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GEOCRES No. 31M-52

DIST. 14 REGION

W.P. No. 288-88-00

CONT. No. 88-357

W. O. No.

STR. SITE No.

HWY. No. 65

LOCATION Embankment Failure
Kerns Township

No of PAGES -

OVERSIZE DRAWINGS TO BE INCLUDED WITH THIS REPORT.

REMARKS:

FOUNDATION INVESTIGATION REPORT

CONTRACT NO 88-357

Ministry of Transportation and Communications

Ontario

I N D E X

NOTE: For the purpose of this Contract, this report supersedes all other reports prepared by or for the Ministry in connection with the above-noted project.

EXPLANATION OF TERMS USED IN REPORT

N VALUE: THE STANDARD PENETRATION TEST (SPT) N VALUE IS THE NUMBER OF BLOWS REQUIRED TO CAUSE A STANDARD 51mm O.D SPLIT BARREL SAMPLER TO PENETRATE 0.3m INTO UNDISTURBED GROUND IN A BOREHOLE WHEN DRIVEN BY A HAMMER WITH A MASS OF 63.5kg, FALLING FREELY A DISTANCE OF 0.76m. FOR PENETRATIONS OF LESS THAN 0.3m N VALUES ARE INDICATED AS THE NUMBER OF BLOWS FOR THE PENETRATION ACHIEVED. AVERAGE N VALUE IS DENOTED THUS $\bar{N}$.

DYNAMIC CONE PENETRATION TEST: CONTINUOUS PENETRATION OF A CONICAL STEEL POINT (51mm O.D. 60° CONE ANGLE) DRIVEN BY 475 J IMPACT ENERGY ON 'A' SIZE DRILL RODS. THE RESISTANCE TO CONE PENETRATION IS MEASURED AS THE NUMBER OF BLOWS FOR EACH 0.3m ADVANCE OF THE CONICAL POINT INTO THE UNDISTURBED GROUND.

SOILS ARE DESCRIBED BY THEIR COMPOSITION AND CONSISTENCY OR DENSENESS.

CONSISTENCY: COHESIVE SOILS ARE DESCRIBED ON THE BASIS OF THEIR UNDRAINED SHEAR STRENGTH (c_u) AS FOLLOWS:

c_u (kPa)	0 - 12	12 - 25	25 - 50	50 - 100	100 - 200	>200
	VERY SOFT	*SOFT*	*FIRM*	*STIFF*	*VERY STIFF*	*HARD*

DENSENESS: COHESIONLESS SOILS ARE DESCRIBED ON THE BASIS OF DENSENESS AS INDICATED BY SPT N VALUES AS FOLLOWS:

N (BLOWS/0.3m)	0 - 5	5 - 10	10 - 30	30 - 50	>50
	VERY LOOSE	*LOOSE*	*COMPACT*	*DENSE*	*VERY DENSE*

ROCKS ARE DESCRIBED BY THEIR COMPOSITION AND STRUCTURAL FEATURES AND / OR STRENGTH.

RECOVERY: SUM OF ALL RECOVERED ROCK CORE PIECES FROM A CORING RUN EXPRESSED AS A PERCENT OF THE TOTAL LENGTH OF THE CORING RUN.

MODIFIED RECOVERY: SUM OF THOSE INTACT CORE PIECES, 100mm+ IN LENGTH EXPRESSED AS A PERCENT OF THE LENGTH OF THE CORING RUN. THE ROCK QUALITY DESIGNATION (R Q D), FOR MODIFIED RECOVERY, IS:

RQD (%)	0 - 25	25 - 50	50 - 75	75 - 90	90 - 100
	VERY POOR	*POOR*	*FAIR*	*GOOD*	*EXCELLENT*

JOINTING AND BEDDING:

SPACING	50mm	50 - 300mm	0.3m - 1m	1m - 3m	>3m
JOINTING	*VERY CLOSE*	*CLOSE*	*MOD. CLOSE*	*WIDE*	*VERY WIDE*
BEDDING	*VERY THIN*	*THIN*	*MEDIUM*	*THICK*	*VERY THICK*

ABBREVIATIONS AND SYMBOLS

FIELD SAMPLING

S S	SPLIT SPOON	T P	THINWALL PISTON
W S	WASH SAMPLE	O S	OSTERBERG SAMPLE
S T	SLOTTED TUBE SAMPLE	R C	ROCK CORE
B S	BLOCK SAMPLE	P H	T W ADVANCED HYDRAULICALLY
C S	CHUNK SAMPLE	P M	T W ADVANCED MANUALLY
T W	THINWALL OPEN	F S	FOIL SAMPLE

STRESS AND STRAIN

u_w	kPa	PORE WATER PRESSURE
r_u	1	PORE PRESSURE RATIO
σ	kPa	TOTAL NORMAL STRESS
σ'	kPa	EFFECTIVE NORMAL STRESS
τ	kPa	SHEAR STRESS
$\sigma_1, \sigma_2, \sigma_3$	kPa	PRINCIPAL STRESSES
ϵ	%	LINEAR STRAIN
$\epsilon_1, \epsilon_2, \epsilon_3$	%	PRINCIPAL STRAINS
E	kPa	MODULUS OF LINEAR DEFORMATION
G	kPa	MODULUS OF SHEAR DEFORMATION
μ	1	COEFFICIENT OF FRICTION

MECHANICAL PROPERTIES OF SOIL

m_v	kPa^{-1}	COEFFICIENT OF VOLUME CHANGE
C_c	1	COMPRESSION INDEX
C_s	1	SWELLING INDEX
C_α	1	RATE OF SECONDARY CONSOLIDATION
c_v	m^2/s	COEFFICIENT OF CONSOLIDATION
H	m	DRAINAGE PATH
T_v	1	TIME FACTOR
U	%	DEGREE OF CONSOLIDATION
σ'_{vo}	kPa	EFFECTIVE OVERBURDEN PRESSURE
σ'_p	kPa	PRECONSOLIDATION PRESSURE
τ_f	kPa	SHEAR STRENGTH
c'	kPa	EFFECTIVE COHESION INTERCEPT
ϕ'	-°	EFFECTIVE ANGLE OF INTERNAL FRICTION
c_u	kPa	APPARENT COHESION INTERCEPT
ϕ_u	-°	APPARENT ANGLE OF INTERNAL FRICTION
τ_R	kPa	RESIDUAL SHEAR STRENGTH
τ_r	kPa	REMOULDED SHEAR STRENGTH
S_t	1	SENSITIVITY $= \frac{c_u}{\tau_r}$

PHYSICAL PROPERTIES OF SOIL

ρ_s	kg/m^3	DENSITY OF SOLID PARTICLES
γ_s	kN/m^3	UNIT WEIGHT OF SOLID PARTICLES
ρ_w	kg/m^3	DENSITY OF WATER
γ_w	kN/m^3	UNIT WEIGHT OF WATER
ρ	kg/m^3	DENSITY OF SOIL
γ	kN/m^3	UNIT WEIGHT OF SOIL
ρ_d	kg/m^3	DENSITY OF DRY SOIL
γ_d	kN/m^3	UNIT WEIGHT OF DRY SOIL
ρ_{sat}	kg/m^3	DENSITY OF SATURATED SOIL
γ_{sat}	kN/m^3	UNIT WEIGHT OF SATURATED SOIL
ρ'	kg/m^3	DENSITY OF SUBMERGED SOIL
γ'	kN/m^3	UNIT WEIGHT OF SUBMERGED SOIL
e	1,%	VOID RATIO
n	1,%	POROSITY
w	1,%	WATER CONTENT
S_r	%	DEGREE OF SATURATION
w_L	%	LIQUID LIMIT
w_P	%	PLASTIC LIMIT
w_s	%	SHRINKAGE LIMIT
I_P	%	PLASTICITY INDEX $= w_L - w_P$
I_L	1	LIQUIDITY INDEX $= \frac{w - w_P}{I_P}$
I_C	1	CONSISTENCY INDEX $= \frac{w_L - w}{I_P}$
e_{max}	1,%	VOID RATIO IN LOOSEST STATE
e_{min}	1,%	VOID RATIO IN DENSEST STATE
I_D	1	DENSITY INDEX $= \frac{e_{max} - e}{e_{max} - e_{min}}$
D	mm	GRAIN DIAMETER
D_n	mm	n PERCENT - DIAMETER
C_u	1	UNIFORMITY COEFFICIENT
h	m	HYDRAULIC HEAD OR POTENTIAL
q	m^3/s	RATE OF DISCHARGE
v	m/s	DISCHARGE VELOCITY
i	1	HYDRAULIC GRADIENT
k	m/s	HYDRAULIC CONDUCTIVITY
j	kN/m^3	SEEPAGE FORCE

FOUNDATION INVESTIGATION REPORT
For
Highway 65
Embankment Failure, Culvert Replacement
W.P. 288-88-00, Kerns Township
District #14, New Liskeard

INTRODUCTION

This report contains the results of a foundation investigation carried out as requested by the Northern Regional Office at the above-mentioned embankment failure site. The request was made following a surficial slope failure at the culvert inlet and subsequent local culvert collapse observed in the Spring of 1987. The fieldwork was conducted during the period from 87 09 29 to 87 10 04 utilizing a continuous flight auger machine equipped with 83 mm I.D. hollow stem augers. The field investigation consisted of four sampled boreholes together with four adjacent dynamic cone penetration tests. Two boreholes were advanced on the shoulders of the roadway and two boreholes were placed at the base of the highway embankment in the vicinity of the culver inlet and outlet.

SITE DESCRIPTION

The site is located at Highway 65, approximately 800 m east of Secondary Highway 562. It is situated in Kerns Township some 30 km outside the town of New Liskeard. The terrain in the immediate vicinity is fairly flat although the culvert lies along a gulley that has been filled to the level of the roadway. The natural ground slopes in the vicinity of the culvert inlet and outlet rise up to 11.2 m on the north side of Highway 65 and 7.0 m on the south side of the highway. Surface erosion is visible on the natural slopes and the highway embankment slopes, in the forms of deep gulleys and rippled slopes. Land use is primarily agricultural. The site lies in the physiographic region known as the Cobalt Plain, a glaciolacustrine clay plain featured in the New Liskeard Lowland.

SUBSURFACE CONDITIONS

General

The subsoil encountered at this location consists predominately of varved silty clay. Boreholes 1 and 2 were advanced on the shoulders of the roadway and were comprised of sand and silty clay fills deposited to a thickness of 7.0 m above the original silty clay deposit. The varved silty clay layer varies in thickness from 11.6 m to 25.9 m. It is underlayen by a thin stratum of silt at two of the borehole locations. A hard material impenetrable by both split spoon and augering was encountered at the base of each borehole.

The boundaries of the different strata encountered at the boring locations together with the obtained field and laboratory test results are shown on the Record of Borehole sheets found in the Appendix of this report. A sketch showing the relative location of the boreholes is also appended. A description of the different strata is provided below.

Sand (Fill Material)

A sand fill material was encountered directly beneath the asphalt in BH's 1 and 2 located on the shoulders of Highway 65. It extends to a depth of 4.4 m in BH 1 and to a depth of 4.3 m in BH 2 where it is intersected by a layer of silty clay fill material. The sand fill contains varying proportions of gravel, trace to some silt, traces of asphalt and occasional silty clay zones. The 'N' values range from 12 to 85 reflecting a denseness of compact to very dense. From laboratory testing, the natural moisture content varies from 8% to 12.5%. Grain size distribution curves for the sand fill are shown in Figure 1.

Silty Clay (Fill Material)

A silty clay fill deposit was present in the boreholes advanced on the shoulders of Highway 65. In BH 1, the silty clay fill extends beneath the sand fill for a thickness of 2.6 m. In BH 2, layers of sand fill alternate with silty clay fill layers to a depth of 5.2 m. The cohesive fill material contains varying proportions of sand and gravel, and traces of asphalt were present in the upper most layer in BH 2. 'N' values obtained from field testing range from 4 to 22 blows per 30 cm. The consistency of the material varies from firm to very stiff and it exhibits low to high plasticity.

Field and laboratory testing performed on the material yielded the following physical properties:

	Range
Natural Moisture Content (%)	11-42
Liquid Limit (%)	28-67
Plastic Limit (%)	15-25
Unit Weight (kN/m^3)	19.2
Undrained Shear Strength - Field Vane (kPa)	75-77

Silty Clay

An extensive deposit of varved silty clay was encountered in all of the boreholes. It is present beneath the fill materials in BH's 1 and 2 and occurs as the surficial deposit in BH's 3 and 4. The thickness of the deposit varies from 11.6 m to 20.7 m, the depth and thickness increasing in the boreholes advanced at the east end of the culvert.

The silty clay contains a trace of sand and organic material is present near the ground surface of all boreholes except BH 3 where some excavation had taken place. The silty clay is varved, the layers varying in thickness from 0.5 cm to 5.0 cm. Laboratory testing on the individual varve layers indicate that the varves are composed of silt to silty clay material of low plasticity and of clay to silty clay of medium to high plasticity. Where testing was performed on a sample containing both materials the plasticity ranged from low to medium plasticity. The range of plasticities are graphed on the Plasticity Chart, Figure 2. 'N' values obtained from field sampling range from 2 to 10 blows per 30 cm. The consistency varies from very soft to stiff. The following properties were obtained from laboratory and field testing:

	Range
Natural Moisture Content (%)	25.0-67.0
Liquid Limit (%)	22.0-68.0
Plastic Limit (%)	16.0-24.0
Unit Weight (kN/m^3)	17.3-19.2
Undrained Shear Strength - Field Vane (kPa)	33.0-92.0
Unconfined Shear Strength (kPa)	21.5-45.6

Silt

In BH's 2, 3 and 4 a stratum of non-plastic silt was encountered below the varved silty clay deposit. The thickness of the silt layer ranges from 2.9 m to 3.7 m and it overlies the hard material encountered at the bottom of each of the boreholes. The 'N' values obtained range from 0 to 4 reflecting a denseness of very loose to loose. From laboratory testing, the natural moisture content of the silt varies from 29% to 31%.

