

Geocres No:
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Ministry of Transportation

Northern Region
North Bay, Ontario

Geocres No. 411-151

Foundation Investigations and Design Report

Highway 607A

FINAL

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Acres International
Oakville, Ontario, Canada

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Part 1 Foundation Investigations

1 Introduction

Acres International (Acres) was retained by the Ministry of Transportation Ontario (MTO) to undertake foundation investigations and testing, laboratory testing, engineering analysis and preparation of foundation reports for (i) Highway (Hwy) 510 swamp, (ii) Hwy 607A swamp, and 3 sand/salt storage structures located in the Northern Region. The work was authorized by MTO Agreement P.O.5005A000167 dated July 2000.

This report presents the results of foundation investigations for the proposed embankment raising/widening at Highway 607A in Northern Ontario.

2 Site Description

Highway 607A is located east of Highway 69 just north of the French River, and runs south off Highway 607 toward the French River, Figure 1.

Approximately 1 km south of the intersection of Highway 607 and 607A, the existing road, situated across a swamp, consists of a low earth and rockfill embankment approximately 230 m long and 9 m wide. At the present time, the traveled surface of the embankment is less than 0.6 m above the water level in the adjacent swamp. A 0.9 m diameter CSP culvert crosses the embankment near the midpoint of the crossing.

At the south end of the embankment, a high bedrock outcrop was noted immediately adjacent to the road. At the north end, bedrock outcrops were visible within a few tens of metres of the road. It appears that the swamp is contained within a depression in the underlying rock.

The main objective of the investigation is to provide information for raising and widening the road embankment to prevent seasonal flooding of the road.

3 Investigation Procedures

3.1 Field Investigations

The site investigations were carried out between August 1 and 4, 2000. A total of fourteen boreholes, labelled BH-1 to BH-14, were drilled at the locations shown in Figure 1.

The boreholes were advanced to depths ranging from 2.3 to 29 m using truck-mounted continuous flight hollow-stem augering and sampling equipment owned and operated by Boart Longyear Inc. of Maple, Ontario. Soil samples were obtained at approximately 0.75 m and 1.5 m intervals using a split spoon sampler in conjunction with Standard Penetration Test (SPT), in accordance with ASTM D1586 designation. SPT 'N' values were recorded and used to provide an assessment of the relative denseness of the cohesionless soils and consistency of cohesive soils. At depth, dynamic cone penetration testing was also carried out to determine the overall thickness of the soft clay and silt deposit and the depth to refusal.

A representative of Acres was present throughout the drilling and sampling operations to monitor and inspect drilling and sampling operations. All soil samples were identified and described in the field, and then transported to Acres Geotechnical Laboratory in Niagara Falls for further detailed examination and laboratory testing.

A summary of borehole data is given in Table 1. Detailed information for each borehole is presented in the Record of Boreholes in Appendix A.

As per MTO guidelines, soil samples were classified according to Unified Soil Classification Systems. The clay content reported as per MTO format in the Record of Boreholes forms is based on grain size less than 0.002 mm.

3.2 Field Survey

Survey of location and ground surface elevation of the boreholes was carried out by Acres. The elevation was referenced to an MTO marker and incorporated into an MTO site plan that was modified to produce Figure 1. Boreholes were located

relative to the distance along the embankment south of the end of the paved surface, designated Station 0+00, and east or west of the centre line.

3.3 Laboratory Testing

Selected samples of the overburden obtained from the boreholes were tested in accordance with applicable ASTM standards, as follows:

- moisture content
- Atterberg index limits
- grain size distribution
- natural unit weight
- undrained triaxial
- laboratory vane shear tests
- drained triaxial
- consolidation.

Testing was carried out at Acres Geotechnical Laboratory in Niagara Falls and the results are summarized in Tables 2 and 3 and also included as part of Record of Borehole in Appendix A.

These results are presented as follows:

Test	Number	Figure No.
Grain Size	9	2 to 4
Plasticity	8	5
Consolidated-Undrained Triaxial with PWP	one envelope	6
Consolidated-Drained Triaxial Test	one envelope	7
Consolidation	4	8 to 11

4 Subsurface Conditions

The soils encountered at the site, shown in Figure 1, comprised existing granular embankment fill overlying a thin, discontinuous organic deposit on top of very soft

to soft clayey silt to silty clay (CH). Details of the various soils encountered at the borehole locations, together with the summary of SPT 'N' and CPT and other test results are given in the Record of Boreholes in Appendix A. The water level is at or slightly above the ground surface. A brief description of the soils encountered at the site in the order of depth is given below.

4.1 Fill (SW)

The existing embankment, granular fill extends 0.5 to 3.1 m below the existing traveled surface of the roadway, from a minimum elevation of 184 m to a maximum road elevation over 189 m. The fill varies from sand to sand and gravel with cobbles. Along the shoulders of the roadway, about 0.5 m thickness of rockfill was noted.

4.2 Organic Soil

Beneath the embankment, the drilling up to 1.5 m of organic materials represents the original surface of the swamp. Away from the embankment, where hand-sampling was carried out to a depth of about 2.5 m at Boreholes BH-4, 5, 8 and 9, 0.3 m to 0.5 m of fibrous organic material was encountered. The latter was underlain with a layer of thickness 0.9 m to 1.3 m consisting of loose wet silty sand mixed with decomposed organic debris. The organic materials are extremely weak and highly compressible.

4.3 Soft Silty Clay (CH - CL)

A deposit of silty clay to clayey silt extends to significant depths (as much as 29 m) in the swamp, from a top elevation of 184-187.3 metres to a bottom at the assumed bedrock elevation of 158 to 184 m. The undrained shear strength based on field vane testing ranged from 7 to 22 kPa, which represent weak unconsolidated soils. Further, this soil has high moisture content and, in the upper part, high plasticity with an index ranging from 27 to 82%. All indicators, including low unit weight, suggest soft to very soft soil and highly compressible foundation. Also, variations in properties can be expected both horizontally and with depth.

4.4 Bedrock

The roadway crosses an assumed bedrock depression inferred from the local topography and rock outcrops. The depth to assumed bedrock ranges from 3 m

below ground surface (elevation 184 m) at Borehole BH-11 at the south end of embankment to 29 m below ground (158 m elevation) at BH-12 in the middle of the swamp crossing.

5 Groundwater Conditions

During drilling, the water level in all boreholes was approximately similar to the water level in the swamp which was about el 186.1 m.

There was no evidence of drainage condition or pervious materials underlying the soft clayey silt deposit. The pore pressure distribution through these materials is therefore equivalent to hydrostatic, except for excess pressure due to new loading.

Part 2 Engineering and Construction

6 Engineering Considerations

6.1 Embankment Foundation

The proposed roadway embankment is to be raised a maximum of 2.0 m which is sufficient to avoid seasonal flooding. The foundation soils along the roadway are summarized as follows:

- compact sand with gravel (SW) fill from 0.5 m to 3.0 m thick
- organic soil constituting swamp surface to a maximum of about 1.5 m in thickness. Away from the existing roadway, fibrous organic soils were encountered about 0.3 m to 0.5 m thick. The latter was underlain with wet loose silty sand mixed with decomposed organic debris between 0.9 m to 1.3 m in thickness
- silty clay to clayey silt (CH - CL) high moisture, soft to very soft and plastic and of considerable thickness to a minimum of about 26 m.

The site is a wet swamp rising to el 186.1 m. The surface of the roadway varies from el 186.9 m in the middle of the swamp to over 189 m at the north end.

6.2 Foundation Resistance

The shearing resistance of the foundation soil was evaluated as follows:

(i) Undrained Strength

The results of shear vane testing is summarized below.

Borehole	Depth (m)	Plastic Limit (%)	Vane Shear Strength (kPa)	Vane Shear Correction Factor	Corrected Undrained Shear Strength kPa
BH-1	4.3	8	15	1	15
	5.0		22	1	22
BH-2	5.0	43	20	0.8	16

Borehole	Depth (m)	Plastic Limit (%)	Vane Shear Strength (kPa)	Vane Shear Correction Factor	Corrected Undrained Shear Strength kPa
BH-3	4.1	38	17	0.88	15
BH-6	7.1	15	21	1	21
BH-7	7.1	27	7	0.92	6
	8.5		13		12
BH-10	4.0	-	15	0.84	13

Based on the above, the average measured undrained strength is about 15 kPa, and for the purpose of this report, a value of 12 kPa is selected.

(ii) Drained Strength

In terms of effective stress, the results of triaxial testing are shown in Figures 6 and 7. For the condition of no effective cohesion, the effective angle of shearing resistance of the foundation soil is about 17 and 20 degrees. For the purpose of this report a value of 17 degrees is used.

6.3 Maximum Embankment Height

To determine the maximum height of the proposed embankment rotational sliding through the foundation was analyzed using total stress and effective stress analyses. The total width of embankment was maintained at less than 25 m, the minimum width of the road allowance along the embankment section, Figure 1. Additionally, a live load of 50 kN/m was applied as shown in Figures 12 and 13, which corresponds to approximately the load of a 40 Tonne loaded trailer.

The results, shown in Figures 12 and 13, are as follows:

Analysis	Total Height of Embankment (m)	Factor of Safety
Total Stress $C_u = 12$ kPa	2.0	1.30
Effective stress $\phi^1 = 17$ degrees $C^1 = 0$	1.7	1.26

Using the effective stress analysis, it is concluded that the maximum height of roadway embankment is 1.7 m or a raise of 1.2 m from the existing embankment. Based on considerations of consolidation settlement, a height of 1.5 m for the raised and widened embankment is used for the purpose of this report. As discussed later in this report, reaching this height requires particular care in construction.

6.4 Embankment Geometry

Embankment construction on weak compressible soil require flat slopes in order not to overstress the foundation. For practical purposes, the overall flat slopes can be achieved by means of stabilizing berms. The maximum fill slopes should be built at no steeper than 3:1 for considerations of ease of construction and long term resistance to erosion. The basic geometry of the 1.5 m high embankment is shown in Figure 14. Two main alternative details are considered. In all cases, the existing embankment is retained and the raised embankment will consist of granular fill with slope protection such as rockfill or coarse gravel. The use of light-weight fill in building the embankment has worthwhile advantages on weak soil foundation. However, consideration of this approach depends on local availability, properties and economics of light weight fill materials.

Options 1A and 1B - Embankment on Existing Ground

Option 1A, shown in Figure 14 without reinforcement calls for placement of new fill on the existing ground surface including the swamp. Option 1B utilizes the same section plus a geogrid reinforcement as shown in Figure 14.

Options 2A and 2B - Embankment on Excavated Ground

Option 2A, shown in Figure 15, calls for the removal of the upper organic layer in the swamp, if this were mandated by MTO policies. It is noted that excavation in the swamp will cause reworking and disturbance of soils which are already in a weak state. Further softening of the foundation may promote

greater displacement of soil during fill placement. It may be possible to perform construction in panels or strips especially in the vicinity of the existing embankment.

Option 2B incorporates a geogrid reinforcement such as Terrafix BX-1200 to overlay the excavated surface. This option would raise significant problems as discussed below.

Recommended Scheme

Excavation of Organic Soil

It is remarked here that the soil in question is a silty clay matrix containing some organic component. This is expected to behave as an engineering material rather than true organics such as readily degradable vegetation containing grass and branches and little or no soil.

