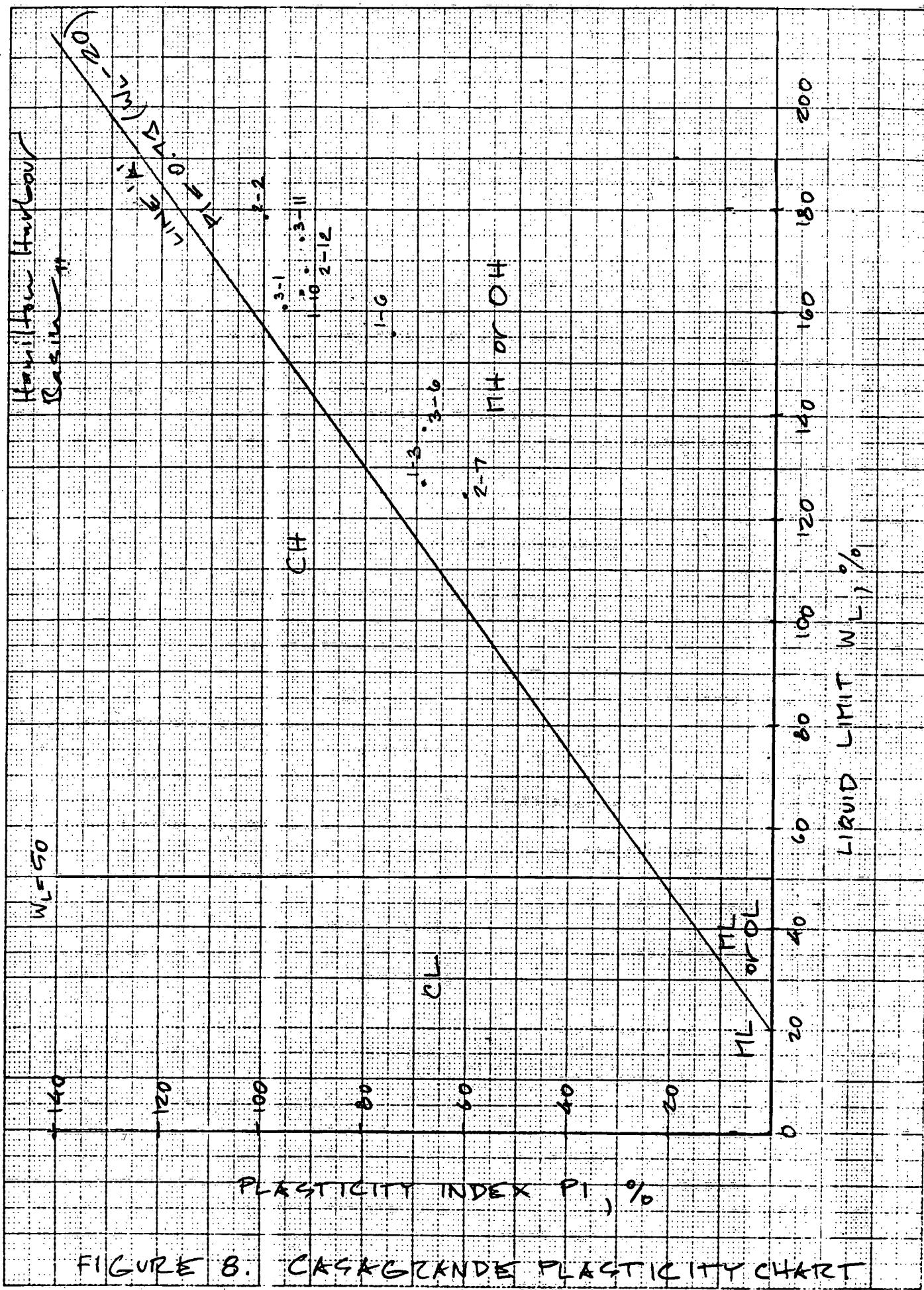


FIGURE 8. CASAGRANDE PLASTICITY CHART

46 4490
CLAY

SHEPARD'S CLASSIFICATION

- 1-1 sandy silty clay
- 1-6 clayey sand
- 1-10 sandy clay
- 2-2 clayey sand
- 2-7 clayey sand
- 2-12 sandy silty clay
- 3-2 clayey sand
- 3-6 clayey sand
- 3-11 sandy silty clay