Groundwater Conditions

Groundwater was encountered in each of the four boreholes at considerable depths. The following groundwater levels were observed during the field investigation:

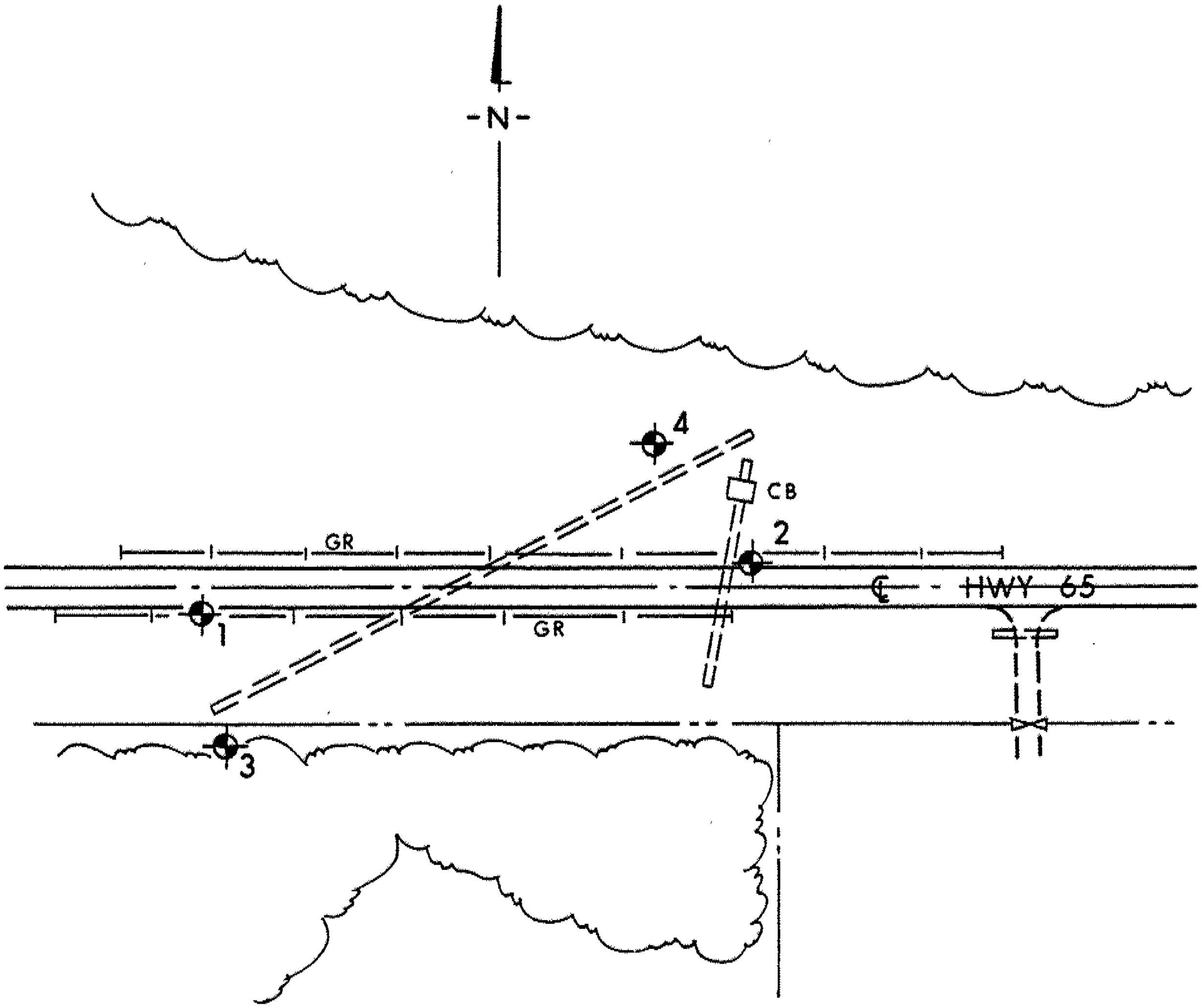
Borehole	Groundwater Elevation
1	239.6 m
2	227.7 m
3	230.7 m
4	227.2 m

No artesian water conditions were experienced

P. Payer, P. Eng.
Senior Foundation Engineer

M. Devata, P. Eng.
Chief Foundation Engineer

APPENDIX



SKETCH SHOWING BORE HOLE LOCATION

NTS

WP 288-88-00
KERNS TOWNSHIP

Ministry of Transportation and Communications
Ontario

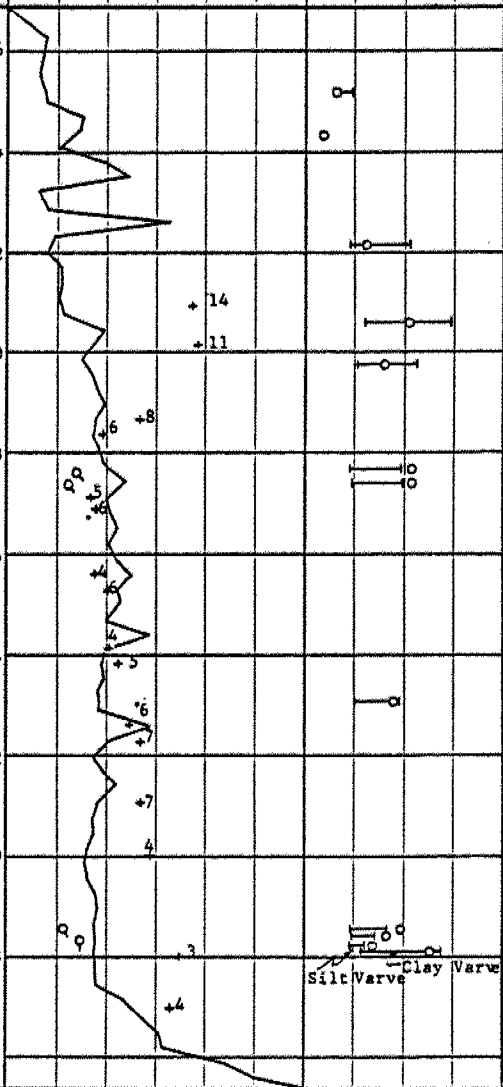
RECORD OF BOREHOLE No 1

METRIC

W P 288-88-00 LOCATION Sta. 18 + 750 O/S 3.8 m Lt. ORIGINATED BY BB
DIST 14 HWY 65 BOREHOLE TYPE H.S. Auger COMPILED BY BB
DATUM Geodetic DATE 87 09 29 - 87 09 20 CHECKED BY [signature]

ELEV DEPTH	DESCRIPTION	STRAT PLOT	SAMPLE NUMBER	TYPE	'N' VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
246.9	Ground Surface								
0.0	Asphalt								
0.2	Traces of Asphalt		1	SS	12		246		
	Sand (Fill Material)		2	SS	19				9 51 (40)
	Some/with Gravel		3	SS	71				33 58 (9)
	Occ. Silty Clay Zones						244		
	Compact to		4	SS	31				
	Very Dense		5	SS	34				
242.5 / 4.4	Silty Clay (Fill Material)		6	SS	18		242	19.2	0 5 (95)
	Trace Sand		7	SS	12				
	Trace Gravel								
	Soft to		8	SS	4				0 4 (96)
239.9	Very Stiff								
7.0	Thin Seams of Peat		9	SS	8	▼	240		0 0 (100)
			10	SS	5				
							238	17.6	0 0 (100)
	Silty Clay		11	TW	PH			17.4	
	Varved		12	SS	2		236		
	Soft		13	SS	3				
	to						234		
	Firm		14	SS	2			18.1	
			15	SS	3		232		
							230		
			16	TW	PH			18.0	0 0 (100)
							228	18.9	0 0 (100)
									0 0 (100)
							226		
225.6	Probable Hard Glacial Till		17	SS	60/8 cm				
21.5	End of Borehole								

DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100
SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE 20 40 60 80 100
PLASTIC LIMIT W_p NATURAL MOISTURE CONTENT W LIQUID LIMIT W_L
WATER CONTENT (%) 20 40 60



OFFICE REPORT ON SOIL EXPLORATION

+3, ×5 : Numbers refer to Sensitivity

15 -○- 5 (%) STRAIN AT FAILURE (20 above, 10 below)

Ministry of Transportation and Communications
Ontario

OFFICE REPORT ON SOIL EXPLORATION

RECORD OF BOREHOLE No 2

METRIC

W P 288-88-00 | LOCATION Sta. 18 + 658.8 O/S 3.1 m Rt. | ORIGINATED BY BB
DIST 14 HWY 65 | BOREHOLE TYPE H.S. Auger | COMPILED BY BB
DATUM Geodetic | DATE 87 10 01 - 02 | CHECKED BY [signature]

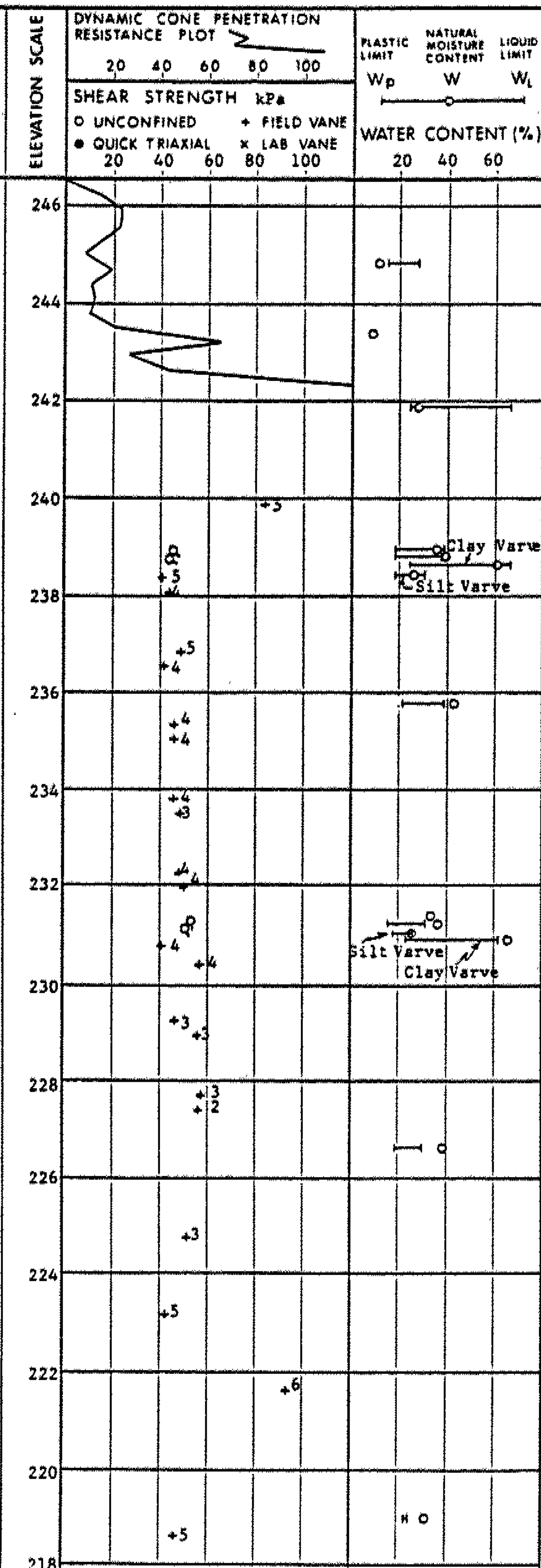
Soil Profile and Samples

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	'N' VALUES
246.6	Ground Surface			
246.4 / 0.2	Sand (Fill Material) Trace Gravel Trace Silt Compact	1	SS	23
245.2 / 1.4	Silty Clay (Fill Material) Some/with Sand Trace/Some Gravel Traces of Asphalt Stiff to Very Stiff	2	SS	22
		3	SS	10
243.7 / 2.9	Sand (Fill Material) Some/With Gravel Some Silt Dense to Very Dense	4	SS	30
		5	SS	85
242.3 / 4.3	Silty Clay (Fill Material) Trace Sand Very Stiff	6	SS	19
241.4 / 5.2	Silty Clay Varved Soft to Stiff (Trace Organics)	7	SS	10
		8	SS	9
		9	TW	PH
		10	SS	3
		11	SS	2
		12	SS	3
		13	SS	4
		14	TW	PH
		15	SS	4
		16	SS	5
		17	SS	2
		18	SS	3
		19	SS	2
		20	SS	3
220.7 / 25.9	Silt Very Loose	21	SS	0
217.8 / 28.8	Auger Refusal / End of Borehole			

Ground water level indicated at approx. elev. 228.

Unit Weight and Remarks

Sample	UNIT WEIGHT γ (kN/m³)	GR	SA	SI CL
2		17	55	(28)
4		22	64	(14)
6		0	0	(100)
9	18.4	0	0	(100)
9	18.2	0	0	(100)
9		0	0	(100)
11	17.7			
14	18.7	0	0	(100)
14	18.2	0	0	(100)
14		0	0	(100)



$+^3$, $\times^5$: Numbers refer to Sensitivity

15 -◇- 5 (%) STRAIN AT FAILURE (20 top, 10 bottom)

Ministry of Transportation and Communications
Ontario

RECORD OF BOREHOLE No 3

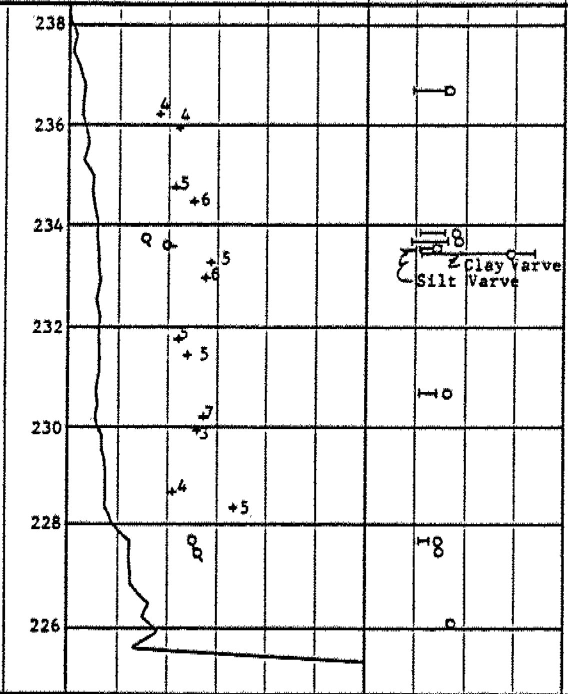
METRIC

W P 288-88-00 | LOCATION Sta. 18 + 747.9 O/S 28.0 m Lt. | ORIGINATED BY BB

DIST 14 HWY 65 | BOREHOLE TYPE H.S. Auger | COMPILED BY BB

DATUM Geodetic | DATE 87 10 03 | CHECKED BY [signature]

ELEV / DEPTH	DESCRIPTION (SOIL PROFILE)	SAMPLE NUMBER	TYPE	'N' VALUES	GROUND WATER CONDITIONS	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
238.4	Ground Surface						
0.0	Silty Clay, Varved, Trace Sand, Soft to Firm	1	SS	4			
		2	SS	4		18.5	0 0 (100)
		3	SS	2			
		4	TW	PH		17.8 / 17.8	0 0 (100) / 0 0 (100) / 0 0 (100)
		5	SS	2			
		6	SS	2	▼	19.0	0 1 (99)
		7	SS	5			
227.7 / 10.7	Silt, Loose	8	TW	PH		19.2 / 19.2	0 0 97 3
		9	SS	4			0 0 (100)
224.7	Probable Hard Glacial Till	10	SS	60/0 cm			
13.7	End of Borehole						