The removal of the organic soil, if necessary, raises concerns in constructability such as:

- The thickness is variable reaching a depth of 1.5 m. It is transitional and the limit of excavation is not well defined.
- Excavation will be inundated with swamp water and control of excavation will be onerous and difficult.
- Disposal would have to be contained so the fluid material does not spread out. Also it is not clear whether disposal of organics need to comply with regulatory constraints.
- Other difficulties pertain to soil disturbance, further weakening of soils, especially next to the existing road, increase in fill volume, larger differential settlement.
- The installation of geosynthetic reinforcement would be even more beneficial if excavation of organics was to take place, because of the inevitable local shearing and disturbance that would be induced by such excavation. During such a procedure, however, the installation of the reinforcement would be rendered extremely difficult in practical terms by the necessity to deploy the (buoyant) reinforcing material under water in a water-filled excavation in soft soil.

Use of Geosynthetic Reinforcement

- At this site, the use of geosynthetic reinforcement would bring some benefits. While a woven geotextile reinforcing layer may provide good results, it is considered that in this specific case, geogrid should be selected on the basis of its improved ease of deployment. The installation of a geogrid reinforces the overall embankment and facilitates construction.
- Geogrid tends to reduce differential settlement as well distortion and excessive deformation in the roadway.
- Geogrid will further minimize quantity overrun as well as being generally economical.

Recommendations

The conditions at the site as well as considerations of constructability and superior long-term performance suggest preference for an embankment on existing ground underlain with geogrid reinforcement. Given site conditions, the excavation of organic materials would be problematic, and rendered especially difficult in deploying geosynthetic reinforcement.

The scheme shown in Figure 14 is recommended on the expectation that it can be considered in compliance with MTO requirements. The geogrid reinforcement should have a tensile strength of 12 kN/m such as Tensar BX 1200 or equivalent.

6.5 Settlement

Consolidation testing was performed on four samples and the resulting plots of void ratio versus vertical loading are given in Figures 7 to 10. The following table provides a summary of consolidation properties. The relatively high values of the compression index are noted.

Borehole	Sample Depth (m)	Initial Void Ratio e_0	Compression Index C_c	Coefficient of Consolidation C_v (m^2/y)
BH-4	2.3	3.0	1.3	0.4
BH-6	6.1	1.54	0.7	2.4
BH-7	6.1	1.5	0.7	0.9
BH-10	3.1	2.5	0.95	0.6

These test data were used to estimate the magnitude of consolidation settlement. Results are summarized in Table 3. For a 1.5 m high embankment, the total consolidation settlement is estimated at about 0.9 m in the middle of the swamp crossing where the clayey deposits are at maximum thickness.

The consolidation will take a number of years to complete. Assuming 1-dimensional drainage, the time to 90% consolidation is over 10 years. In practice, consolidation will be somewhat faster. Nevertheless, there will be significant movement of the embankment over time.

6.6 Cost Comparison

On examination of Figures 14 and 15, it is observed that the quantity of fill required in Option 1 is approximately 11 m^3 /linear metre (l.m.) of embankment.

Considering a maximum depth of 1.5 m of organics to be removed under Option 2, additional excavation and fill would be 8 m^3 /l.m. Using reasonable unit cost figures for the excavation of the organic materials and the placement of granular, the increment of cost associated with removal of shallow organics would be greater than \$200/l.m. not including any costs associated with working under water or deploying geosynthetic reinforcement that might be required.

In contract, geogrid placed as shown in Figure 14 is not expected to cost more than \$130/l.m. based on a 20 m width of reinforcement (10 m on both sides) and using a unit rate of geogrid reinforcement (installed) of \$6.50/ m^2 . Therefore Option 1 geosynthetic reinforcement has a cost advantage.

7 Construction Considerations

The construction of fill embankments, even to low heights on soft unconsolidated soil foundation presents special challenges in equipment selection, placement methods and construction planning. Technical specifications, data for tenderers and contract documents must be aimed at alerting prospective contractors that the building of the Highway 607A embankment in the swamp will not be a conventional exercise and will present some challenges as a result of the weak foundation conditions.

Further, observations made on-site during construction by experienced geotechnical construction staff would allow the procedure to be optimized and would help to reduce the disruptions and delays associated with unexpected or undesirable foundation performance.

The fundamental objective in construction is to minimize the impact methods or activities which cause significant overstressing in a soil foundation which offers particularly low in-situ resistance. The factors contributing to the weak foundation include lack of drainage, fine-grained soils and swampy environment. The overstressing of the soil will lead to disturbing and reworking the foundation as well as loss of soil strength. The resulting development of "mud waves" is disruptive to construction and contribute to differential settlement and potential cracking of the roadway.

The following remarks are presented:

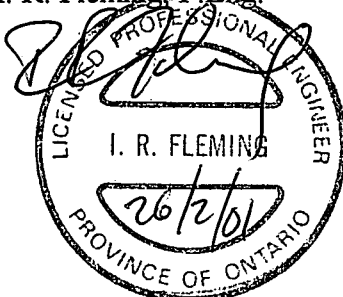
- (i) The embankment fill should consist of granular material such as Granular 'B'. Rockfill should be avoided due to potential of puncturing the foundation. However, rockfill may be used for slope protection.
- (ii) No compaction is necessary for the initial 0.6 m of fill except for wide-pad low ground pressure construction equipment. Light compaction equipment such as 5-ton static steel drum roller without vibrations, may be used on a trial basis in subsequent lifts. During widening of the embankment out onto the existing swamp surface, trucks should avoid dumping entire loads of fill directly upon the weak foundation soils, in order to avoid localized failure of these soft soils. Rather, loads should be dumped onto the existing embankment and spread carefully over the geosynthetic reinforcement out onto the swamp surface.

- (iii) Spread initial lift at a thickness of 0.6 m, using light wide-tracked equipment such as small dozers, or backhoes to cast fill ahead. Haulage equipment should not be permitted on this fill.
- (iv) Lifts above 0.6 m can be reduced to 0.3 m thickness and compaction performed provided such activity will not damage the foundation. Throughout fill placement, ensure grades favoring satisfactory surface drainage.
- (v) Ensure special care in placement of fill in water or in the swamp.
- (vi) It is preferred that the root-mat not be removed and no foundation excavation is carried out except on a small local scale.
- (vii) Settlement of the embankment will occur during construction and in the long term. It is estimated that the embankment volume should allow for settlement in the order of 60% over theoretical volume. The use of geogrid reinforcement would reduce differential settlement and distortion of the roadway.
- (viii) Require the Contractor, after a given period of time, say one year, to return to the site and build up the settled embankment, as well as placement of slope protection.

Design and Construction

Information in this report is intended to provide general characterization of ground conditions. Variations in the subsurface should be expected and provided for in detailed engineering and construction practices. Supervision of excavations and backfill should be performed and approved by experienced geotechnical staff familiar with the requirements of design.

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A. H. Tawil, P.Eng.



Tables

Table 1

Summary of Borehole Data

Borehole	Ground Surface Elevation (m)	Bottom of Borehole (m)	
		Depth	Elevation
BH-1	188.84	20.17	168.67
BH-2	187.68	23.77	163.91
BH-3	186.81	6.09	180.72
BH-4	186.10	2.74	183.36
BH-5	186.10	2.28	183.82
BH-6	187.08	11.27	175.81
BH-7	187.11	9.75	177.36
BH-8	186.10	2.74	183.36
BH-9	186.10	2.74	183.36
BH-10	186.91	5.63	181.28
BH-11	186.89	3.10	183.79
BH-12	187.01	28.95	158.05
BH-13	187.06	16.76	170.30
BH-14	187.13	27.13	160.00

Table 2

Summary of Laboratory Test Results

Borehole	Depth From-To (m)	Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Unit Weight (kN/m3)
BH-1	0.00 - 0.61	1.6	23	15	8	13.20
	0.76 - 1.37	20.4				
	2.29 - 2.90					
	4.57 - 5.18	81.6				
	7.62 - 8.23	79.4				
	10.67 - 11.28	46.1				
BH-2	4.80 - 5.50	81.9	72	29	43	
	6.09 - 6.71	79.3				
	7.62 - 8.23	63.7				
BH-3	0.76 - 1.37	55.8	55	19	36	13.89
	3.05 - 3.66	101.1				
	4.57 - 5.18	78.0	65	27	38	15.50
	5.49 - 6.10		66	28	38	
BH-4	1.98 - 2.13		116	34	82	13.13
	2.13 - 2.74	125.1				
BH-6	6.10 - 6.71	53.4	36	21	15	16.17
	7.62 - 8.23	64.0				
	9.14 - 9.75	55.0				
BH-7	3.05 - 3.66	42.0	53	26	27	13.40
	4.57 - 5.18	80.0				
	6.10 - 6.71	57.8				
	7.62 - 8.23	61.0				
BH-10	1.52 - 2.13	29.0				13.62
	2.29 - 2.90					
	3.05 - 3.66	106.4				
BH-14	10.67 - 11.28	49.0				
	12.19 - 12.80	30.0				
	13.72 - 14.33	29.0				
	15.24 - 15.85	33.0				

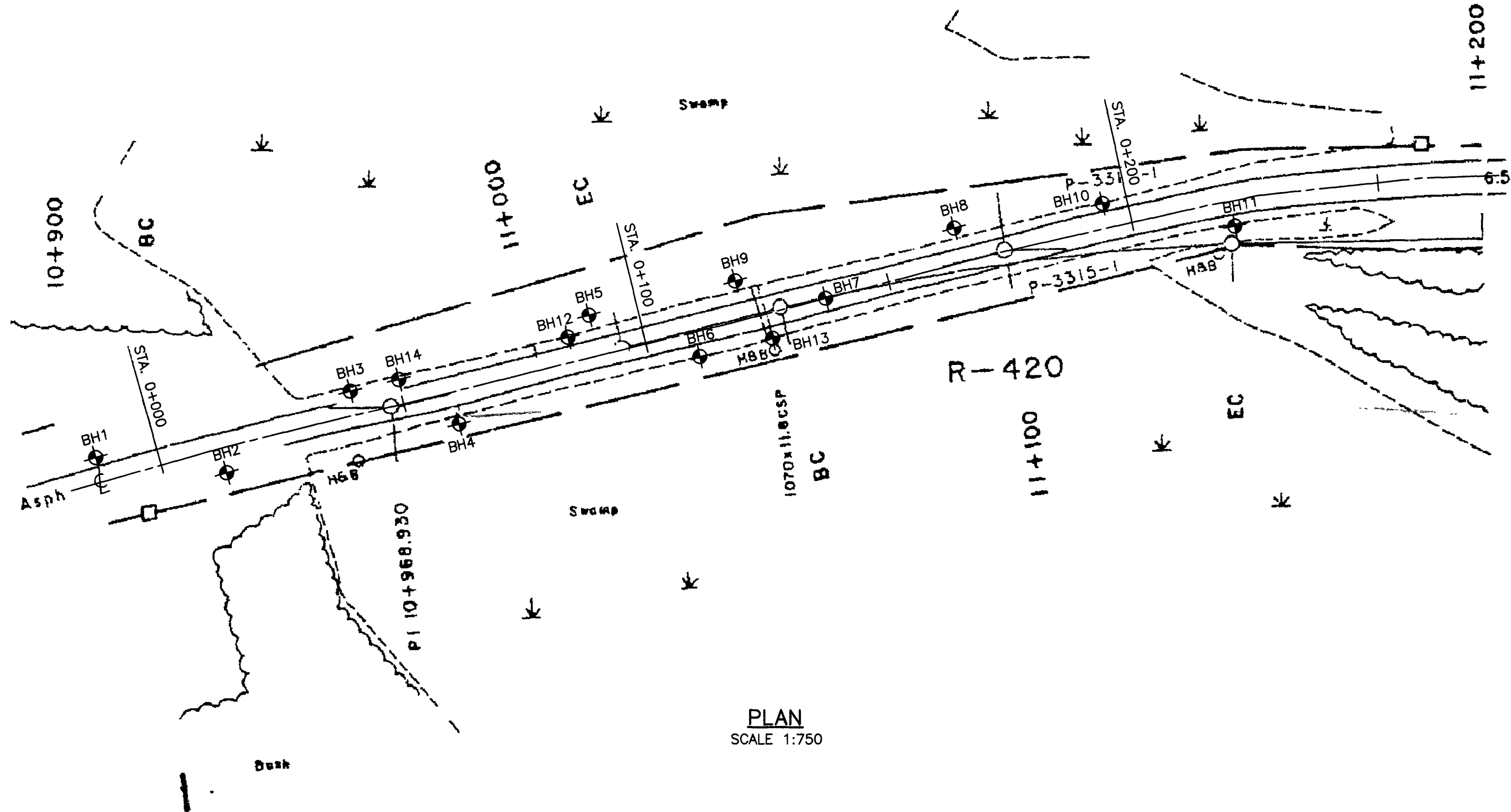
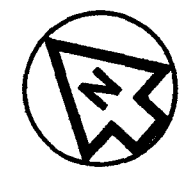
TABLE 3 Summary of Consolidation Settlement Calculations