Hamilton Harbour
Bogaine

14

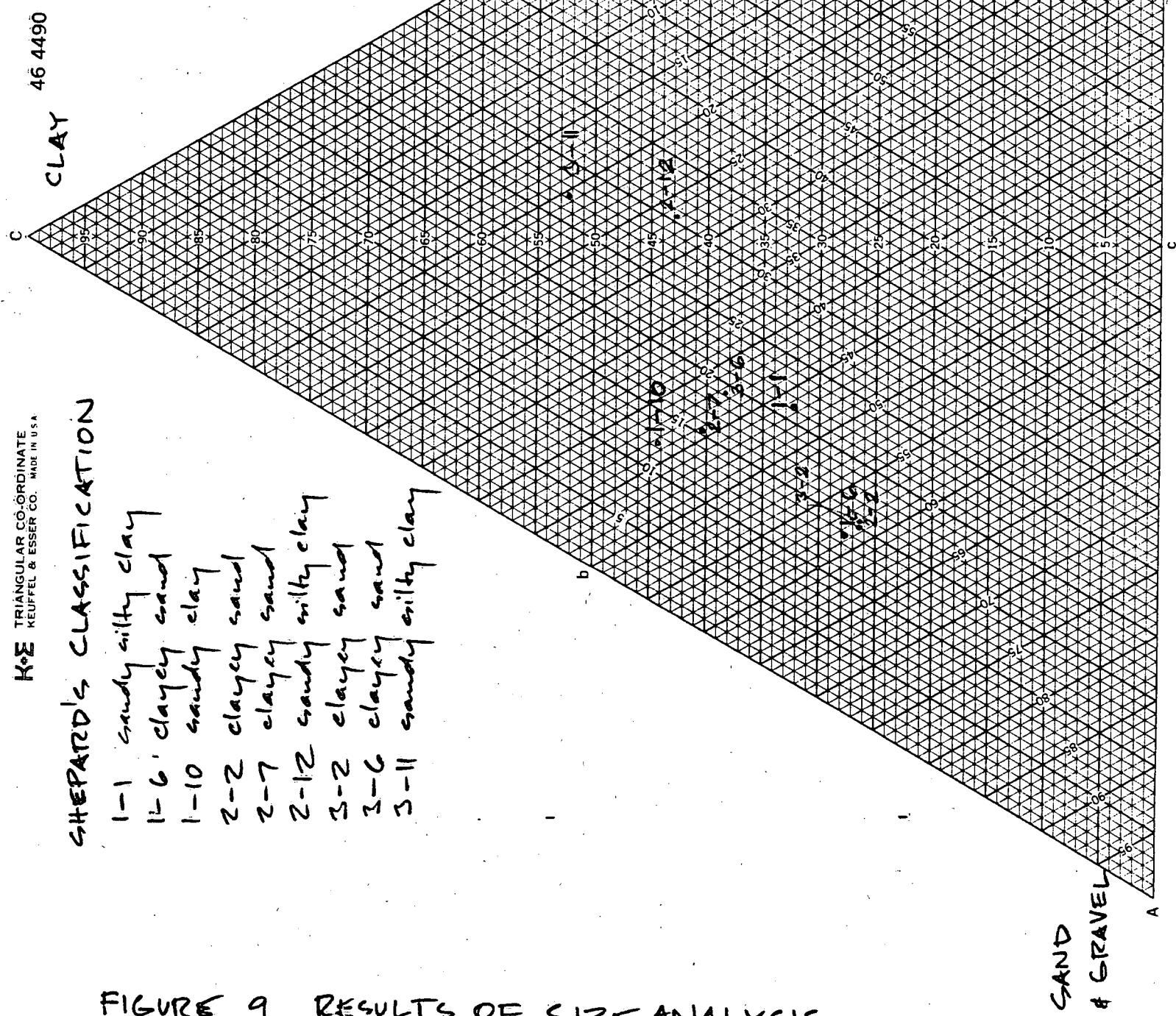


FIGURE 9. RESULTS OF SIZE ANALYSIS