+3, ×5 : Numbers refer to Sensitivity

20 / 15 ⌖ 5 / 10 (%) STRAIN AT FAILURE

OFFICE REPORT ON SOIL EXPLORATION

Ministry of Transportation and Communications
Ontario

RECORD OF BOREHOLE No 4

METRIC

W P 288-88-00	LOCATION Sta. 18 + 675.1 O/S 24.2 m Rt.	ORIGINATED BY BB
DIST 14 HWY 65	BOREHOLE TYPE H.S. Auger	COMPILED BY BB
DATUM Geodetic	DATE 87 10 03 - 04	CHECKED BY [signature]

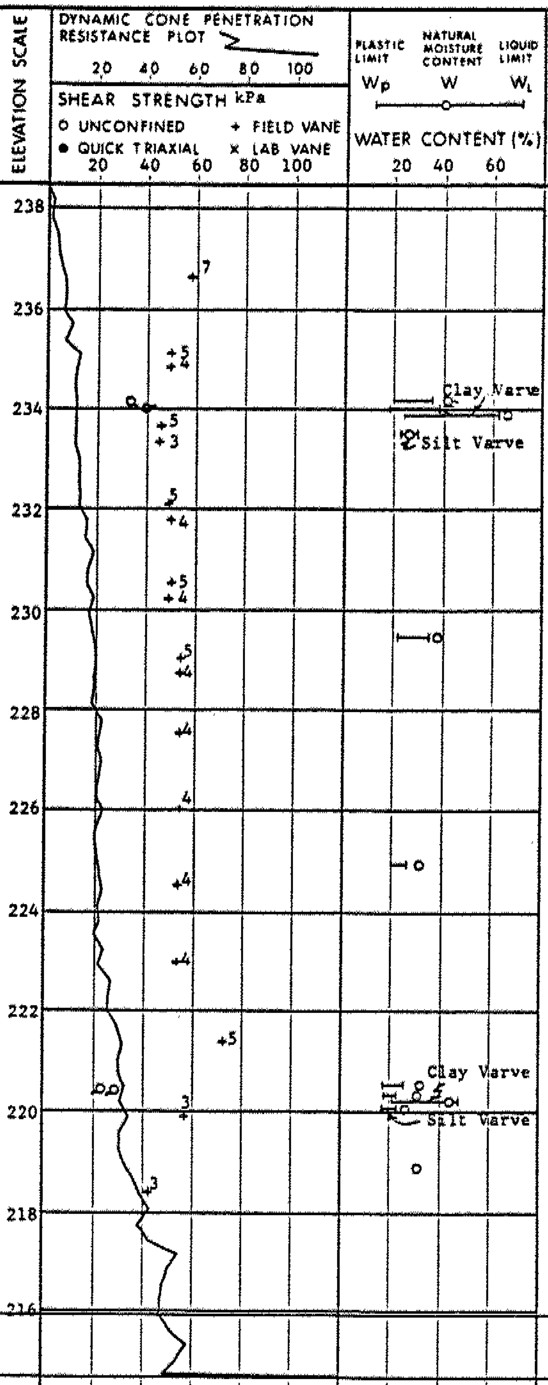
SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
238.5	Ground Surface
0.0	Trace Organics; Silty Clay; Varved; Soft to Firm
219.6 / 18.9	Silt; Very Loose
215.9 / 22.6	Probable Hard Glacial Till; End of Borehole
214.7 / 23.8	End of Cone Test

SAMPLES

NUMBER	TYPE	'N' VALUES
1	SS	4
2	SS	4
3	SS	2
4	TW	PH
5	SS	3
6	SS	5
7	SS	5
8	SS	5
9	SS	2
10	SS	3
11	SS	2
12	SS	2
13	TW	PH
14	SS	2
15	SS	1
16	SS	60/0 cm

GROUND WATER CONDITIONS: water level at approx. elev. 227.7



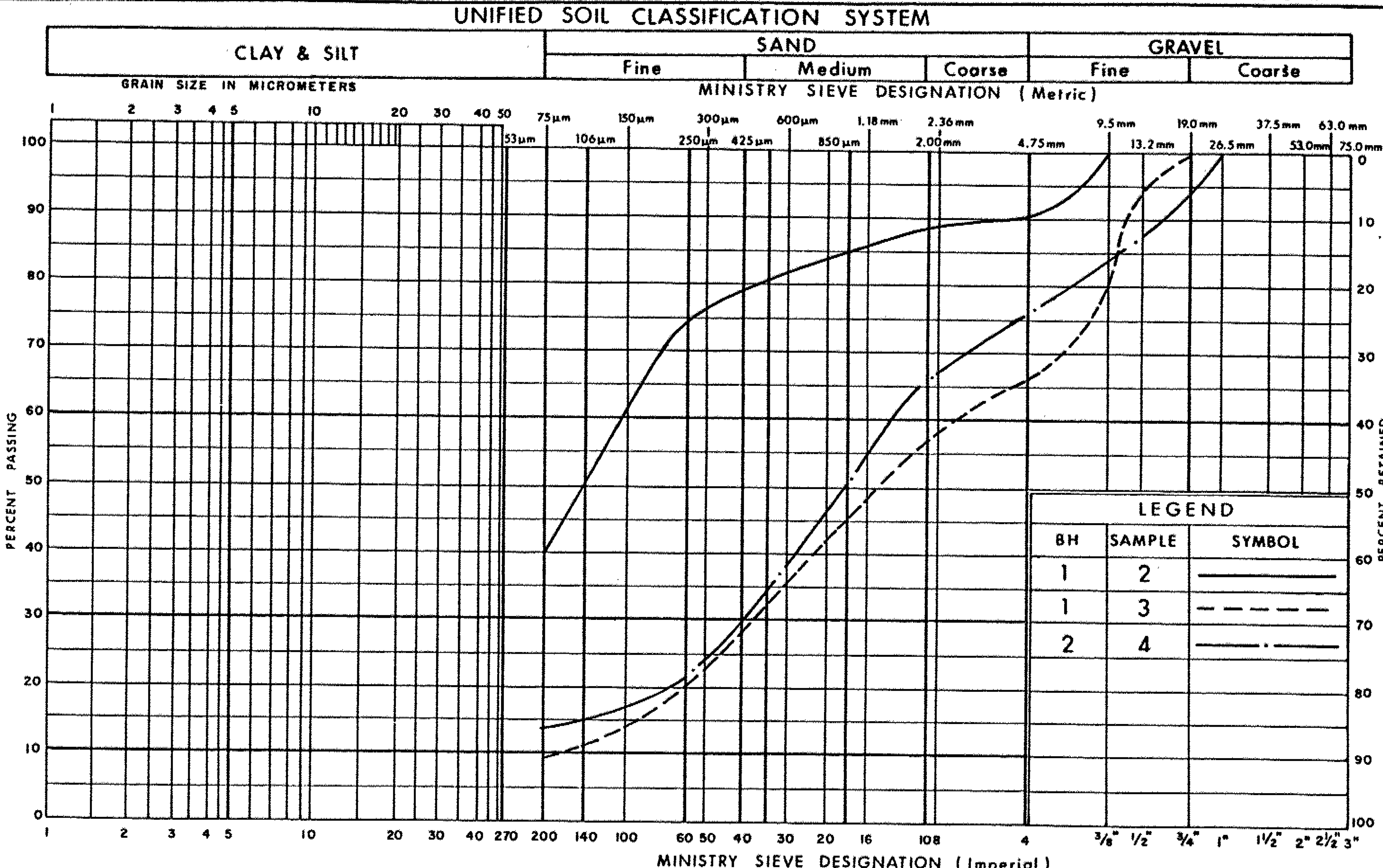
UNIT WEIGHT / REMARKS & GRAIN SIZE DISTRIBUTION (%)

Elev. (approx.)	UNIT WEIGHT γ kN/m³	GR	SA	SI	CL
234 (Clay Varve)	17.4	0	0	55	45
234	17.3	0	0	(100)	
234 (Silt Varve)		0	0	(100)	
229.8	18.6				
225.5	19.2				
220.5 (Clay Varve)	18.7	0	0	(100)	
220.2	18.7	0	0	(100)	
219.9 (Silt Varve)		0	0	(100)	
219.2		0	0	(100)	

$+^3$, x^5 : Numbers refer to Sensitivity

15 -◇- 5 (%) STRAIN AT FAILURE (20 above, 10 below)

78 12 M



Ministry of Transportation and Communications

Ontario

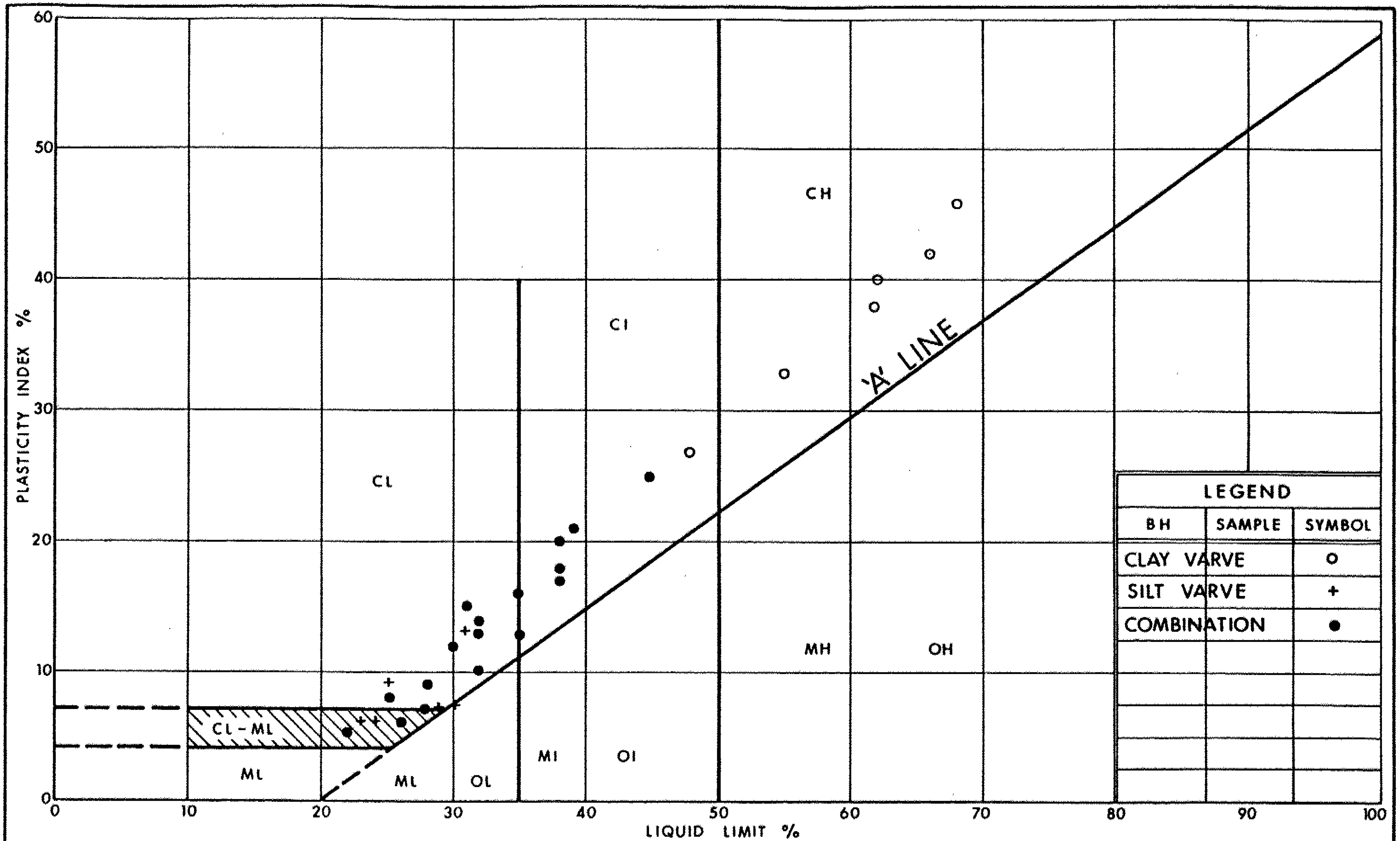
GRAIN SIZE DISTRIBUTION

SAND (Fill Material)

FIG No 1

W P 288-88-00

Oct 75, FF-5-21



Ministry of Transportation
Ontario

PLASTICITY CHART
SILTY CLAY - Varved

FIG No 2
W P 288-88-00

ENGINEERING MATERIALS OFFICE
FOUNDATION DESIGN SECTION

288-88-00

WP ~~140-80-03~~ DIST 14

HWY 65 STR SITE

Highway 65
Embankment Failure, Culvert Replacement

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GEOCRES 31M-52 DATE

FOUNDATION INVESTIGATION REPORT

For

Highway 65

Embankment Failure, Culvert Replacement

WP ~~140-80-03~~ 288-88-00, Kerns Township

District #14, New Liskeard

INTRODUCTION

This report contains the results of a foundation investigation carried out as requested by the Northern Region Office at the above-mentioned embankment failure site. The request was made following a surficial slope failure at the culvert inlet and subsequent local culvert collapse observed in the spring of 1987. The fieldwork was conducted during the period from 87 09 29 to 87 10 04 utilizing a continuous flight auger machine equipped with 83 mm I.D. hollow stem augers. The field investigation consisted of four sampled boreholes together with four adjacent dynamic cone penetration tests. Two boreholes were advanced on the shoulders of the roadway and two boreholes were placed at the base of the highway embankments in the vicinity of the culvert inlet and outlet.

In addition to the results of the field investigation, this report contains recommendations for the stability of the embankments and the design and construction for replacement of the culvert.

SITE DESCRIPTION

The site is located at Highway 65, approximately 800 m east of secondary Highway 562. It is situated in Kerns Township some 30 km outside the town of New Liskeard. The terrain in the immediate vicinity is fairly flat although the culvert lies along a gulley that has been filled to the level of the roadway. The embankment slopes in the vicinity of the culvert inlet and outlet rise up to 11.2 m on the north side of Highway 65 and 7.0 m on the south side of the highway. Surface erosion is visible on both the embankments in the form of deep gulleys and rippled slopes. Land use is primarily agricultural. The site lies in the physiographic region known as the Cobalt Plain, a glaciolacustrine clay plain featured in the New Liskeard Lowland.