Highway 607A		under centre of embankment			water level bgs		0.5		height of embankment = 1.52 metres							
(all depths from elevation of existing embankment)												settlement in metres at time in years				
		change in total stress	bulk density	unit weight	pore water pressure	initial total stress	initial effective stress	final effective stress	compressi on index	initial void ratio	settlement	coeff of consol'n				
Layer		delta sigma' (kPa)	Dbulk (kg/m³)	Yeff (kN/m³)	u (kN/m³)	p _o (kPa)	p _o ' (kPa)	p ₁ ' (kPa)	Cc	e _o	s _c	cv= (m2/yr)	1	3	5	12
0	0.80	32	2150	21.07	0	8	8.4	40	0.00	0.5	0.00					
0.8	2.50	31	1340	3.3	13	30	17.2	49	1.30	3	0.25	0.4	0.11	0.18	0.21	0.24
2.5	4.60	29	1400	3.9	26	49	22.3	51	0.95	2.6	0.20	0.6	0.08	0.14	0.17	0.20
4.6	8.00	23	1650	6.4	54	91	36.7	60	0.70	1.47	0.20	0.6	0.06	0.09	0.12	0.17
8	12.50	16	1675	6.6	93	156	62.7	79	0.70	1.43	0.13	1.7	0.04	0.07	0.09	0.12
12.5	17.50	12	1700	6.9	142	238	96.4	108	0.70	1.32	0.07	1.7	0.02	0.04	0.05	0.07
17.5	24.00	9	1725	7.1	191	322	131.3	140	0.70	1.2	0.06	1.7	0.02	0.02	0.03	0.04
24	32.00	6	1750	7.4	270	459	189.1	196	0.70	1.1	0.04	1.7	0.01	0.01	0.02	0.02
total settlement											0.95	metres	0.34	0.56	0.68	0.87
													36%	58%	72%	91%

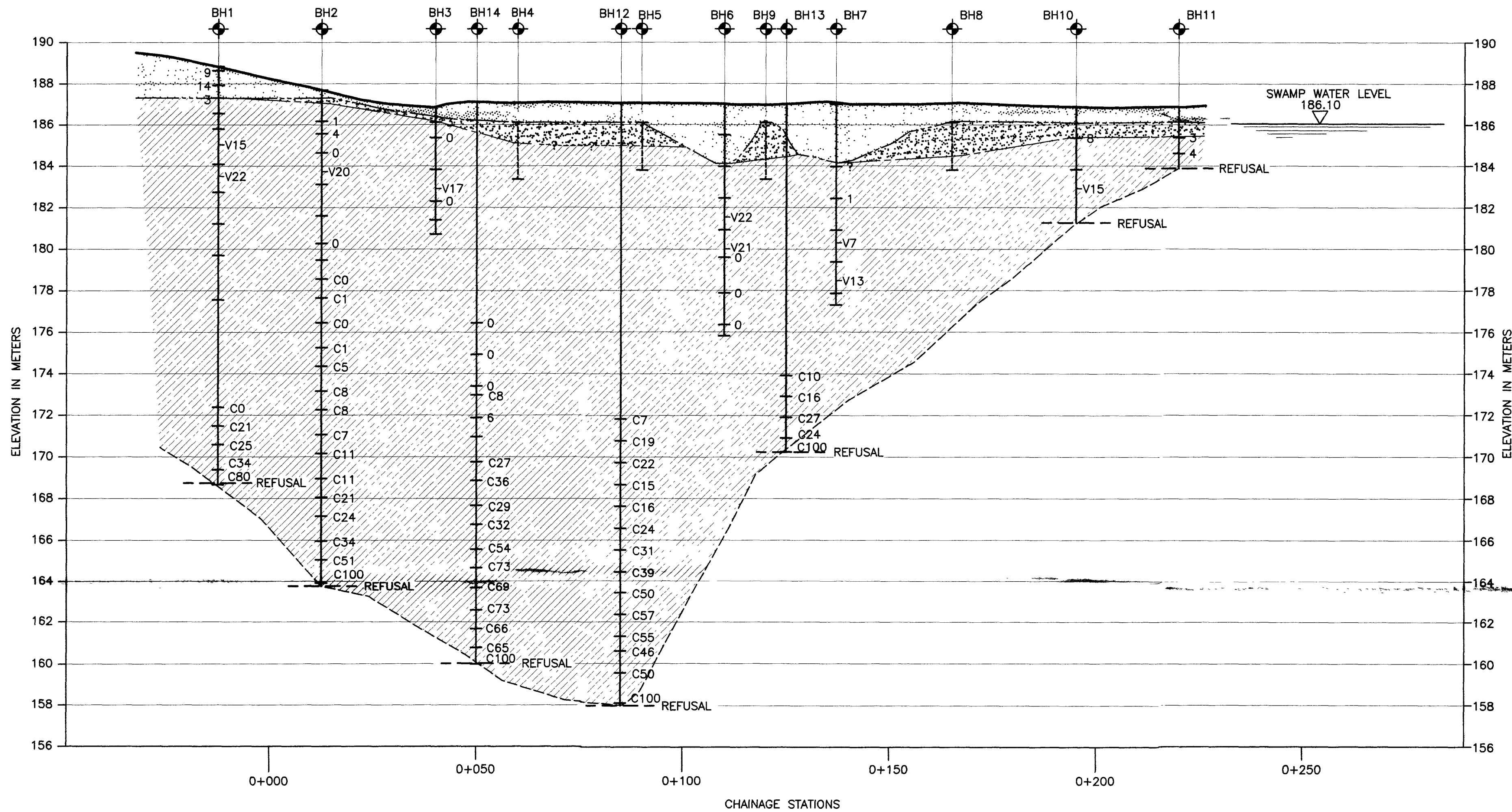
variation of total settlement with total thickness of silty clay

8	0.7 m
12.5	0.8 m
17.5	0.8 m
24	0.9 m
32	0.9 m

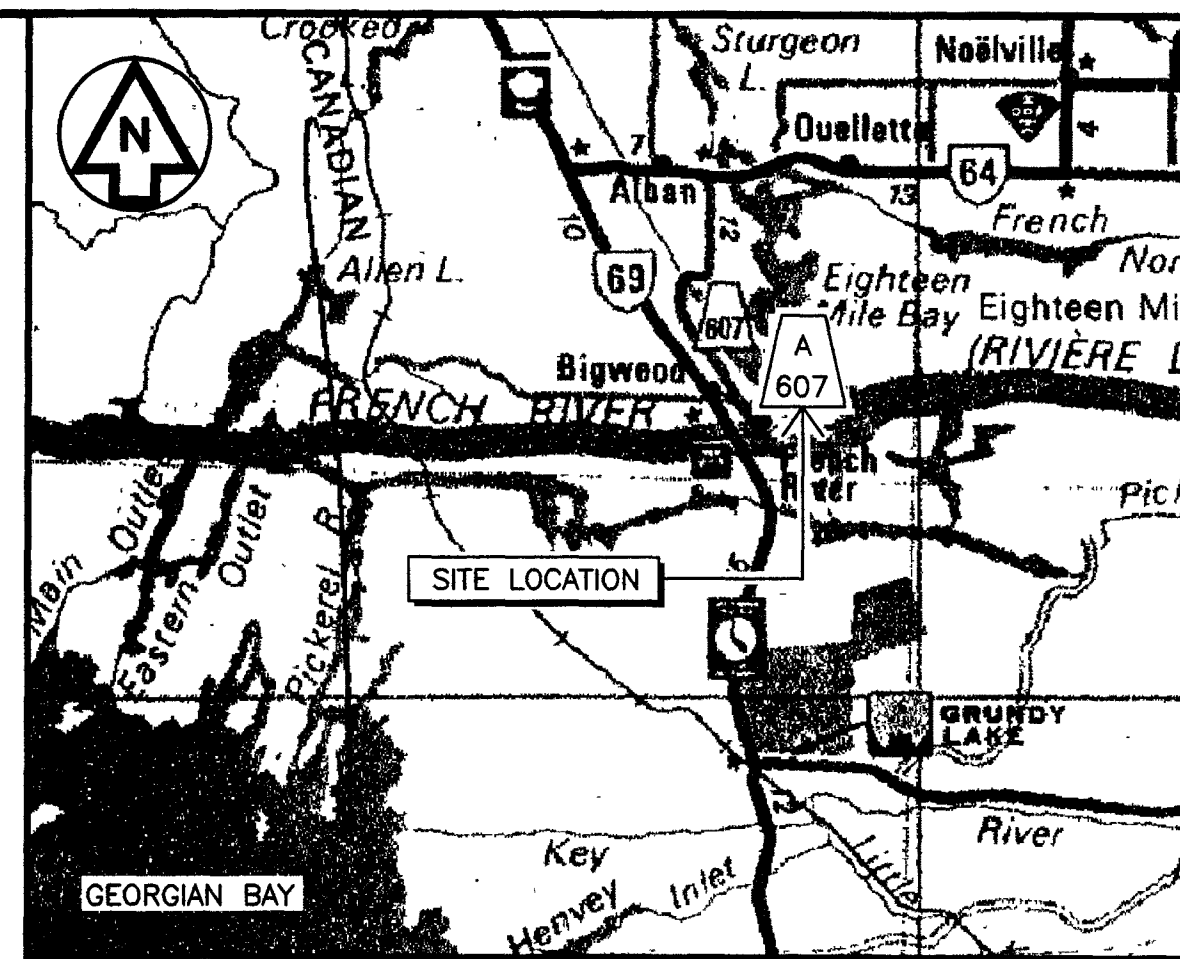
Figures



PLAN
SCALE 1:750



ROAD CENTERLINE PROFILE
SCALE: HORIZONTAL 1:750
VERTICAL 1:150



KEY PLAN

LEGEND	
	EMBANKMENT FILL (COARSE SAND & GRAVEL WITH COBBLES AND BOULDERS)
	SAND AND SILTY SAND WITH ORGANIC MATERIALS
	SILTY CLAY
	BH11 BOREHOLE
	REFUSAL
	STANDARD PENETRATION N VALUE BLOWS/300mm
	CONE PENETRATION N VALUE BLOWS/300mm
	V20 FIELD VANE (kPa)