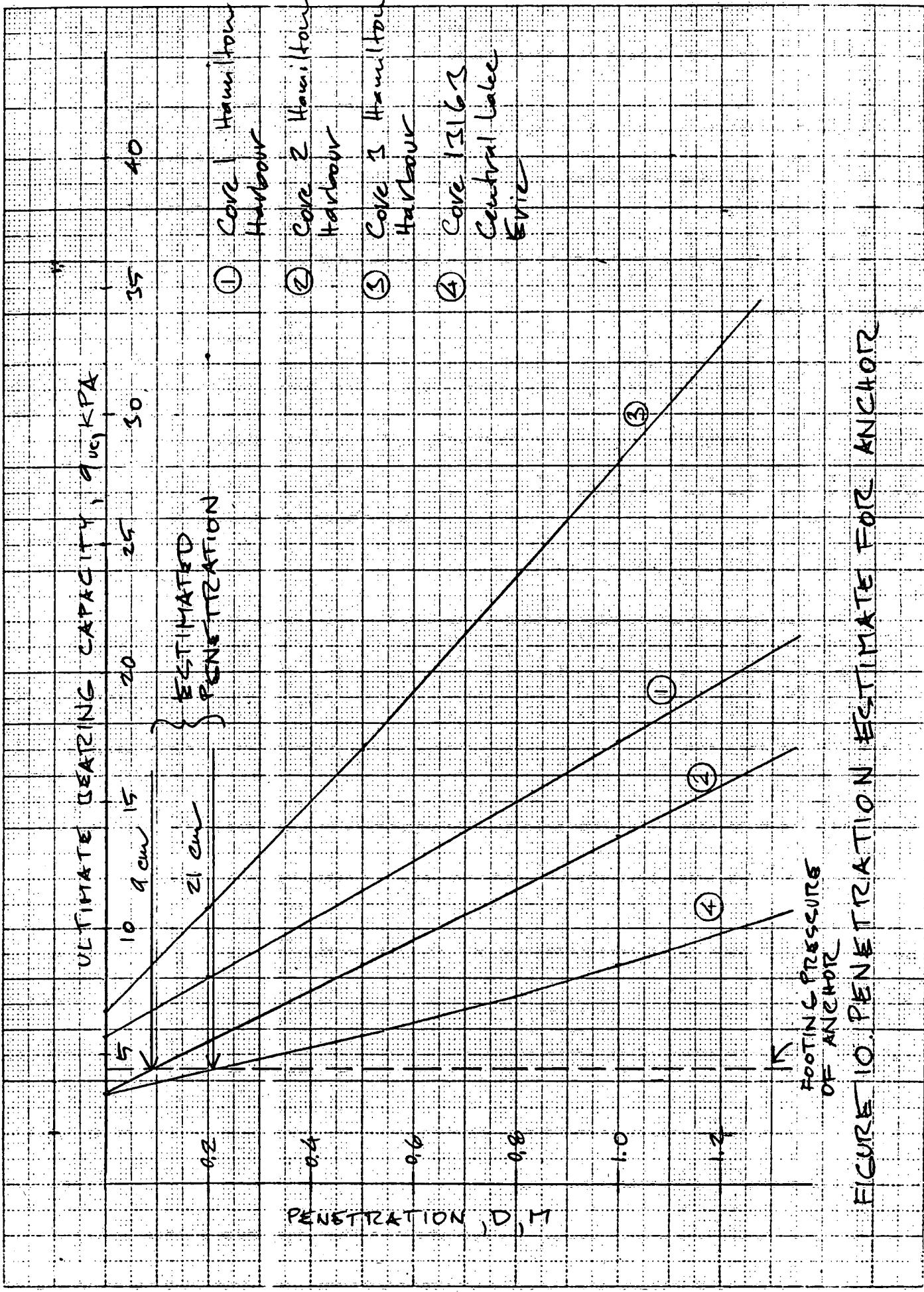
**FIGURE 10 PENETRATION TEST-MATE FOR ANCHOR**

FIGURE 11. PENETRATION ESTIMATE FOR PROFILE LINE C WHICH