SUBSURFACE CONDITIONS

General

The subsoil encountered at this location consists predominately of varved silty clay. Boreholes 1 and 2 were advanced on the shoulders of the roadway and were comprised of sand and silty clay fills deposited to a thickness of 7.0 m above the original silty clay deposit. The varved silty clay layer varies in thickness from 11.6 m to 25.9 m. It is underlayen by a thin stratum of silt at two of the borehole locations. A hard material impenetrable by both split spoon and augering was encountered at the base of each borehole. The material is very likely a till deposit and possibly bedrock.

The boundaries of the different strata encountered at the boring locations together with the obtained field and laboratory test results are shown on the Record of Borehole sheets found in the Appendix of this report. A sketch showing the relative location of the boreholes is also appended. A description of the different strata is provided below.

Sand (Fill Material)

A sand fill material was encountered directly beneath the asphalt in BH's 1 and 2 located on the shoulders of Highway 65. It extends to a depth of 4.4 m in BH 1 and to a depth of 4.3 m in BH 2 where it is intersected by a layer of silty clay fill material. The sand fill contains varying proportions of gravel, trace to some silt, traces of asphalt and occasional silty clay zones. The 'N' values range from 12 to 85 reflecting a denseness of compact to very dense. From laboratory testing, the natural moisture content varies from 8% to 12.5%. Grain size distribution curves for the sand fill are shown in Figure 1.

Silty Clay (Fill Material)

A silty clay fill deposit was present in the boreholes advanced on the shoulders of Highway 65. In BH 1, the silty clay fill extends beneath the sand fill for a thickness of 2.6 m. In BH 2, layers of sand fill alternate with silty clay fill layers to a depth of 5.2 m. The cohesive fill material contains varying proportions of sand and gravel, and traces of asphalt were present in the upper most layer in BH 2. 'N' values obtained from field testing range from 4 to 22 blows per 30 cm. The consistency of the material varies from firm to very stiff and it exhibits low to high plasticity.

Field and laboratory testing performed on the material yielded the following physical properties:

	Range
Natural Moisture Content (%)	11-42
Liquid Limit (%)	28-67
Plastic Limit (%)	15-25
Unit Weight (kN/m^3)	19.2
Undrained Shear Strength - Field Vane (kPa)	75-77

Silty Clay

An extensive deposit of varved silty clay was encountered in all of the boreholes. It is present beneath the fill materials in BH's 1 and 2 and occurs as the surficial deposit in BH's 3 and 4. The thickness of the deposit varies from 11.6 m to 20.7 m, the depth and thickness increasing in the boreholes advanced at the east end of the culvert.

The silty clay contains a trace of sand and organic material is present near the ground surface of all boreholes except BH 3 where some excavation had taken place. The silty clay is varved, the layers varying in thickness from 0.5 cm to 5.0 cm. Laboratory testing on the individual varve layers indicate that the varves are composed of silt to silty clay material of low plasticity and of clay to silty clay of medium to high plasticity. Where testing was performed on a sample containing both materials the plasticity ranged from low to medium plasticity. The range of plasticities are graphed on the Plasticity Chart, Figure 2. 'N' values obtained from field sampling range from 2 to 10 blows per 30 cm. The consistency varies from very soft to stiff. The following properties were obtained from laboratory and field testing:

	Range
Natural Moisture Content (%)	25.0-67.0
Liquid Limit (%)	22.0-68.0
Plastic Limit (%)	16.0-24.0
Unit Weight (kN/m^3)	17.3-19.2
Undrained Shear Strength - Field Vane (kPa)	33.0-92.0
Unconfined Shear Strength (kPa)	21.5-45.6

Silt

In BH's 2, 3 and 4 a stratum of non-plastic silt was encountered below the varved silty clay deposit. The thickness of the silt layer ranges from 2.9 m to 3.7 m and it overlies the hard material encountered at the bottom of each of the boreholes. The 'N' values obtained range from 0 to 4 reflecting a denseness of very loose to loose. From laboratory testing, the natural moisture content of the silt varies from 29% to 31%.

Groundwater Conditions

Groundwater was encountered in each of the four boreholes at considerable depths. The following groundwater levels were observed during the field investigation:

Borehole	Groundwater Elevation
1	239.6 m
2	227.7 m
3	230.7 m
4	227.2 m

No artesian water conditions were experienced.

DISCUSSION AND RECOMMENDATIONS

Existing Culvert

There are two culverts that extend beneath Highway 65 in this area. One of the culverts is a 0.9 m x 33.2 m C.I.P. running perpendicularly across the highway at Sta. 18 + 661.4 and is connected to a catch basin on the north side. The flow of water through this culvert is not obstructed although considerable surface erosion is visible in the vicinity of the catch basin.

The second culvert is a 1.2 m x 102.8 m C.I.P. culvert intersecting Highway 65 at Sta. 18 + 710 and running at a skew of approximately 27° to the highway. It was installed in or about the year 1958 and is overlayen by up to 7.0 m of fill. In the mid-1960's additional sections were added at the ends of the culvert. No problems with the culvert were noted until the spring of 1987 when heavy rainfalls caused a wash out of the slope at the culvert inlet. The accumulation of material resulted in the collapse of the end of the culvert. Although no immediate action was taken, water appeared to continue flowing through the culvert. The situation was remedied several months later by placing granular material over the washed out slope and clearing the area of sloughed material. The damaged end of the culvert was removed and replaced with a section of 0.5 m diameter. The section of damaged culvert removed was crushed and segments of the bottom rusted out.

At the culvert outlet, there are several pieces of dislocated steel pipe. A 4.5 m section of pipe comprising the culvert outlet has broken away from the main culvert, as have other pieces of pipe, and is severely distorted for its entire length. A deep trench surrounds the sections of disjointed pipe approximately 1.5 m in depth. At the time of the investigation some water flow was evident at the culvert outlet.

Frequently, during the spring thaw, the water level has been known to extend 0.5 m to 1.0 m above the top of the culvert at the inlet. Generally, however, the water depth through the culvert in the spring season is about 0.3 m.

The washout of the embankment and culvert collapse did not appear to affect the roadway from observations made at the time of the investigation. Previous road work was visible on the eastbound lane of the highway in the vicinity of the culvert inlet. Its extent is not known.

The embankments on both sides of the highway exhibit no deep seated failures or instabilities. This was verified by the results obtained from conducting stability analyses for several sections along the highway. However, considerable surficial erosion was visible along both embankments at the site and requires attention.

RECOMMENDATIONS

The 1.2 m diameter C.I.P. culvert and the surrounding embankments are in need of rehabilitation following the incidents occuring in the spring of 1987. The condition of the existing culvert for much of its length is not known and, as a result, recommendations are provided only for complete replacement of the existing culvert. Further visual inspection of the culvert by District Maintenance staff would be required to determine if partial replacement only is necessary at the inlet and outlet segments of the culvert and the exact extent of this replacement. Should such an inspection indicate that partial replacement would be adequate then earth work recommendations for the necessary remedial work will be provided by this office at such time.

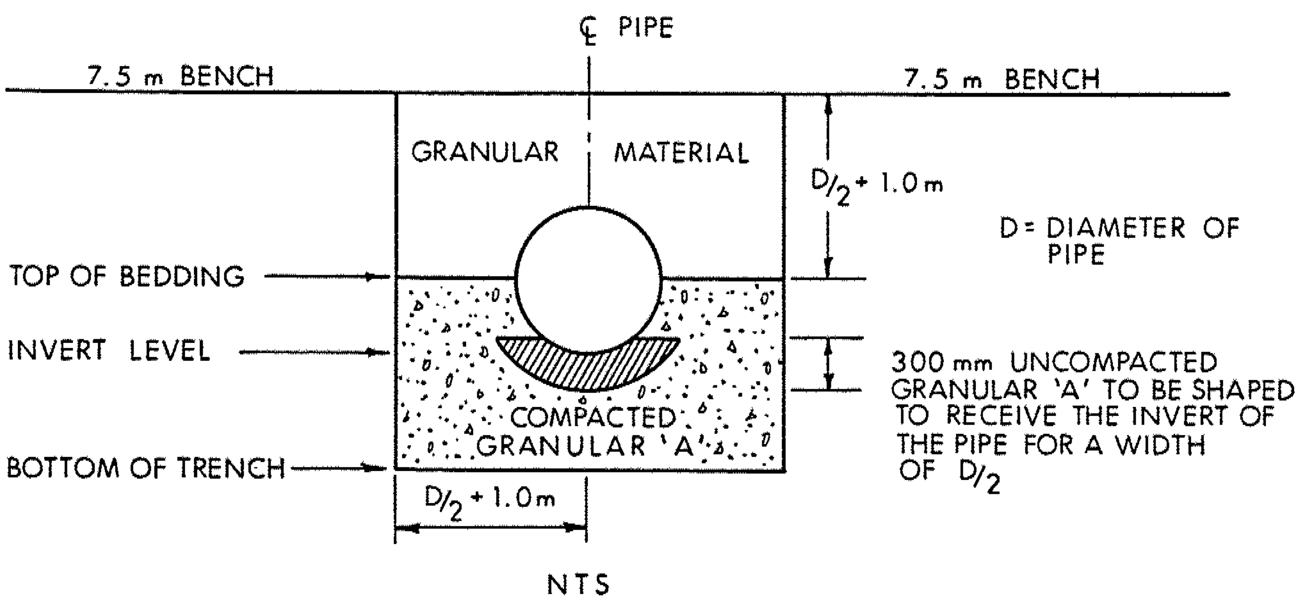
CULVERT CONSTRUCTION

Excavation

The excavation required for total culvert replacement is extensive as a 7.5 m bench is necessary to maintain overall stability. A typical section for culvert excavation is shown in Figure 3. Excavation should proceed from the top downward in a regular sequence with side slopes not exceeding 2H:1V. The material removed should not be stockpiled on the roadway. It should either be removed from the site or placed along the embankment sides providing 2H:1V slopes are maintained and the embankment height does not exceed the pavement elevation. Excavation of the culvert trench should extend a minimum of 1.0 m below the existing culvert invert to allow for the placement of bedding. It must be ensured that the bottom 0.7 m of the bedding is placed as trench excavation progresses to ensure the integrity of the excavation.

Bedding

Bedding should be constructed in accordance with the following sketch using Granular 'A' material. The sketch is similar to that of Type 5 OPSD-802.01.



Backfill

Backfill to the culvert trench should consist of Granular 'A' or Granular 'B' to a minimum height of 1.0 m above the top of the culvert. Above this height, native material may be used as backfill provided that it meets with Ministry requirements.

Traffic Protection

In the event that total culvert replacement is required, the extent of excavation will necessitate either the construction of a detour at the site or the diversion of traffic along another existing route. If the construction of a detour on site is the alternative chosen, then our office will comment on the stability of the detour design as required.

Dewatering

It is anticipated that dewatering can be achieved by diverting water flow using sump pumping techniques.

Culvert Inlet

A seal of cohesive material of medium to high plasticity with a minimum thickness of 0.6 m should be constructed at the culvert inlet. The seal should extend a minimum of 5.0 m on each side of the creek bed, and from the high water level down to the creek bed. The cohesive silty clay deposit at this site would make a suitable seal.

The embankment slope around the culvert entrance should be protected against erosion by placing a minimum of 0.6 m of rock protection. The erosion protection should extend from the high water level to the toe of the slope and 2.0 m along the channel bed. In a transverse direction, it should extend a minimum of 5.0 m on each side of the culvert.

Culvert Outlet

The culvert outlet should be protected with rip-rap treatment as per OPSD-810.01 Type A.

Camber

Due to the compressible nature of the material underlying the culvert slight settlements may be anticipated and should be accounted for by constructing the culvert with a 150 mm mid-span camber.

GENERAL RECOMMENDATIONS

Slope Stability

A series of slope stability analyses was conducted for various cross-sections across the site using Bishop's total stress analysis. Appended to this report are the results for the existing embankment conditions at the culvert inlet and outlet (Figures 4 and 5). The existing embankments do not appear to exhibit evidence of deep-seated failure. However, there is considerable surficial erosion. It is therefore recommended that the embankment slopes be rebuilt where necessary at 2H:1V. Loose or softened soil should be removed and replaced with suitable earth fill.

Stability analysis was also conducted to determine the most suitable configuration for the culvert excavation. The results of the analysis are shown in Figure 6. A minimum bench length of 7.5 m is required to ensure the stability of embankments not exceeding 8.0 m in height.

An observation noted at the time of the investigation was the evidence of water ponding off the north shoulder of the highway, west of the culvert site. it is possible that the accumulation of water by the roadside could infiltrate the granular material of the roadbed and result in a build-up of pressures against the top of the south embankment. The ponded area should be removed by constructing a ditch running in a direction parallel to the highway from the ponded area down to the culvert outlet.

Settlement Considerations

The 7.0 m fill has been in place for approximately 30 years and it is probable that much of the settlement anticipated across the area has already taken place. Upon observation, at the time of the investigation, the roadway appeared not to exhibit any areas of differential settlement. It is anticipated that replacement of the culvert and similar loading conditions will not result in any discernable settlements.

Consolidation characteristics of the compressible varved silty clay are illustrated in Figures 7 and 8. The curves were drawn up as per Casagrande's theory.

Frost Protection

A minimum earth cover of 2.1 m is required for frost protection in the event that concrete headwalls are constructed.

MISCELLANEOUS

The fieldwork for this investigation was carried out by B. Bennett, Jr. Foundation Engineer under the supervision of Mr. P. Payer, Senior Foundation Engineer. The equipment was owned and operated by F.E. Johnston Drilling Company Limited. The report was prepared by Mrs. B. Bennett and reviewed by Mr. K. G. Selby, Chief Foundation Engineer (West).