NOTES

REV. BY	REV. No.	DESCRIPTION OF REVISION	APPROVED BY	DATE
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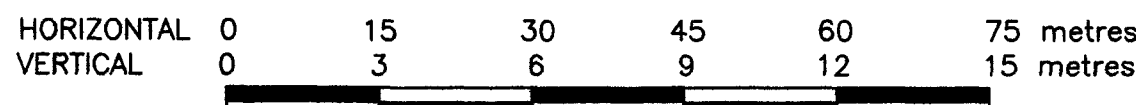
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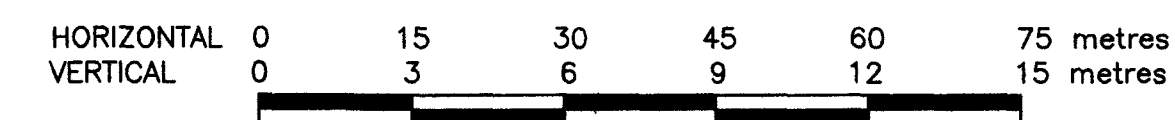
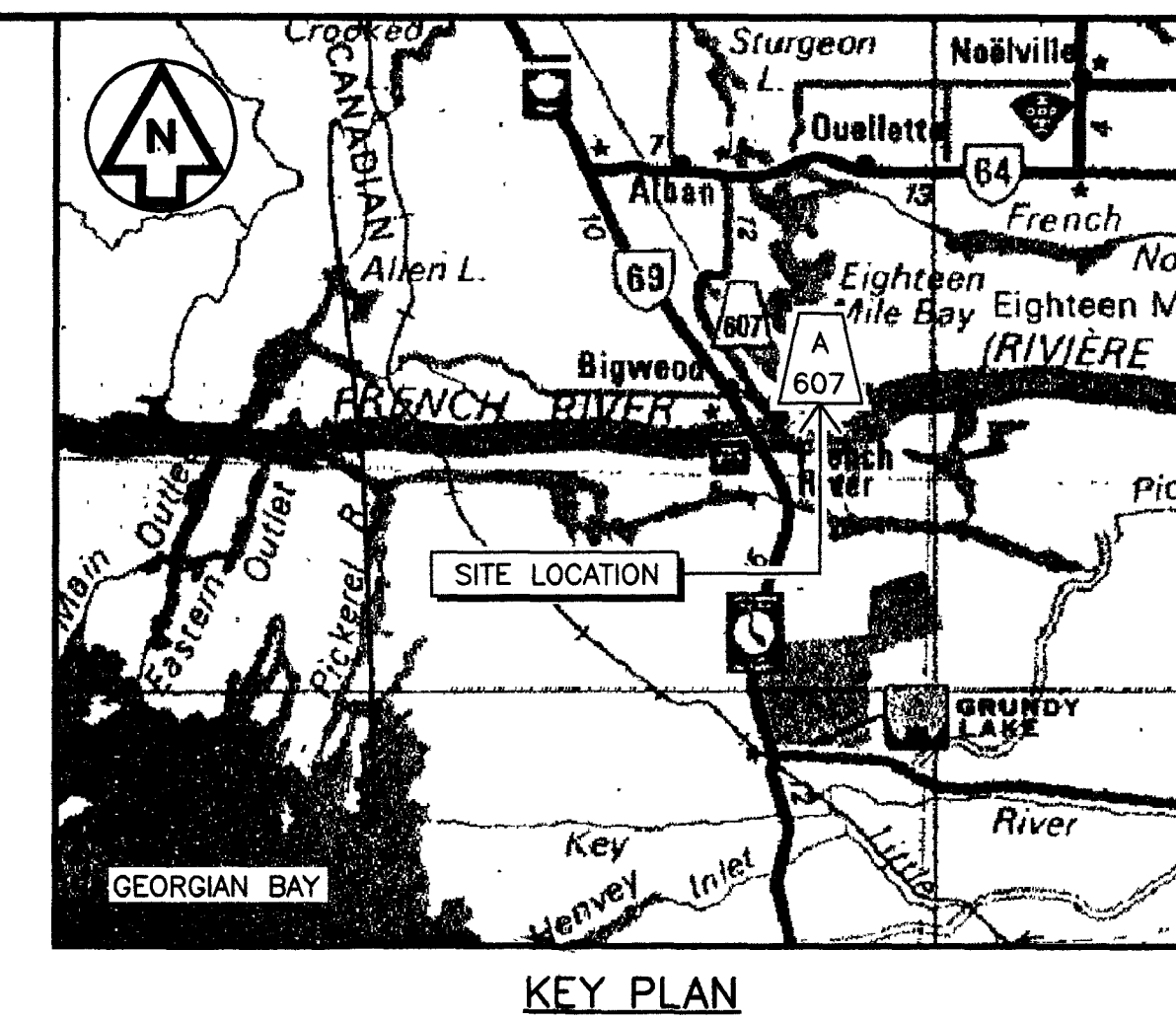
	Ministry of Transportation Ontario
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DISTRICT	LOT
NORTH BAY	CON
	TWP

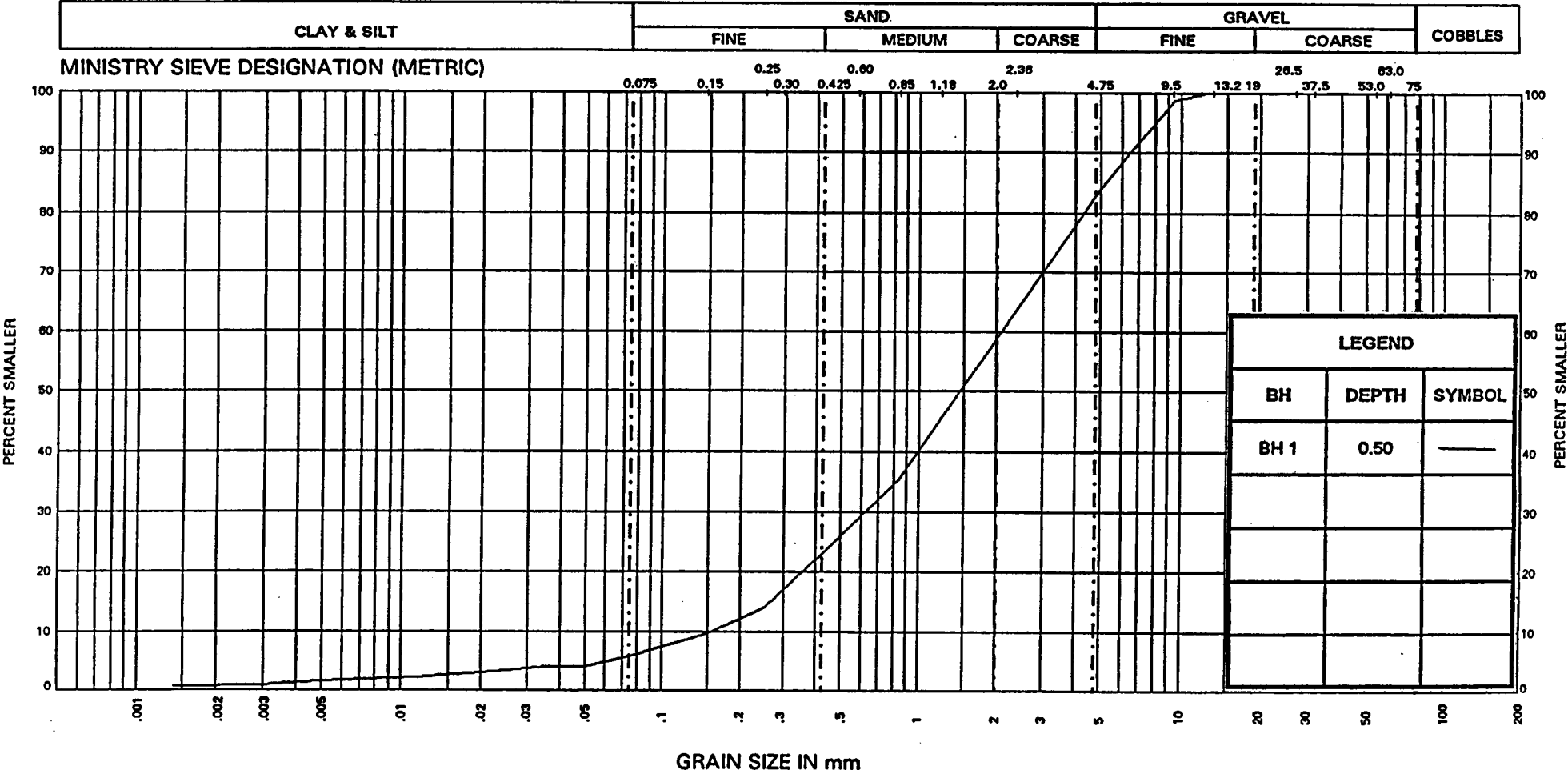
PROJECT TITLE	DRAWING DESCRIPTION / TITLE
HIGHWAY 607A	FIGURE 1. LOCATION OF BOREHOLES AND SOIL STRATIGRAPHY

DATE	NOVEMBER 2000	SCALE	AS NOTED
DRAWN BY	T.DANIEL	DWG. No.	of
DESIGNED BY		PROJ. No.	P1349800
CHECKED BY		FILE No.	1349800-GE-01
APPROVED BY			



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UNIFIED SOIL CLASSIFICATION SYSTEM