LICENSED PROFESSIONAL ENGINEER
B. BEN...
ONTARIO

B. Bennett
Jr. Foundation Engineer

K. G. Selby
Chief Foundation Engineer
(West)

Ministry of Transportation and Communications
Ontario

RECORD OF BOREHOLE No 1

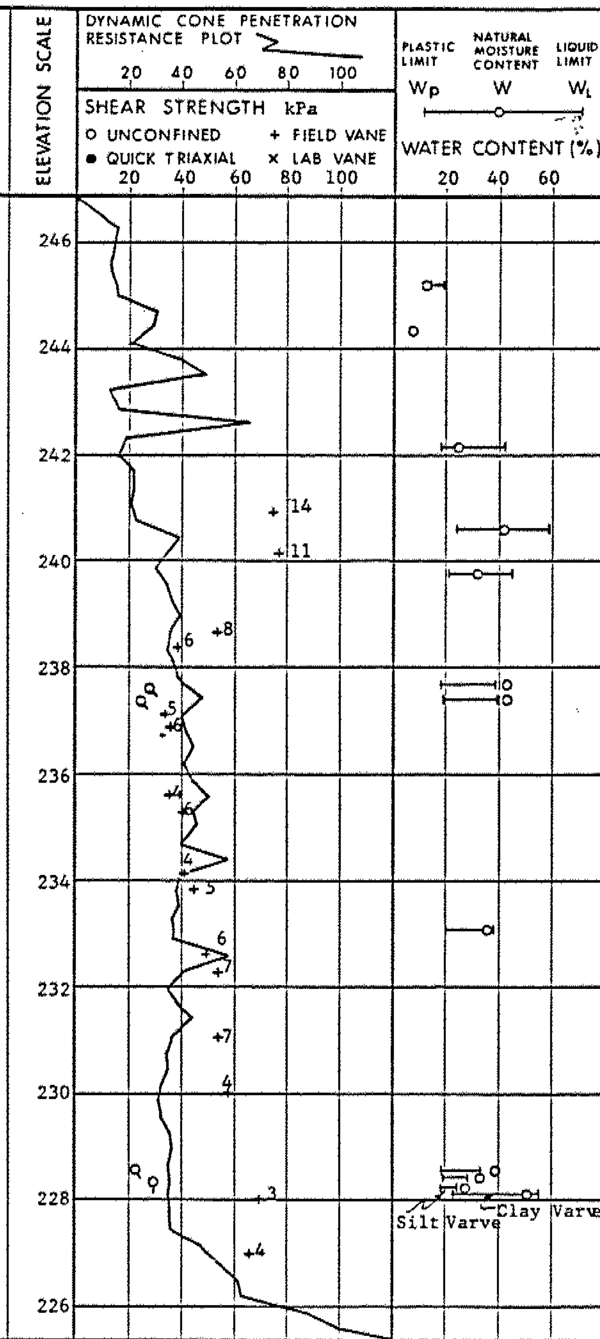
METRIC

W P 140-80-03 LOCATION Sta. 18 + 750 O/S 3.8 m Lt. ORIGINATED BY BB

DIST 14 HWY 65 BOREHOLE TYPE H.S. Auger COMPILED BY BB

DATUM Geodetic DATE 87 09 29 - 87 09 20 CHECKED BY [signature]

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	'N' VALUES	GROUND WATER CONDITIONS	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
246.9	Ground Surface						
0.0	Asphalt						
0.2	Traces of Asphalt	1	SS	12			
	Sand (Fill Material)	2	SS	19			9 51 (40)
	Some/with Gravel	3	SS	71			33 58 (9)
	Occ. Silty Clay Zones	4	SS	31			
242.5	Compact to Very Dense	5	SS	34			
4.4	Silty Clay (Fill Material)	6	SS	18		19.2	0 5 (95)
	Trace Sand, Trace Gravel	7	SS	12			
239.9	Soft to Very Stiff	8	SS	4			0 4 (96)
7.0	Thin Seams of Peat	9	SS	8	▼		0 0 (100)
		10	SS	5			
	Silty Clay	11	TW	PH		17.6 17.4	0 0 (100)
	Varved	12	SS	2			
	Soft to Firm	13	SS	3			
		14	SS	2		18.1	
		15	SS	3			
		16	TW	PH		18.0 18.9	0 0 (100) 0 0 (100) 0 0 (100)
225.6	Probable Hard Glacial Till	17	SS	60/8 cm			
21.5	End of Borehole						



+3, ×5 : Numbers refer to Sensitivity

20 / 15 -○- 5 / 10 (%) STRAIN AT FAILURE

OFFICE REPORT ON SOIL EXPLORATION

Ministry of Transportation and Communications
Ontario

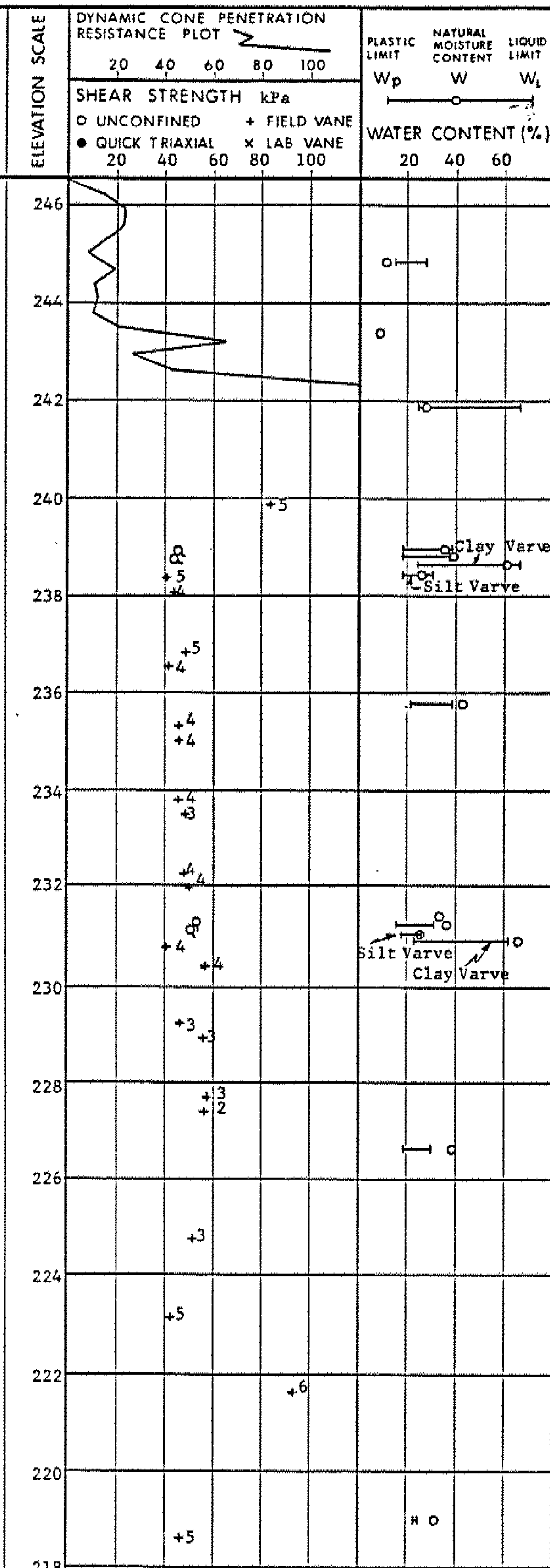
RECORD OF BOREHOLE No 2

METRIC

W P 140-80-03 LOCATION Sta. 18 + 658.8 O/S 3.1 m Rt. ORIGINATED BY BB
DIST 14 HWY 65 BOREHOLE TYPE H.S. Auger COMPILED BY BB
DATUM Geodetic DATE 87 10 01 - 02 CHECKED BY [signature]

ELEV / DEPTH	SOIL PROFILE DESCRIPTION	SAMPLE NUMBER	TYPE	'N' VALUES	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
246.6	Ground Surface					
0.0	Asphalt					
0.2	Sand (Fill Material) Trace Gravel Trace Silt Compact	1	SS	23		
245.2 / 1.4	Silty Clay (Fill Material) Some/with Sand Trace/Some Gravel Traces of Asphalt Stiff to Very Stiff	2	SS	22		17 55 (28)
		3	SS	10		
243.7 / 2.9	Sand (Fill Material) Some/With Gravel Some Silt Dense to Very Dense	4	SS	30		22 64 (14)
		5	SS	85		
242.3 / 4.3	Silty Clay (Fill Material) Trace Sand Very Stiff	6	SS	19		0 0 (100)
241.4 / 5.2	Silty Clay, Varved, Soft to Stiff	7	SS	10		
		8	SS	9		
	Trace Organics					
		9	TW	PH	18.4 18.2	0 0 (100) 0 0 (100) 0 0 (100)
		10	SS	3		
		11	SS	2	17.7	
		12	SS	3		
		13	SS	4		
		14	TW	PH	18.7 18.2	0 0 (100) 0 0 (100) 0 0 (100)
		15	SS	4		
		16	SS	5		
		17	SS	2		
		18	SS	3		
		19	SS	2		
		20	SS	3		
220.7 / 25.9	Silt Very Loose	21	SS	0		
217.8 / 28.8	Auger Refusal End of Borehole					

Ground water level symbol at elevation approx. 228.



+3, ×5 : Numbers refer to Sensitivity

20 / 15 -◇- 5 / 10 (%) STRAIN AT FAILURE

OFFICE REPORT ON SOIL EXPLORATION

Ministry of Transportation and Communications
Ontario

RECORD OF BOREHOLE No 3

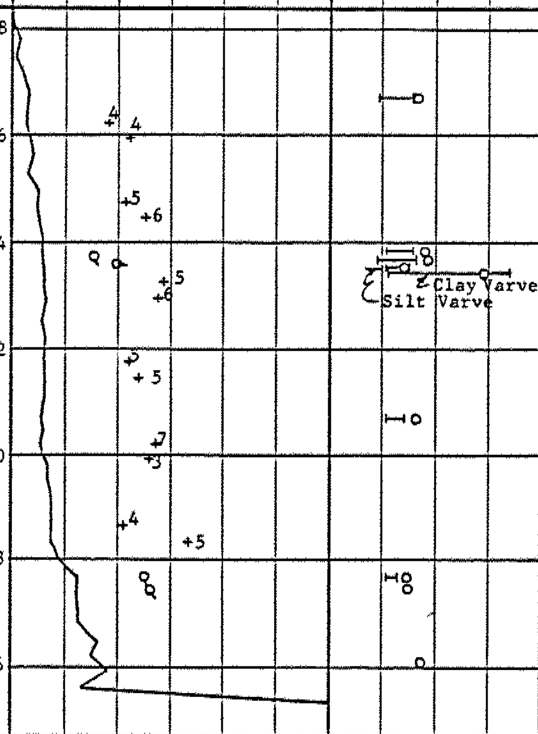
METRIC

W P 140-80-03 LOCATION Sta. 18 + 747.9 O/S 28.0 m Lt. ORIGINATED BY BB

DIST 14 HWY 65 BOREHOLE TYPE H.S. Auger COMPILED BY BB

DATUM Geodetic DATE 87 10 03 CHECKED BY [signature]

ELEV / DEPTH	SOIL PROFILE DESCRIPTION	SAMPLE NUMBER	TYPE	'N' VALUES	GROUND WATER CONDITIONS	UNIT WEIGHT γ kN/m³	GR SA SI CL (%)
238.4	Ground Surface						
0.0	Silty Clay	1	SS	4			
	Varved	2	SS	4		18.5	0 0 (100)
	Trace Sand	3	SS	2			
	Soft to Firm	4	TW	PH		17.8 17.8	0 0 (100) 0 0 (100) 0 0 (100)
		5	SS	2			
		6	SS	2	▽	19.0	0 1 (99)
227.7		7	SS	5			
10.7	Silt	8	TW	PH		19.2 19.2	0 0 97 3
	Loose	9	SS	4			0 0 (100)
224.7	Probable Hard Glacial Till	10	SS	60/0 cm			
13.7	End of Borehole						



+3, ×5 : Numbers refer to Sensitivity

20 / 15 -○- 5 / 10 (%) STRAIN AT FAILURE

OFFICE REPORT ON SOIL EXPLORATION

Ministry of Transportation and Communications
Ontario

RECORD OF BOREHOLE No 4

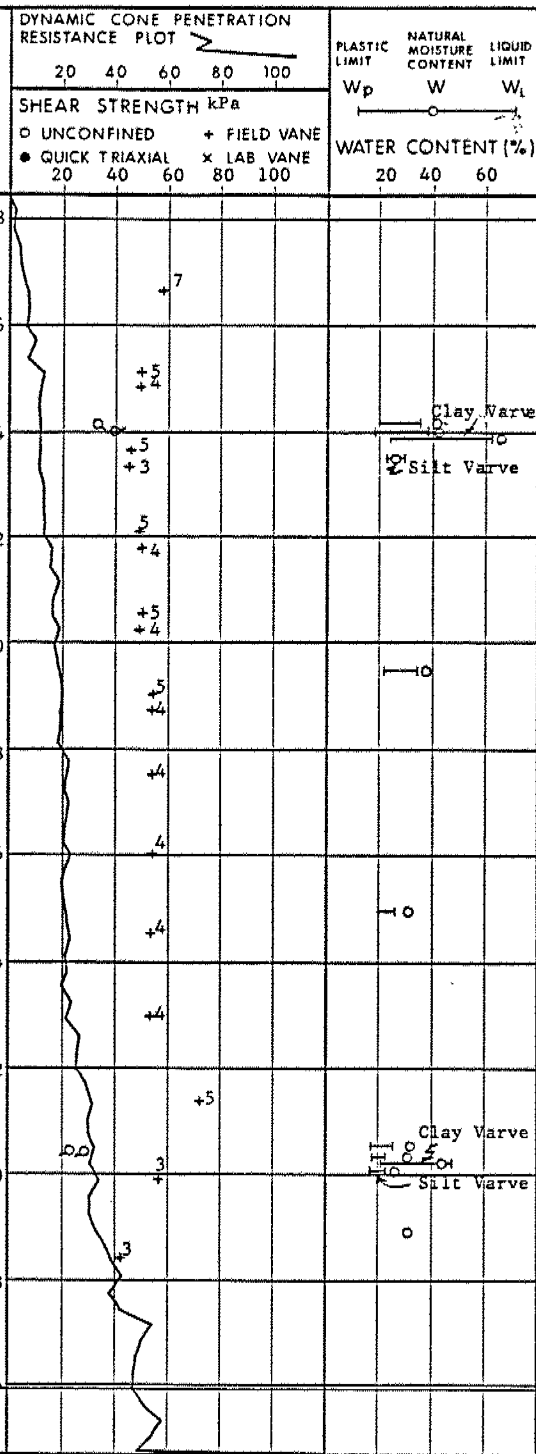
METRIC

W P 140-80-03 LOCATION Sta. 18 + 675.1 O/S 24.2 m Rt. ORIGINATED BY BB

DIST 14 HWY 65 BOREHOLE TYPE H.S. Auger COMPILED BY BB

DATUM Geodetic DATE 87 10 03 - 04 CHECKED BY [signature]