Ministry of
Transportation
Ontario

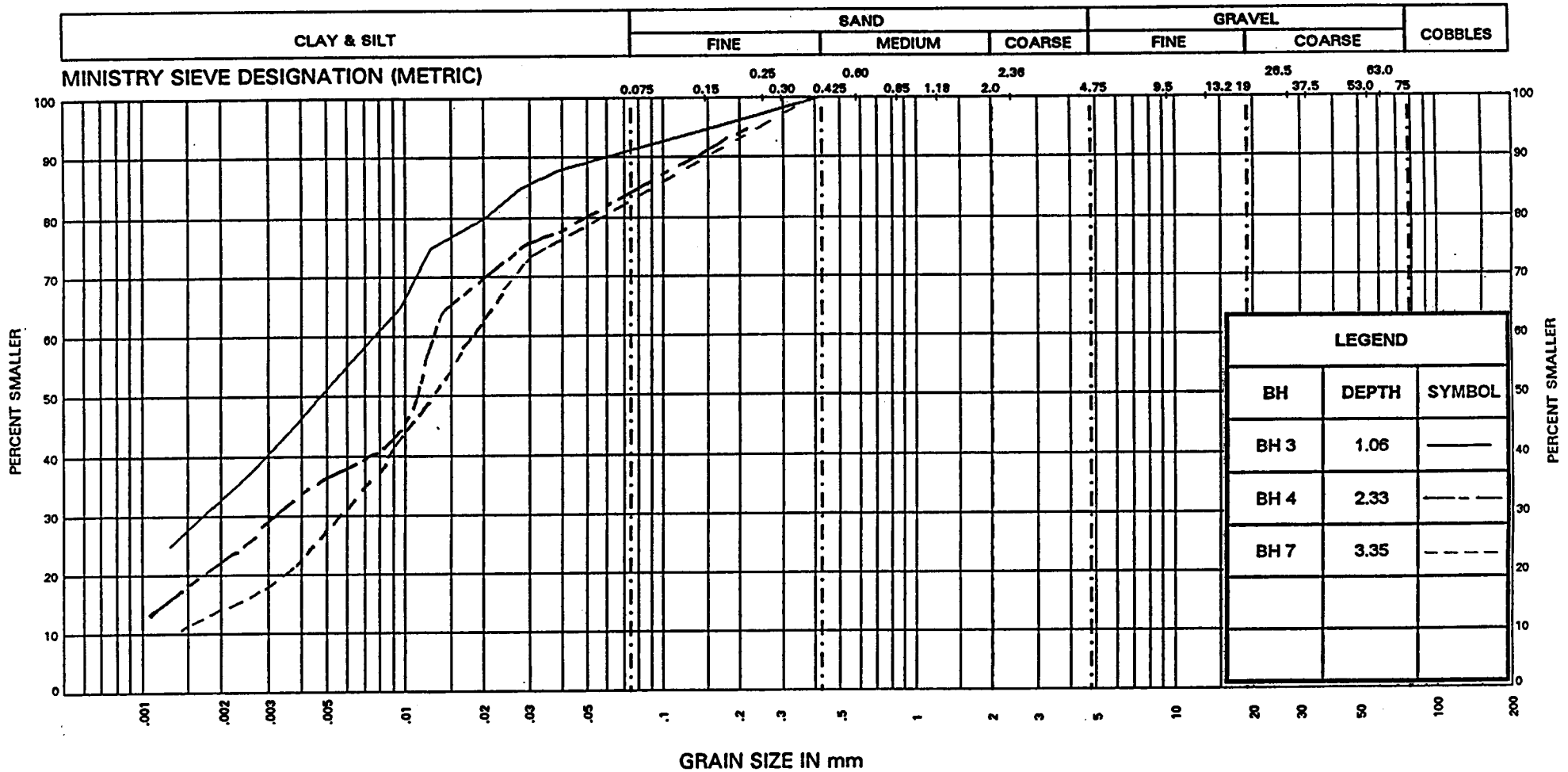
GRAIN SIZE DISTRIBUTION
SAND (SW) WITH TRACE GRAVEL

FIGURE 2

W.P. 7508-00-00

HWY 607A

UNIFIED SOIL CLASSIFICATION SYSTEM



Ministry of
Transportation
Ontario

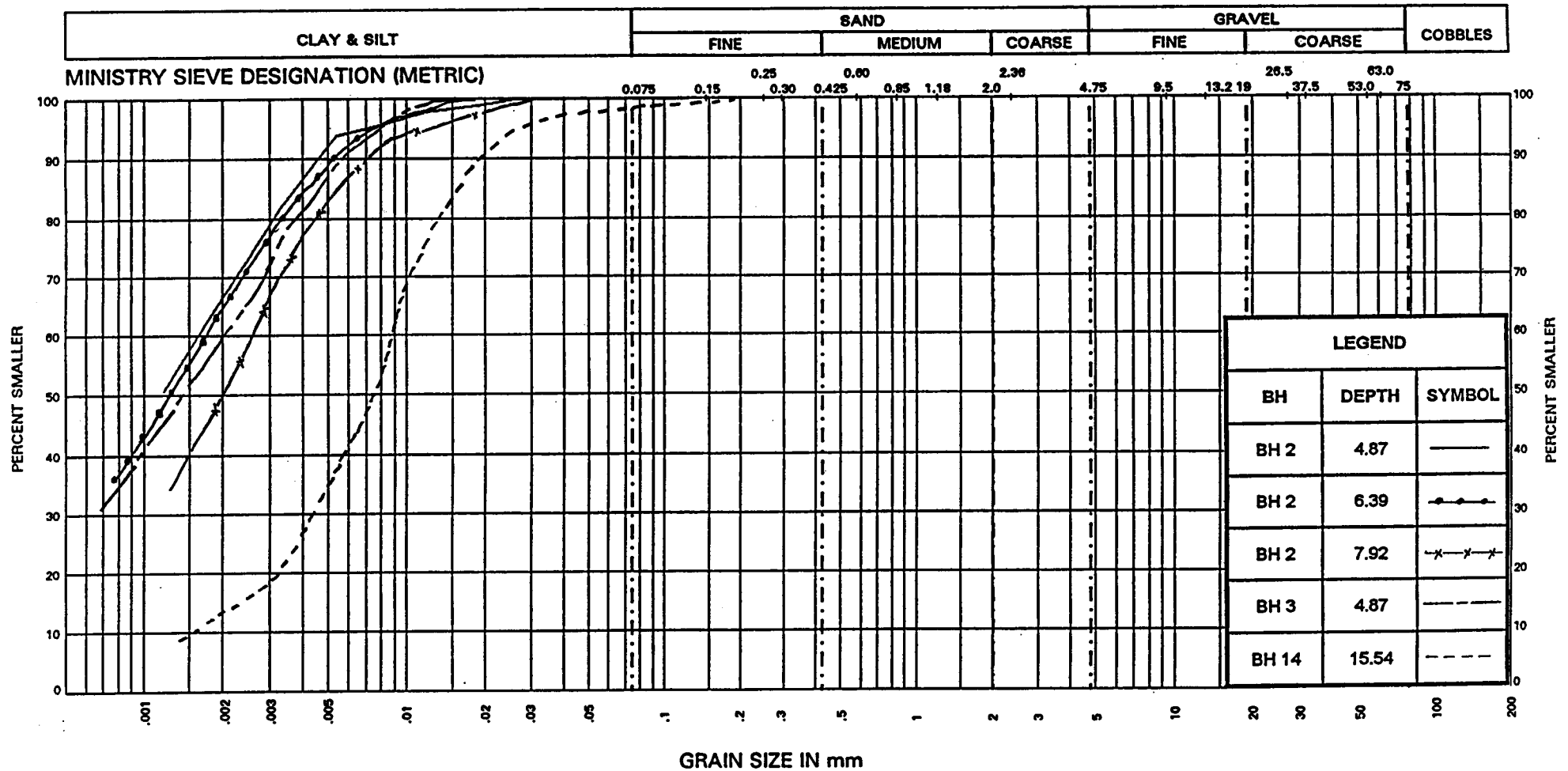
GRAIN SIZE DISTRIBUTION SILTY CLAY WITH SAND (CH)

FIGURE 3

W.P. 7508-00-00

HWY 607A

UNIFIED SOIL CLASSIFICATION SYSTEM



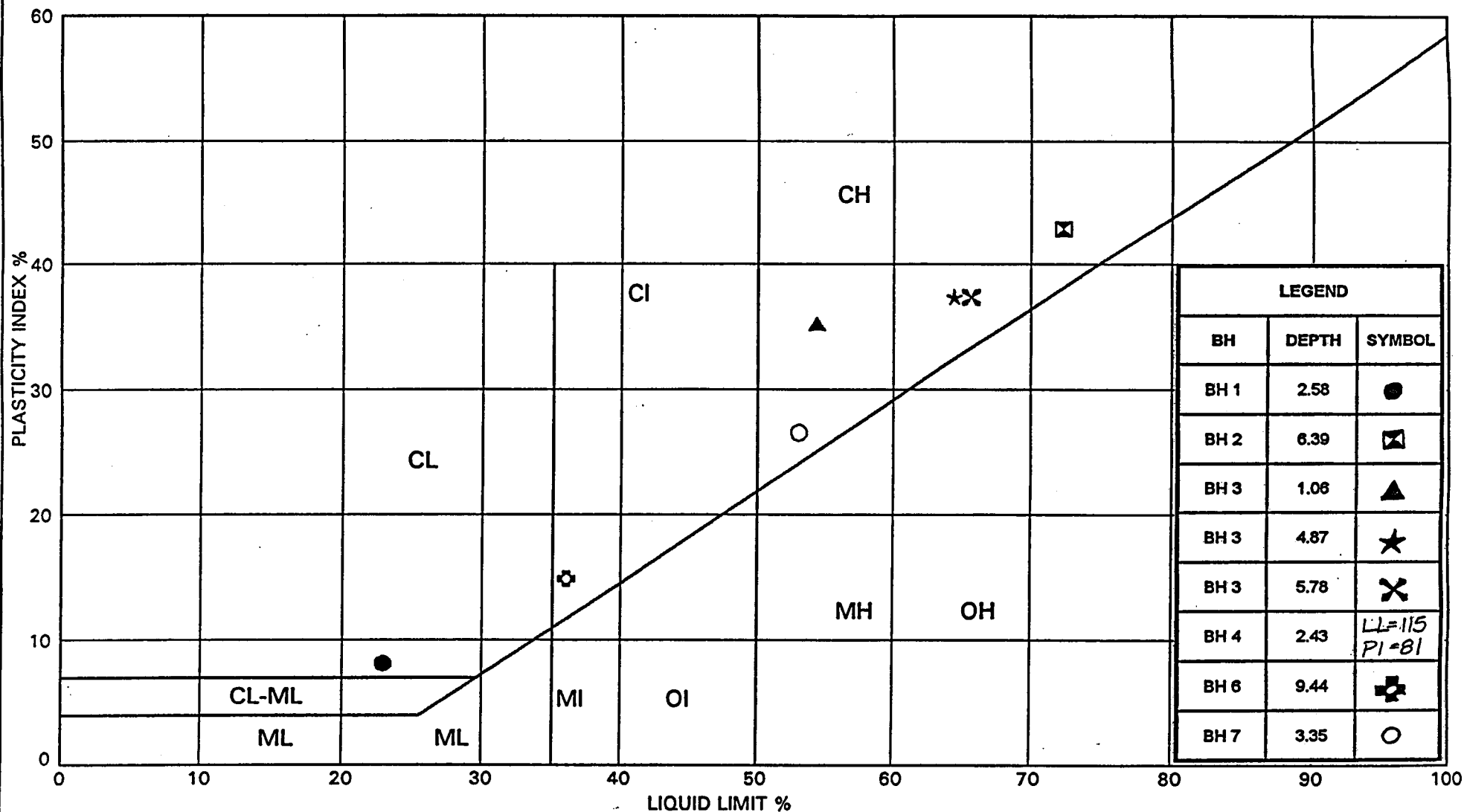
Ministry of
Transportation
Ontario

GRAIN SIZE DISTRIBUTION SILTY CLAY (CL-CH)

FIGURE 4

W.P. 7508-00-00

HWY 607A



Ministry of
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Ontario

PLASTICITY CHART

SILTY CLAY AND CLAY

FIGURE 5

W.P. 7508-00-00

HWY 607A

Figure 6 Results of Triaxial Testing

consolidated undrained with pore pressure measurements
BH4-B01 1.7-1.9 m, $\sigma_3 = 22$ kPa BH3-B04 5.7-5.8 m, $\sigma_3 = 108$ kPa

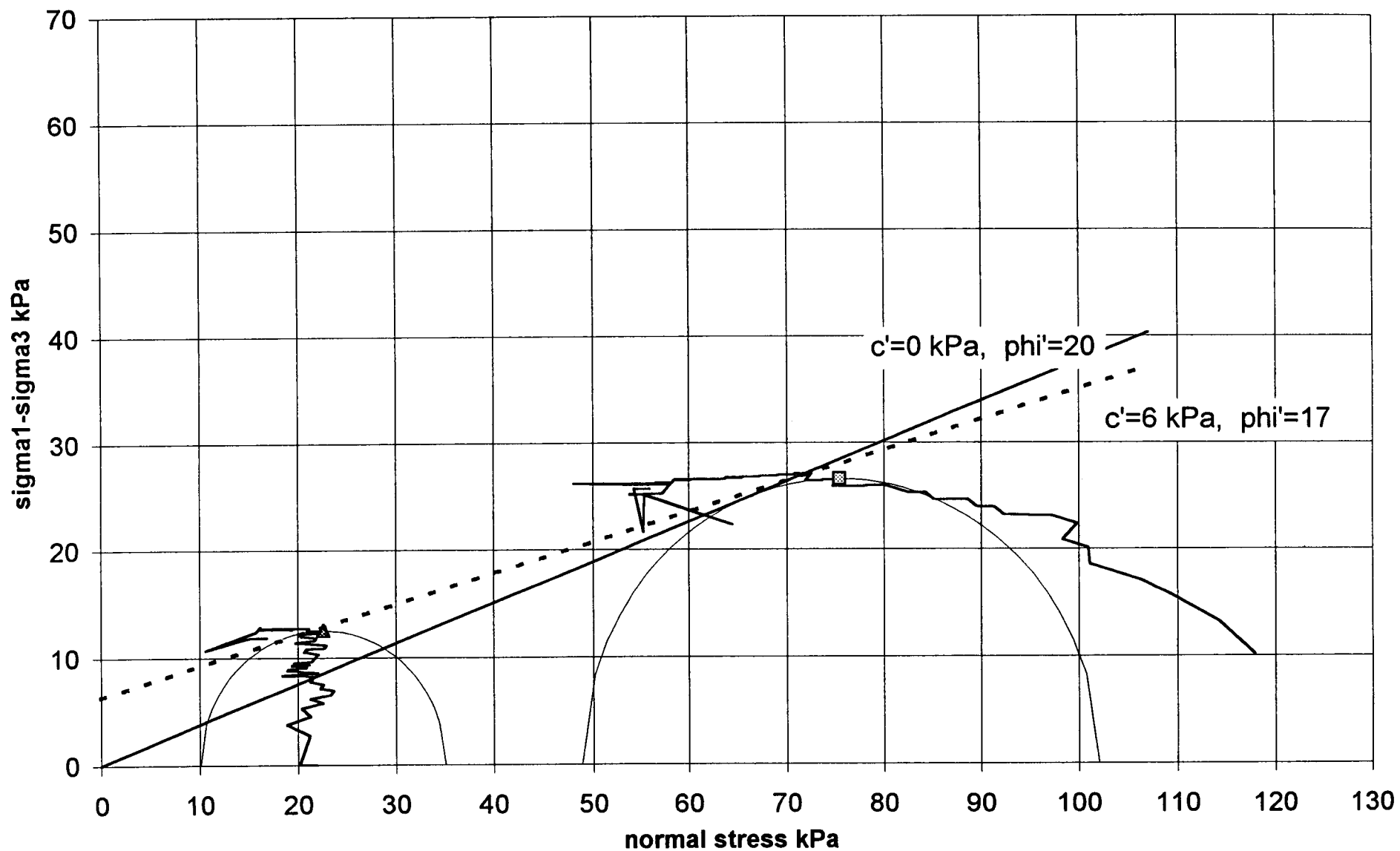


Figure 7 Results of Triaxial Testing

Consolidated drained, BH3-B02, depth 3-3.6 m, BH4-B01, depth 2.1 m

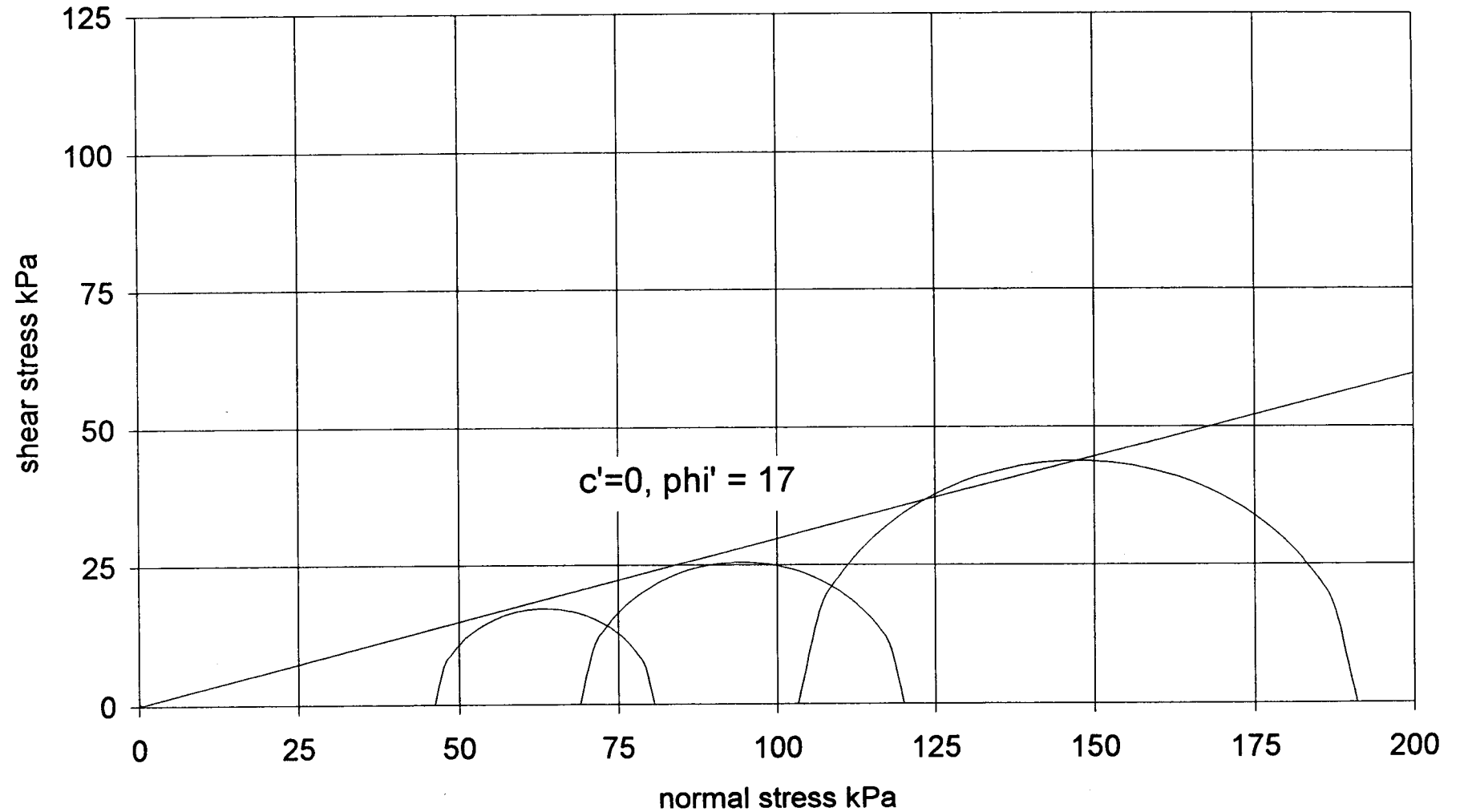


Figure 8 Results of Consolidation Testing

Hwy 607 A, BH4- BO1 2.28m

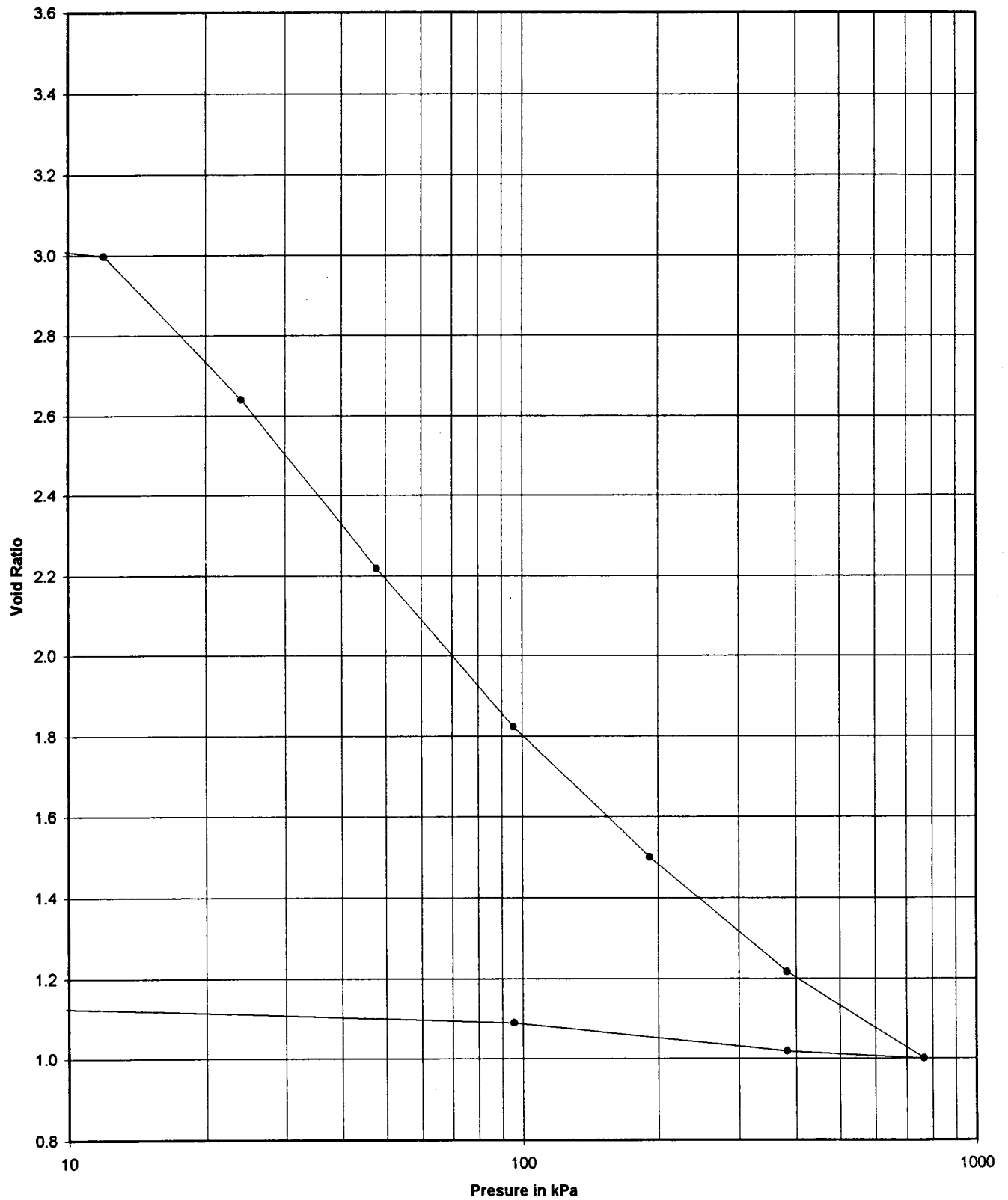


Figure 9 Results of Consolidation Testing