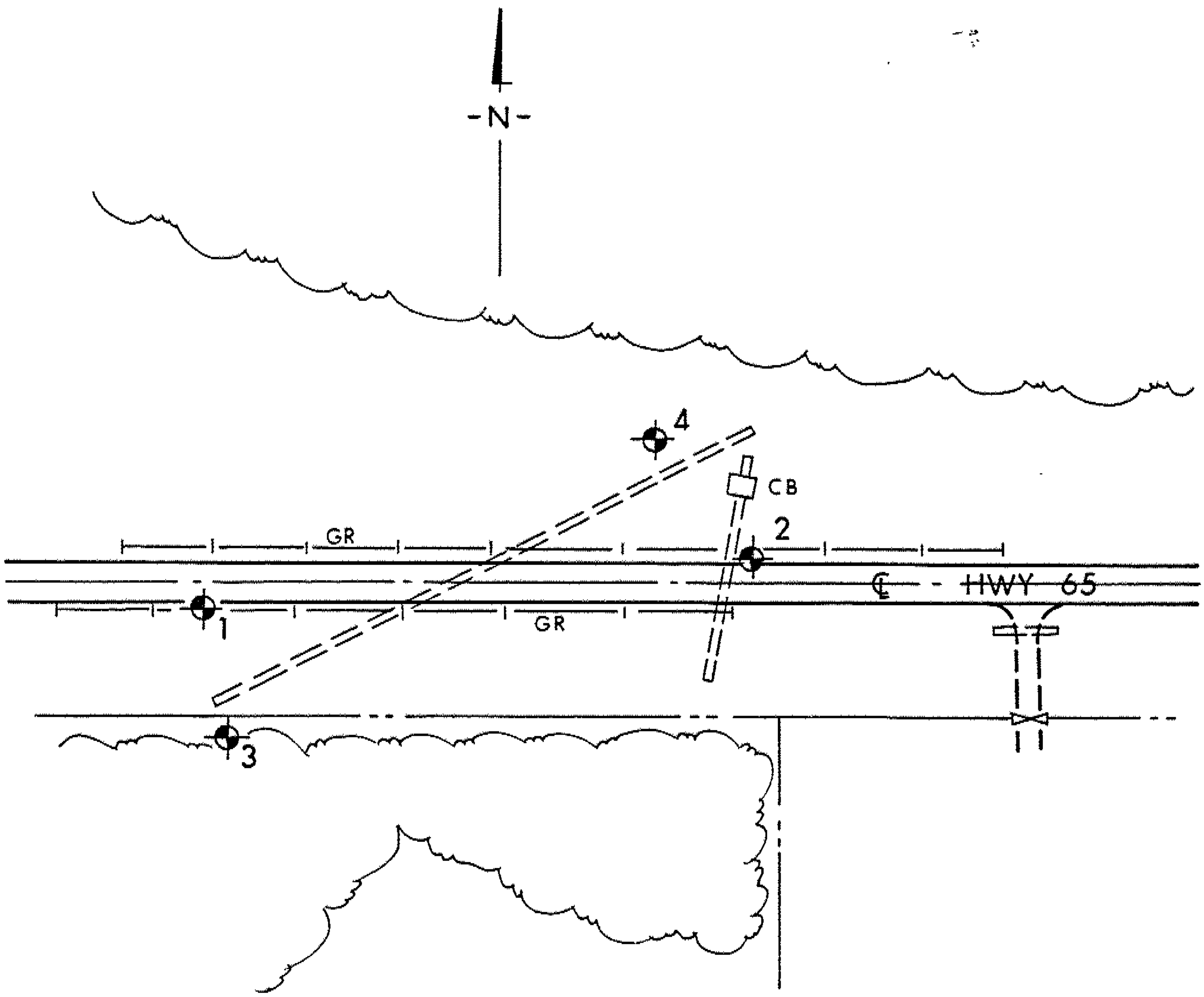
ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	'N' VALUES	GROUND WATER CONDITIONS	UNIT WEIGHT γ kN/m³	GR SA SI CL (%)
238.5	Ground Surface						
0.0	Trace Organics	1	SS	4			
		2	SS	4			
	Silty Clay	3	SS	2			
		4	TW	PH		17.4	0 0 55 45
						17.3	0 0 (100)
	Varved						0 0 (100)
		5	SS	3			
		6	SS	5			
	Soft to Firm	7	SS	5		18.6	
		8	SS	5	▼		
		9	SS	2			
		10	SS	3		19.2	
		11	SS	2			
		12	SS	2			
		13	TW	PH		18.7	0 0 (100)
219.6						18.7	0 0 (100)
18.9	Silt						0 0 (100)
	Very Loose	14	SS	2			0 0 (100)
		15	SS	1			
215.9	Probable Hard Glacial Till	16	SS	60/0 cm			
22.6	End of Borehole						
214.7							
23.8	End of Cone Test						



+3, ×5 : Numbers refer to Sensitivity

15 -◇- 5 (%) STRAIN AT FAILURE (20 above, 10 below)

OFFICE REPORT ON SOIL EXPLORATION

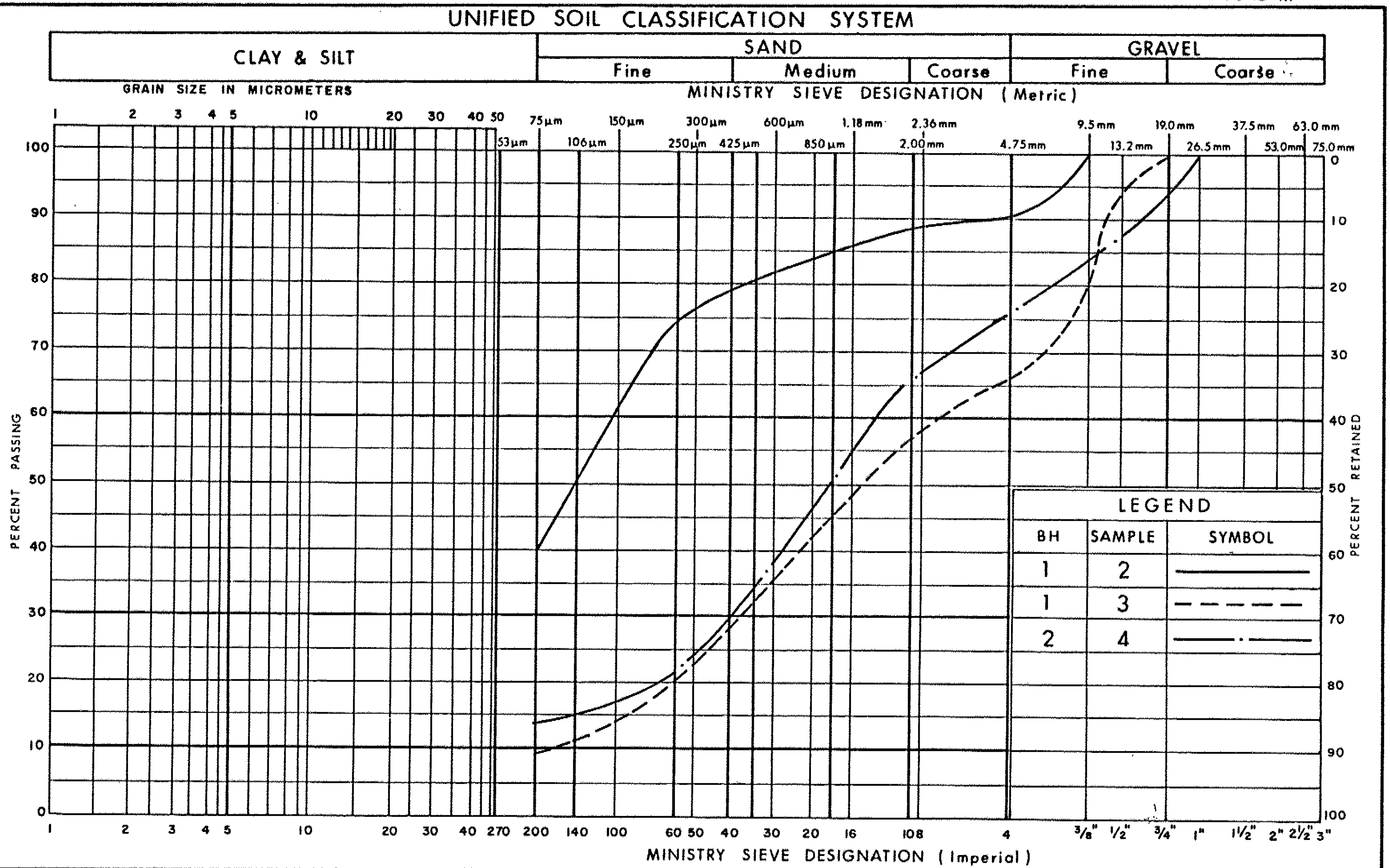


SKETCH SHOWING BORE HOLE LOCATION

NTS

WP 140-80-03
KERNS TOWNSHIP

78 12 M



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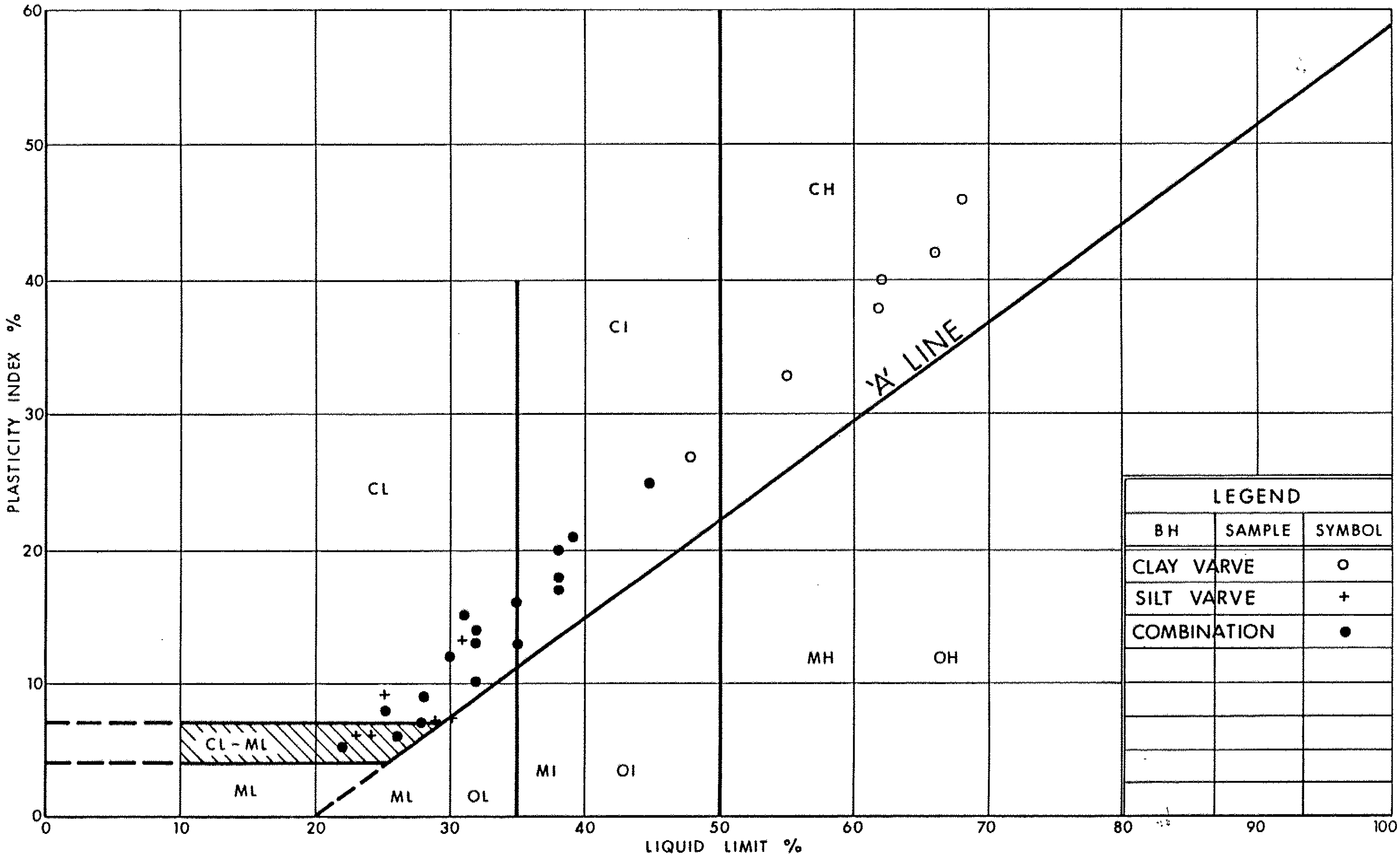
GRAIN SIZE DISTRIBUTION

SAND (Fill Material)

FIG No 1

W P 140-80-03

Oct 75, FF-S-21



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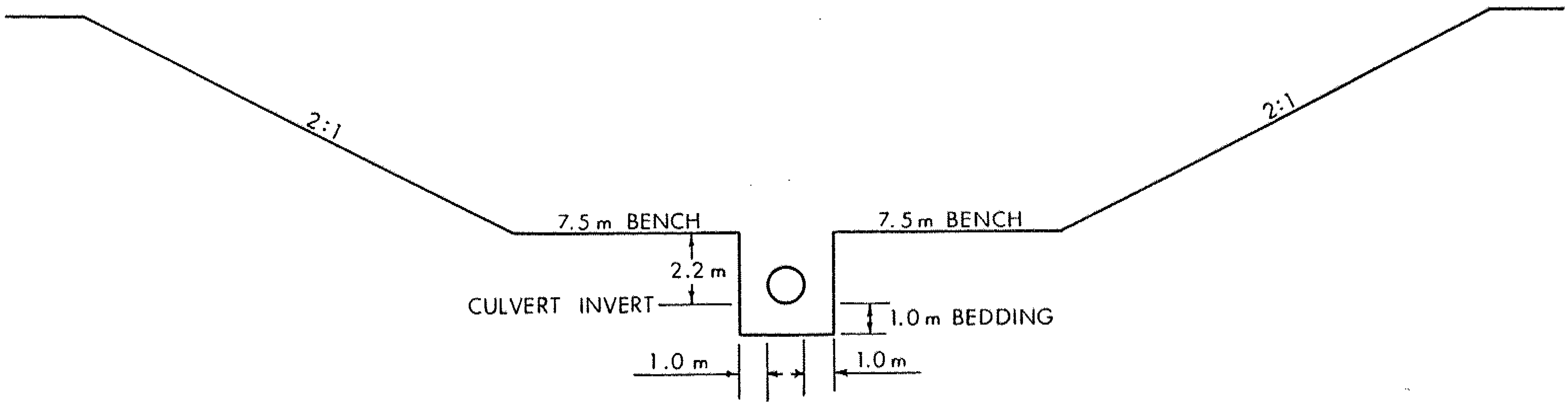
PLASTICITY CHART
SILTY CLAY - Varved