Hwy 607 A, BH6- BO2 6.09m

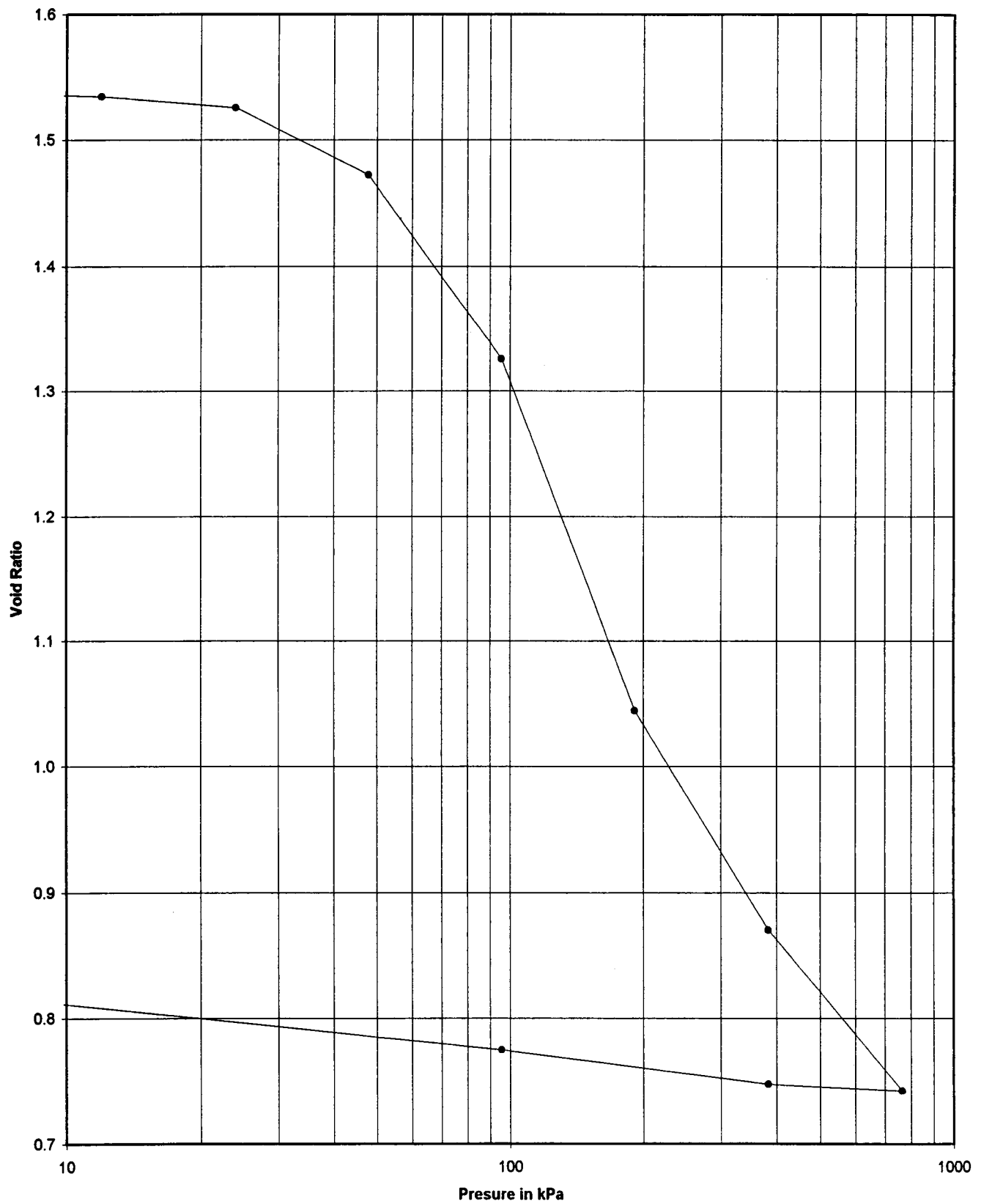


Figure 10 Results of Consolidation Testing

Hwy 607 A, BH7- BO3 6.09m

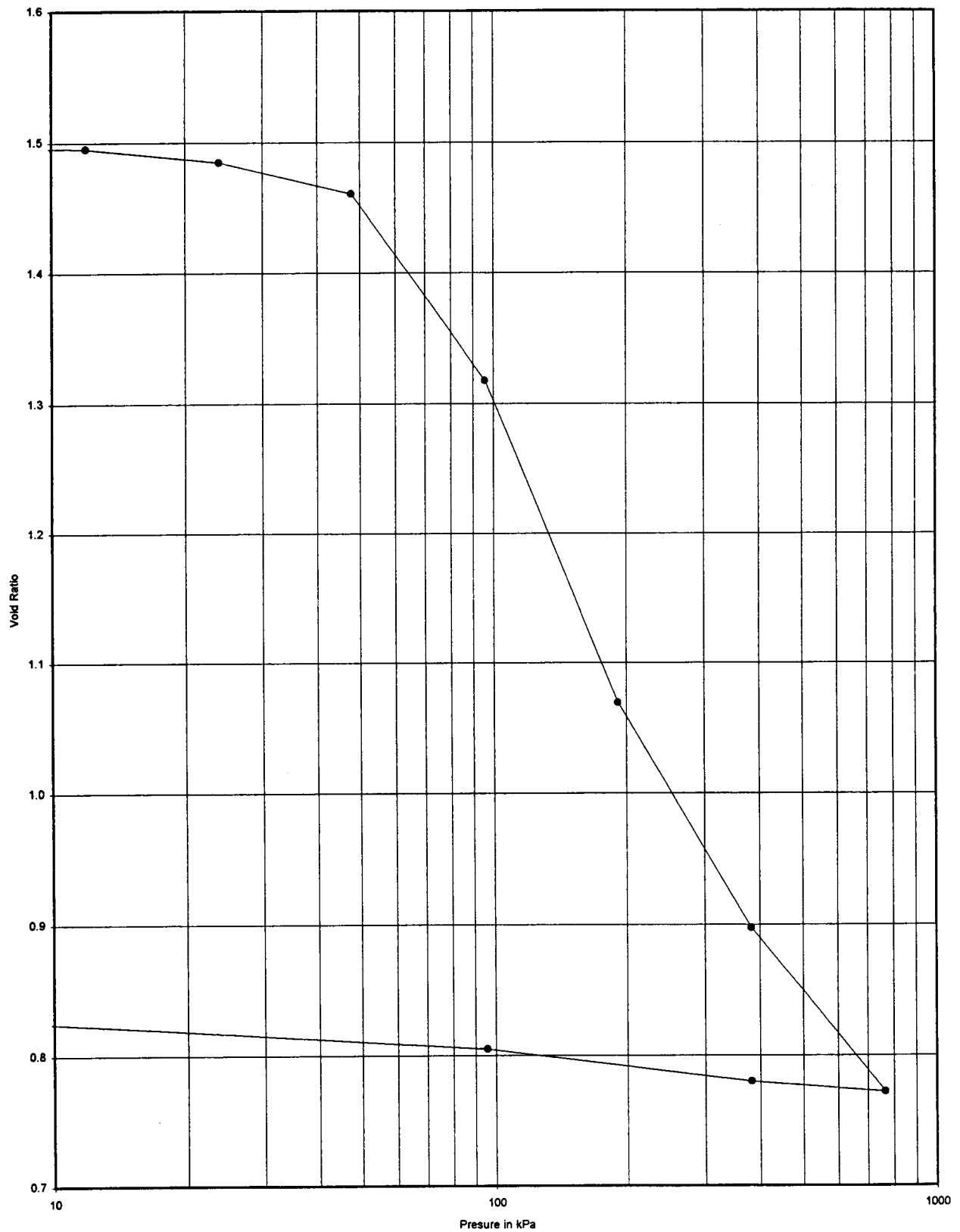


Figure 11 Results of Consolidation Testing

Hwy 607 A, BH10- BO2 3.05m

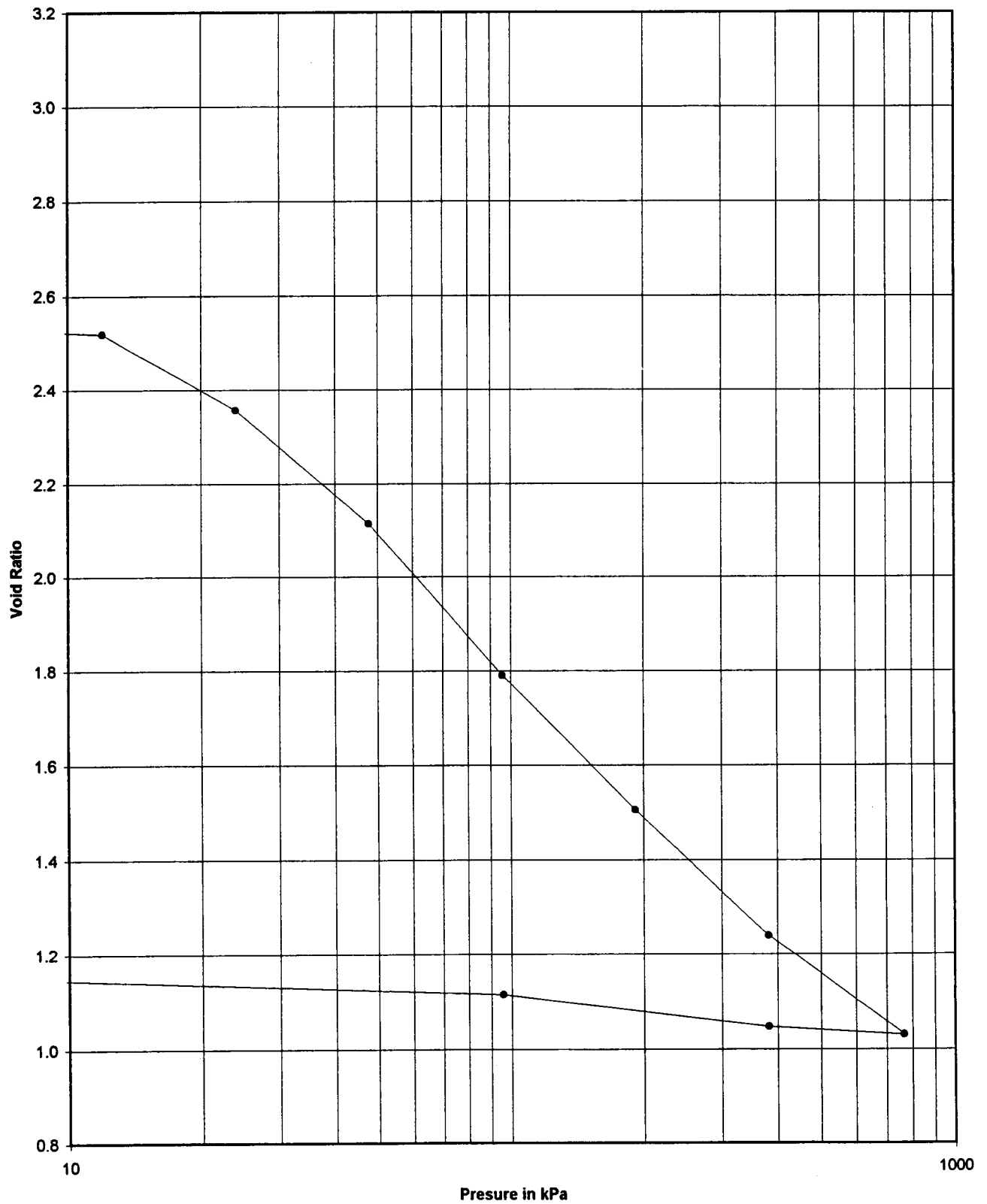


Figure 12 Results of Stability Analysis