FIG No 2

W P 140-80-03

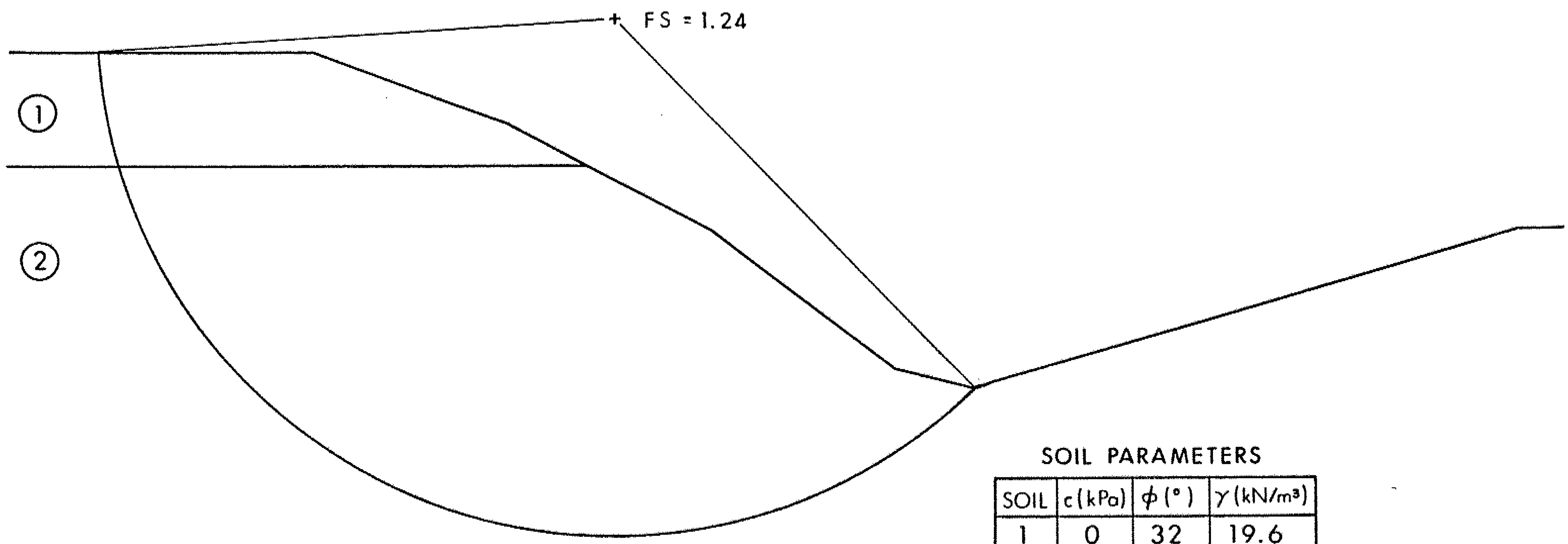


SCALE 1:200

TYPICAL SECTION FOR CULVERT EXCAVATION

FIG. 3

WP 140-80-03



SOIL PARAMETERS

SOIL	c (kPa)	ϕ (°)	γ (kN/m³)
1	0	32	19.6
2	45	0	18.3

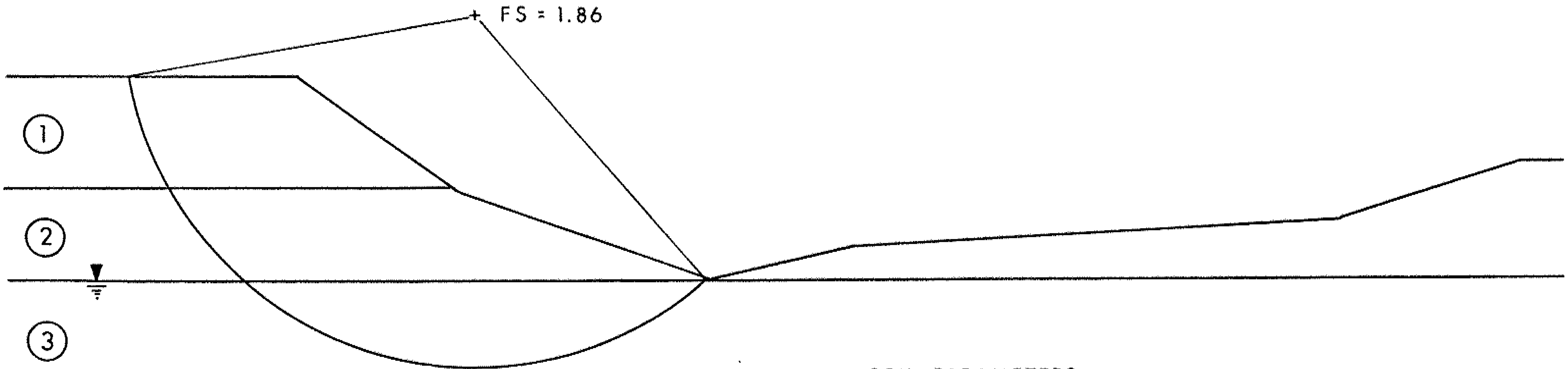
SCALE 1:200

TOTAL STRESS ANALYSIS - STA 18+660 NORTH EMBANKMENT

EXISTING CONDITIONS AT CULVERT OUTLET

FIG 4

WP 140-80-03



SOIL PARAMETERS

SOIL	c(kPa)	ϕ (°)	γ (kN/m³)
1	0	32	19.6
2	45	0	18.3
3	45	0	18.3

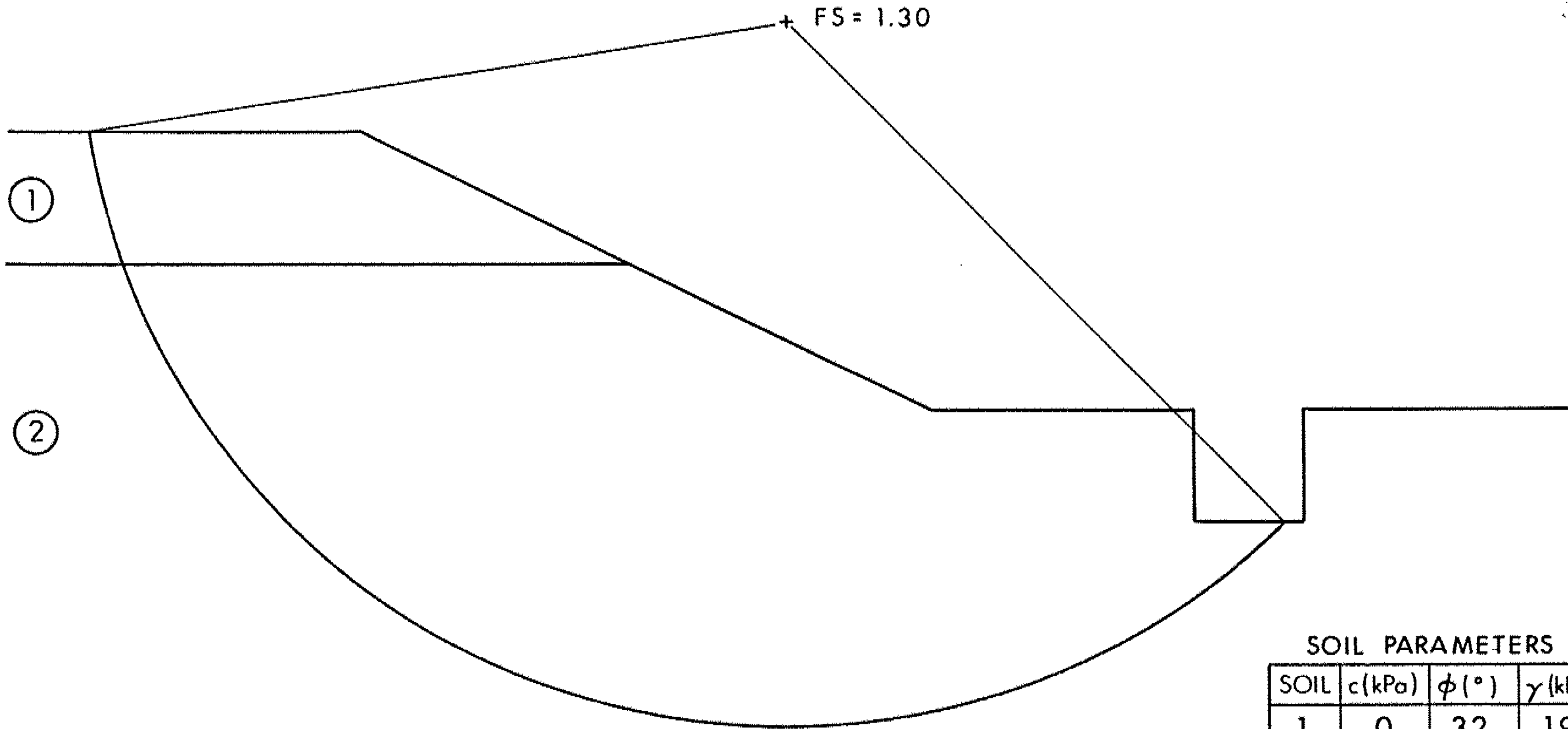
SCALE 1:200

TOTAL STRESS ANALYSIS – STA 18+752.7 SOUTH EMBANKMENT

EXISTING CONDITIONS AT CULVERT INLET

FIG 5

WP 140-80-03



SOIL PARAMETERS

SOIL	c(kPa)	ϕ (°)	γ (kN/m³)
1	0	32	19.6
2	45	0	18.3

SCALE 1:200

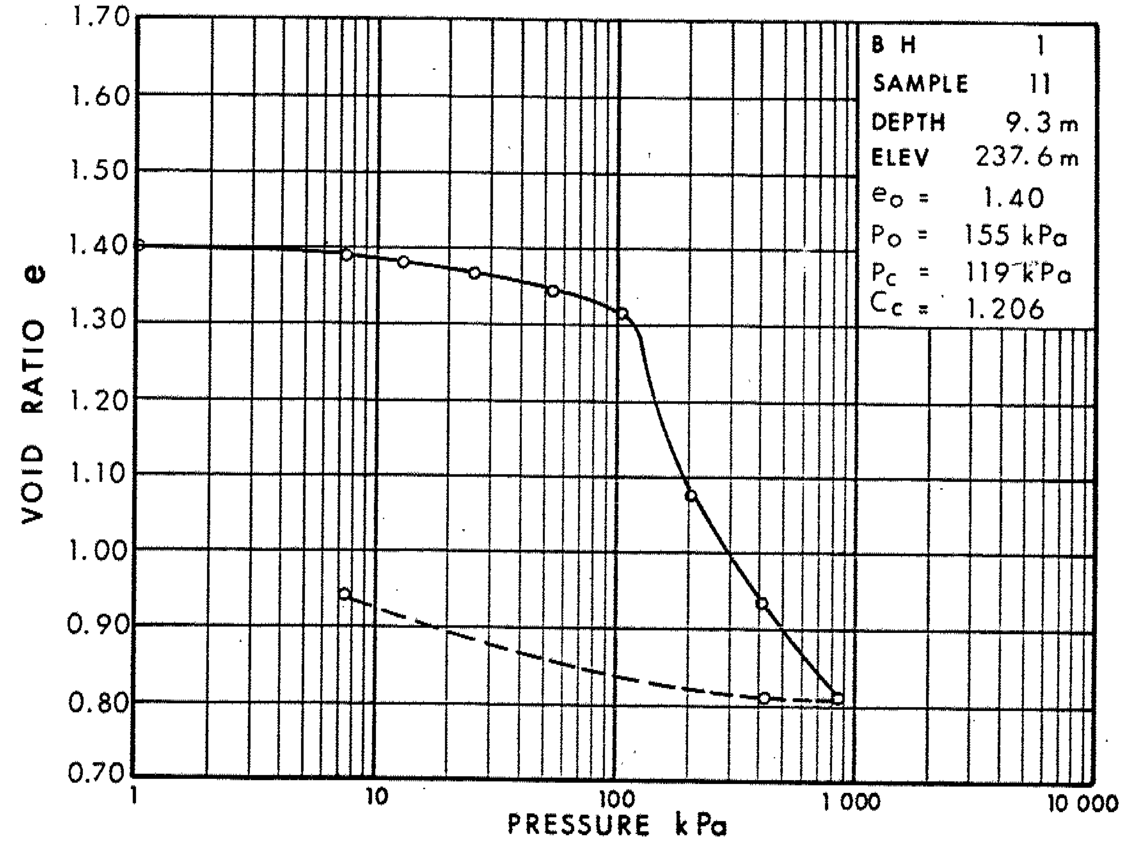
TOTAL STRESS ANALYSIS - 8 m EMBANKMENT HEIGHT (Maximum)

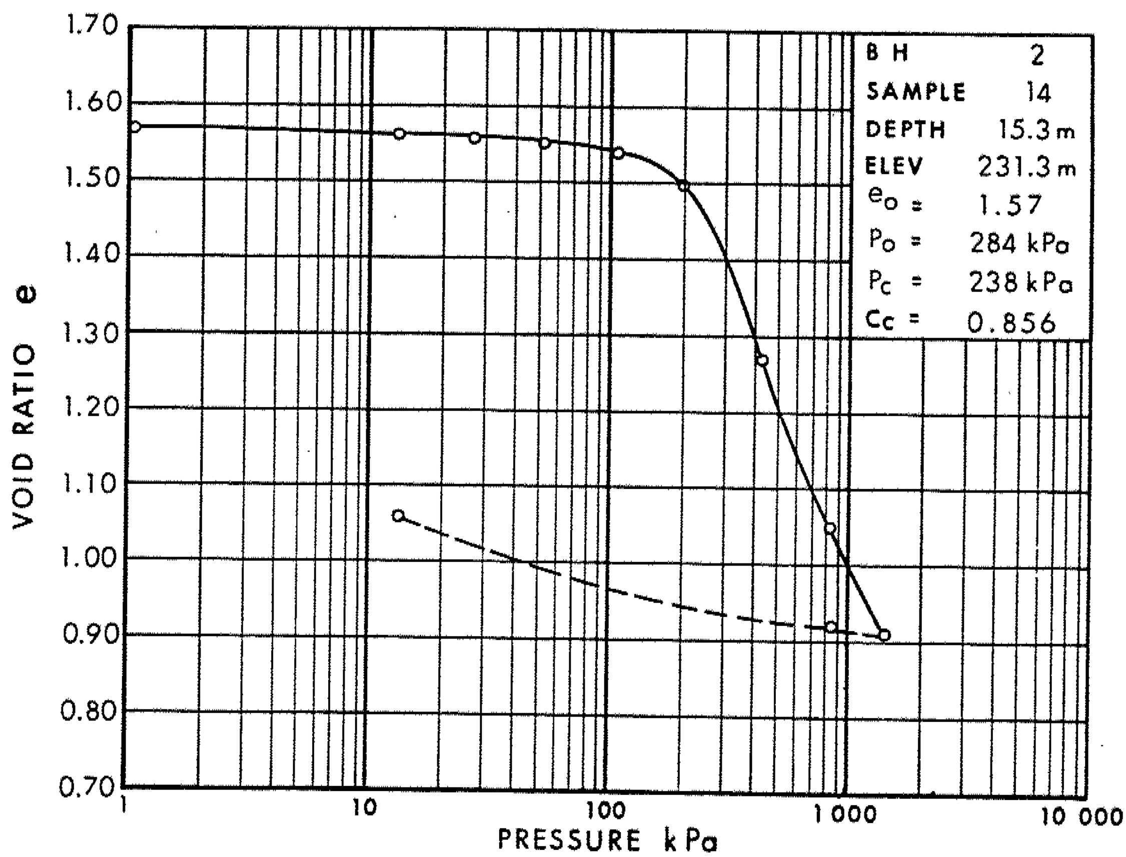
7.5 m BENCH REQUIREMENT FOR CULVERT EXCAVATION

FIG 6

WP 140-80-03

VOID RATIO - PRESSURE CURVES

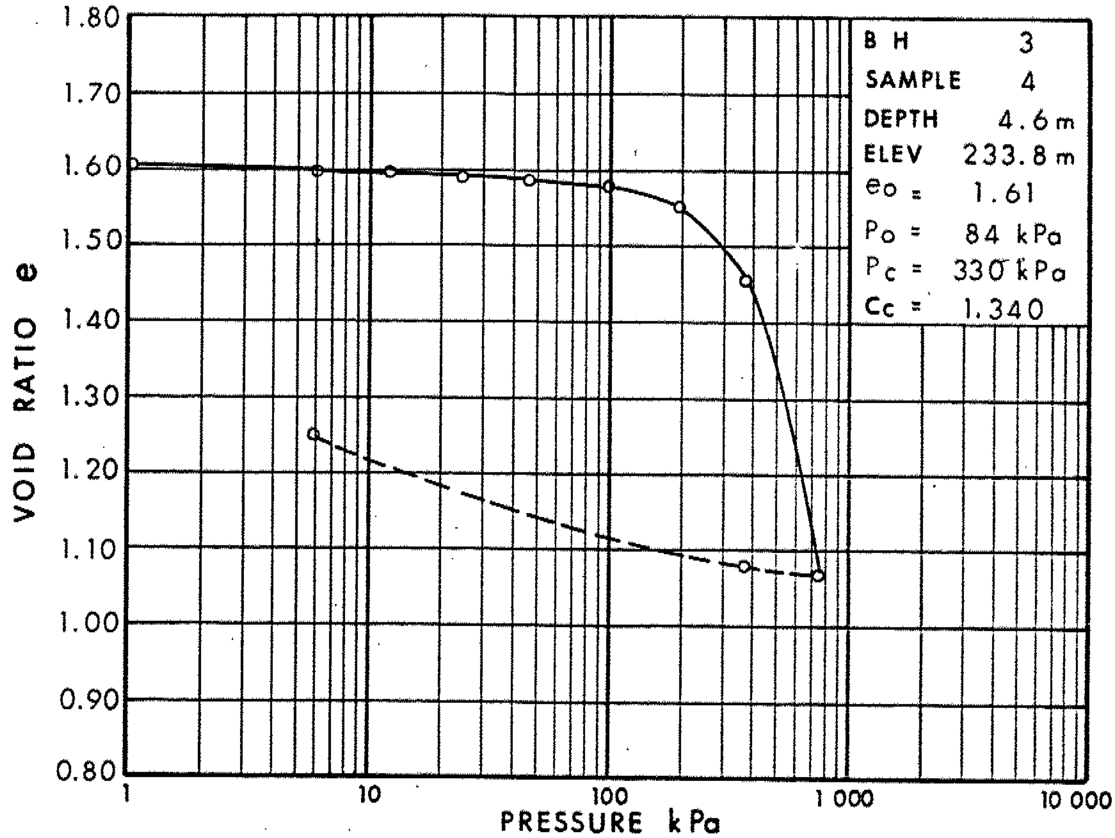


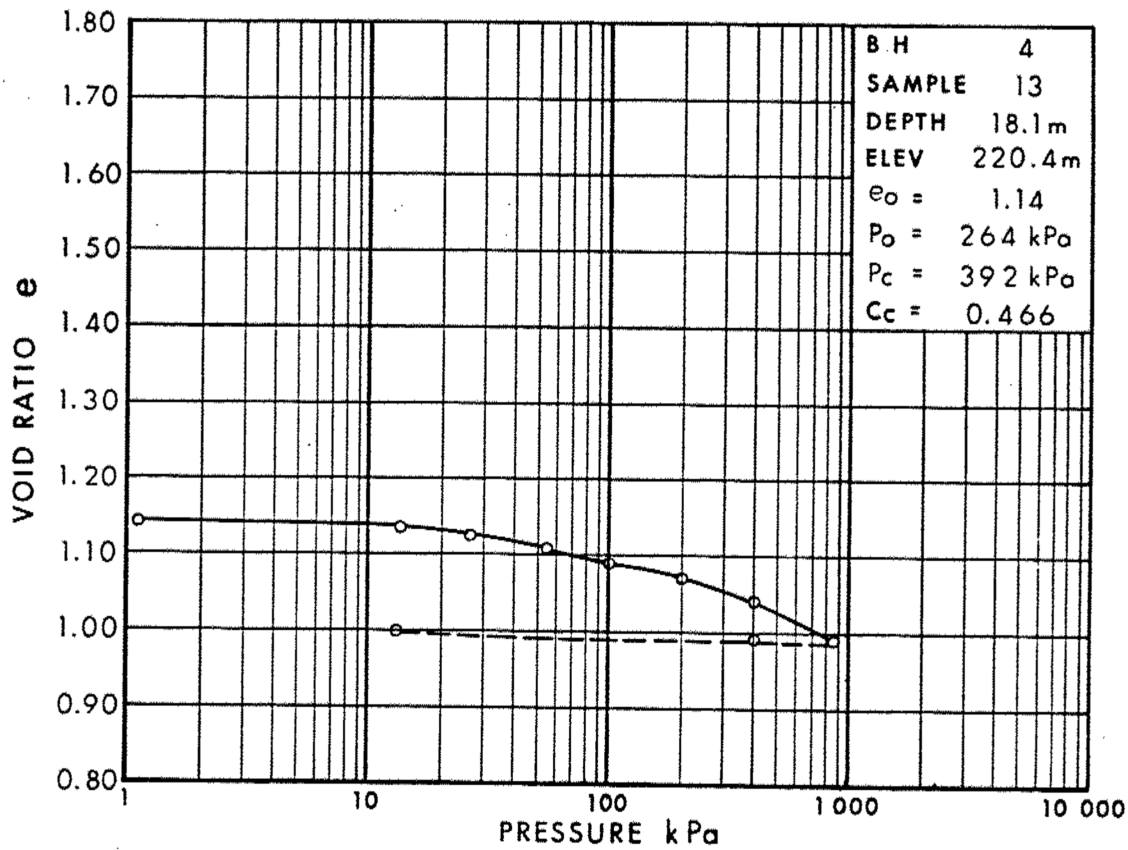


W P 140-80-03

FIG No 7

VOID RATIO - PRESSURE CURVES





WP ~~140-80-03~~

FIG No 8

EXPLANATION OF TERMS USED IN REPORT

N VALUE: THE STANDARD PENETRATION TEST (SPT) N VALUE IS THE NUMBER OF BLOWS REQUIRED TO CAUSE A STANDARD 51mm O.D. SPLIT BARREL SAMPLER TO PENETRATE 0.3m INTO UNDISTURBED GROUND IN A BOREHOLE WHEN DRIVEN BY A HAMMER WITH A MASS OF 63.5kg, FALLING FREELY A DISTANCE OF 0.76m. FOR PENETRATIONS OF LESS THAN 0.3m N VALUES ARE INDICATED AS THE NUMBER OF BLOWS FOR THE PENETRATION ACHIEVED. AVERAGE N VALUE IS DENOTED THUS $\bar{N}$.

DYNAMIC CONE PENETRATION TEST: CONTINUOUS PENETRATION OF A CONICAL STEEL POINT (51mm O.D. 60° CONE ANGLE) DRIVEN BY 475 J IMPACT ENERGY ON 'A' SIZE DRILL RODS. THE RESISTANCE TO CONE PENETRATION IS MEASURED AS THE NUMBER OF BLOWS FOR EACH 0.3m ADVANCE OF THE CONICAL POINT INTO THE UNDISTURBED GROUND.

SOILS ARE DESCRIBED BY THEIR COMPOSITION AND CONSISTENCY OR DENSENESS.

CONSISTENCY: COHESIVE SOILS ARE DESCRIBED ON THE BASIS OF THEIR UNDRAINED SHEAR STRENGTH (c_u) AS FOLLOWS:

c_u (kPa)	0 - 12	12 - 25	25 - 50	50 - 100	100 - 200	>200
	VERY SOFT	*SOFT*	*FIRM*	*STIFF*	*VERY STIFF*	*HARD*

DENSENESS: COHESIONLESS SOILS ARE DESCRIBED ON THE BASIS OF DENSENESS AS INDICATED BY SPT N VALUES AS FOLLOWS:

N (BLOWS/0.3 m)	0 - 5	5 - 10	10 - 30	30 - 50	>50
	VERY LOOSE	*LOOSE*	*COMPACT*	*DENSE*	*VERY DENSE*

ROCKS ARE DESCRIBED BY THEIR COMPOSITION AND STRUCTURAL FEATURES AND / OR STRENGTH.

RECOVERY: SUM OF ALL RECOVERED ROCK CORE PIECES FROM A CORING RUN EXPRESSED AS A PERCENT OF THE TOTAL LENGTH OF THE CORING RUN.

MODIFIED RECOVERY: SUM OF THOSE INTACT CORE PIECES, 100mm+ IN LENGTH EXPRESSED AS A PERCENT OF THE LENGTH OF THE CORING RUN. THE ROCK QUALITY DESIGNATION (R Q D), FOR MODIFIED RECOVERY, IS:

R Q D (%)	0 - 25	25 - 50	50 - 75	75 - 90	90 - 100
	VERY POOR	*POOR*	*FAIR*	*GOOD*	*EXCELLENT*

JOINTING AND BEDDING:

SPACING	50mm	50 - 300mm	0.3m - 1m	1m - 3m	>3m
JOINTING	*VERY CLOSE*	*CLOSE*	*MOD. CLOSE*	*WIDE*	*VERY WIDE*
BEDDING	*VERY THIN*	*THIN*	*MEDIUM*	*THICK*	*VERY THICK*

ABBREVIATIONS AND SYMBOLS

FIELD SAMPLING

S S	SPLIT SPOON	T P	THINWALL PISTON
W S	WASH SAMPLE	O S	OSTERBERG SAMPLE
S T	SLOTTED TUBE SAMPLE	R C	ROCK CORE
B S	BLOCK SAMPLE	P H	T W ADVANCED HYDRAULICALLY
C S	CHUNK SAMPLE	P M	T W ADVANCED MANUALLY
T W	THINWALL OPEN	F S	FOIL SAMPLE

STRESS AND STRAIN

u_w	kPa	PORE WATER PRESSURE
r_u	1	PORE PRESSURE RATIO
σ	kPa	TOTAL NORMAL STRESS
σ'	kPa	EFFECTIVE NORMAL STRESS
τ	kPa	SHEAR STRESS
$\sigma_1, \sigma_2, \sigma_3$	kPa	PRINCIPAL STRESSES
ϵ	%	LINEAR STRAIN
$\epsilon_1, \epsilon_2, \epsilon_3$	%	PRINCIPAL STRAINS
E	kPa	MODULUS OF LINEAR DEFORMATION
G	kPa	MODULUS OF SHEAR DEFORMATION
μ	1	COEFFICIENT OF FRICTION

MECHANICAL PROPERTIES OF SOIL

m_v	kPa^{-1}	COEFFICIENT OF VOLUME CHANGE
C_c	1	COMPRESSION INDEX
C_s	1	SWELLING INDEX
C_α	1	RATE OF SECONDARY CONSOLIDATION
c_v	m^2/s	COEFFICIENT OF CONSOLIDATION
H	m	DRAINAGE PATH
T_v	1	TIME FACTOR
U	%	DEGREE OF CONSOLIDATION
σ'_{vo}	kPa	EFFECTIVE OVERBURDEN PRESSURE
σ'_p	kPa	PRECONSOLIDATION PRESSURE
τ_f	kPa	SHEAR STRENGTH
c'	kPa	EFFECTIVE COHESION INTERCEPT
ϕ'	-°	EFFECTIVE ANGLE OF INTERNAL FRICTION
c_u	kPa	APPARENT COHESION INTERCEPT
ϕ_u	-°	APPARENT ANGLE OF INTERNAL FRICTION
τ_R	kPa	RESIDUAL SHEAR STRENGTH
τ_r	kPa	REMOULDED SHEAR STRENGTH
S_t	1	SENSITIVITY $= \frac{c_u}{\tau_r}$

PHYSICAL PROPERTIES OF SOIL

ρ_s	kg/m^3	DENSITY OF SOLID PARTICLES
γ_s	kN/m^3	UNIT WEIGHT OF SOLID PARTICLES
ρ_w	kg/m^3	DENSITY OF WATER
γ_w	kN/m^3	UNIT WEIGHT OF WATER
ρ	kg/m^3	DENSITY OF SOIL
γ	kN/m^3	UNIT WEIGHT OF SOIL
ρ_d	kg/m^3	DENSITY OF DRY SOIL
γ_d	kN/m^3	UNIT WEIGHT OF DRY SOIL
ρ_{sat}	kg/m^3	DENSITY OF SATURATED SOIL
γ_{sat}	kN/m^3	UNIT WEIGHT OF SATURATED SOIL
ρ'	kg/m^3	DENSITY OF SUBMERGED SOIL
γ'	kN/m^3	UNIT WEIGHT OF SUBMERGED SOIL

e	1,%	VOID RATIO
n	1,%	POROSITY
w	1,%	WATER CONTENT
S_r	%	DEGREE OF SATURATION
w_L	%	LIQUID LIMIT
w_P	%	PLASTIC LIMIT
w_S	%	SHRINKAGE LIMIT
I_P	%	PLASTICITY INDEX $= w_L - w_P$
I_L	1	LIQUIDITY INDEX $= \frac{w - w_P}{I_P}$
I_C	1	CONSISTENCY INDEX $= \frac{w_L - w}{I_P}$
e_{max}	1,%	VOID RATIO IN LOOSEST STATE

e_{min}	1,%	VOID RATIO IN DENSEST STATE
I_D	1	DENSITY INDEX $= \frac{e_{max} - e}{e_{max} - e_{min}}$
D	mm	GRAIN DIAMETER
D_n	mm	n PERCENT - DIAMETER
C_u	1	UNIFORMITY COEFFICIENT
h	m	HYDRAULIC HEAD OR POTENTIAL
q	m^3/s	RATE OF DISCHARGE
v	m/s	DISCHARGE VELOCITY
i	1	HYDRAULIC GRADIENT
k	m/s	HYDRAULIC CONDUCTIVITY
j	kN/m^3	SEEPAGE FORCE