Drained, $\phi' = 17$ degrees

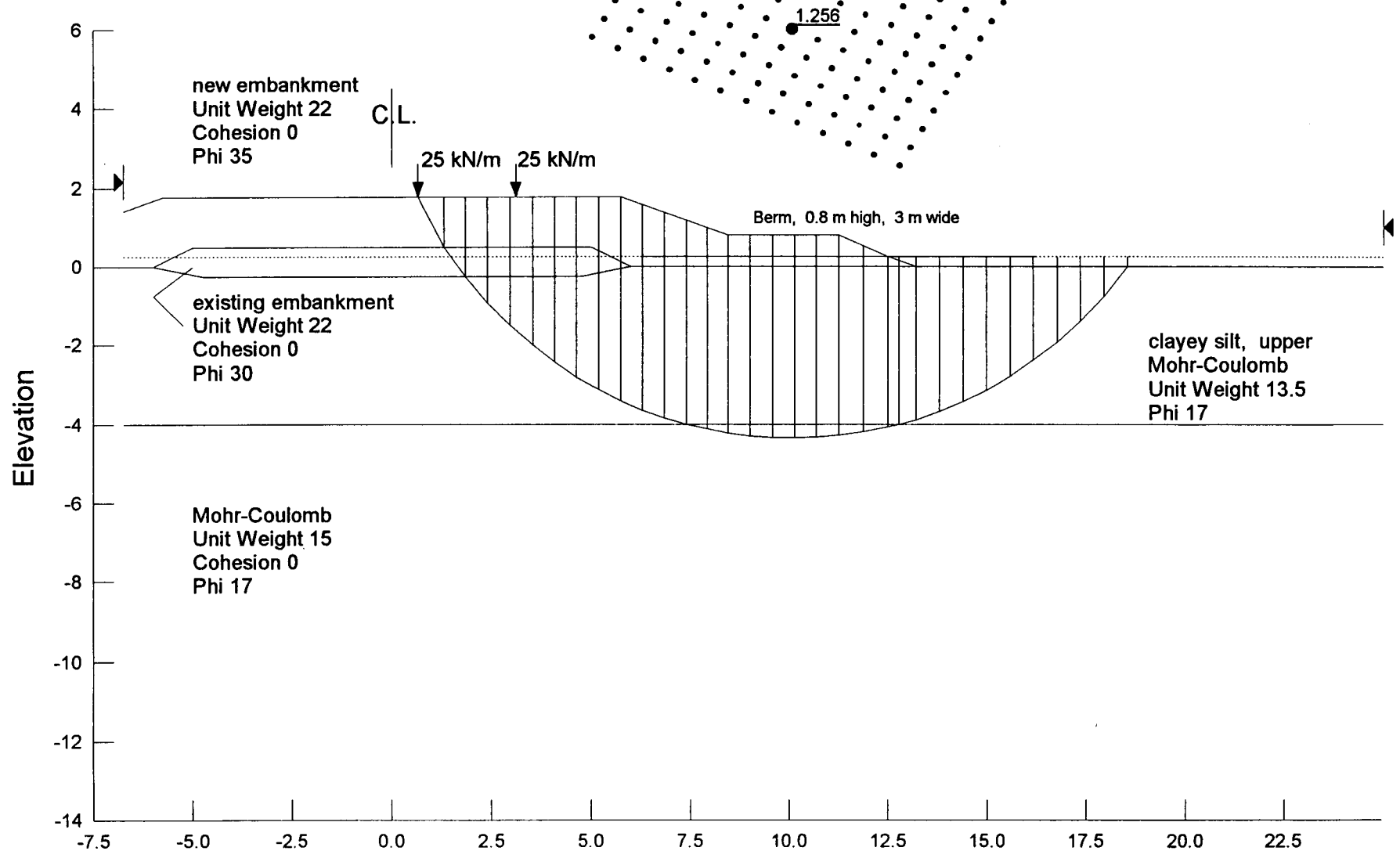
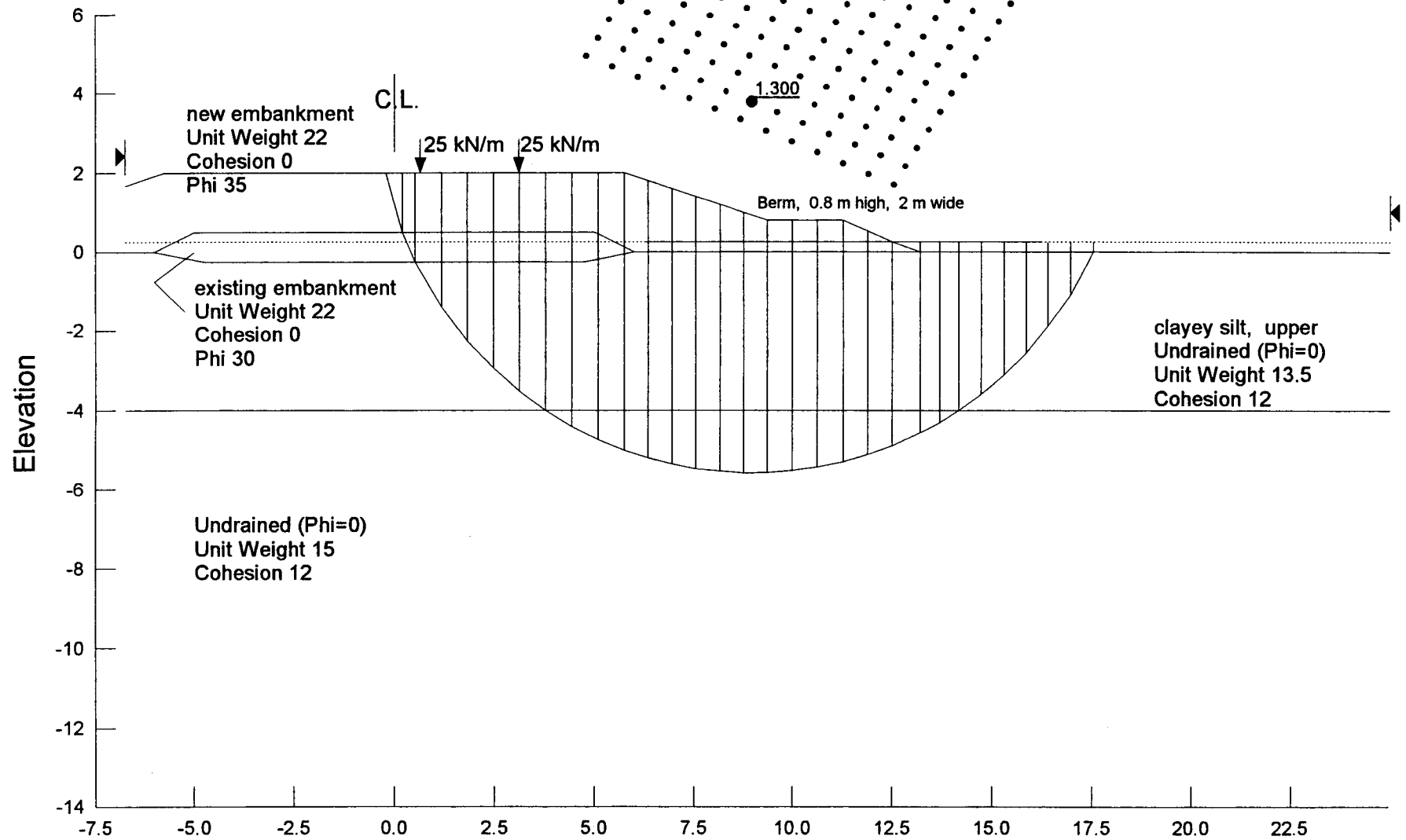


Figure 13 Results of Stability Analysis

Undrained, $C_u = 12 \text{ kPa}$

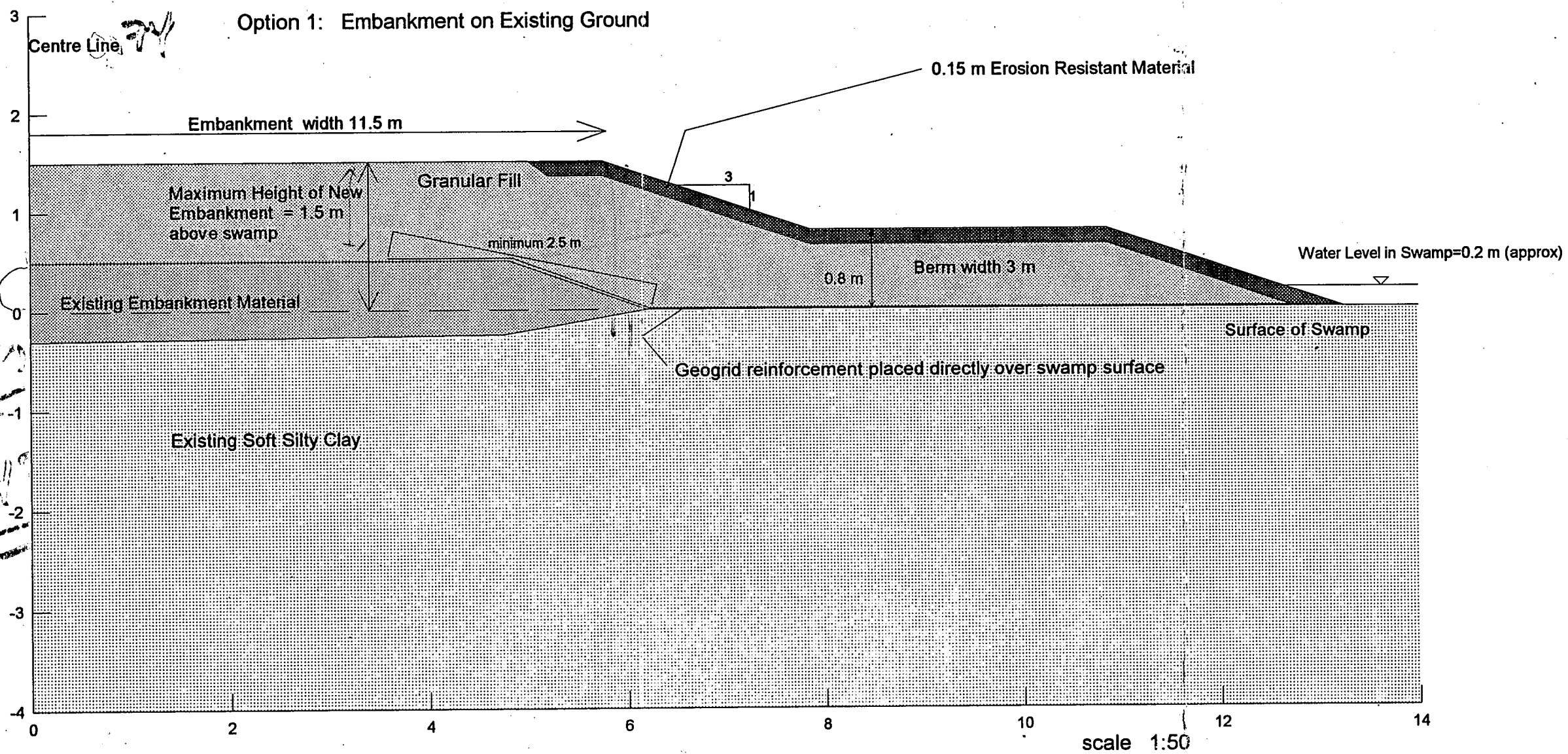


0.9m

Figure 14

Cross Section of Raised and Widened Embankment

Option 1: Embankment on Existing Ground



1-0.76

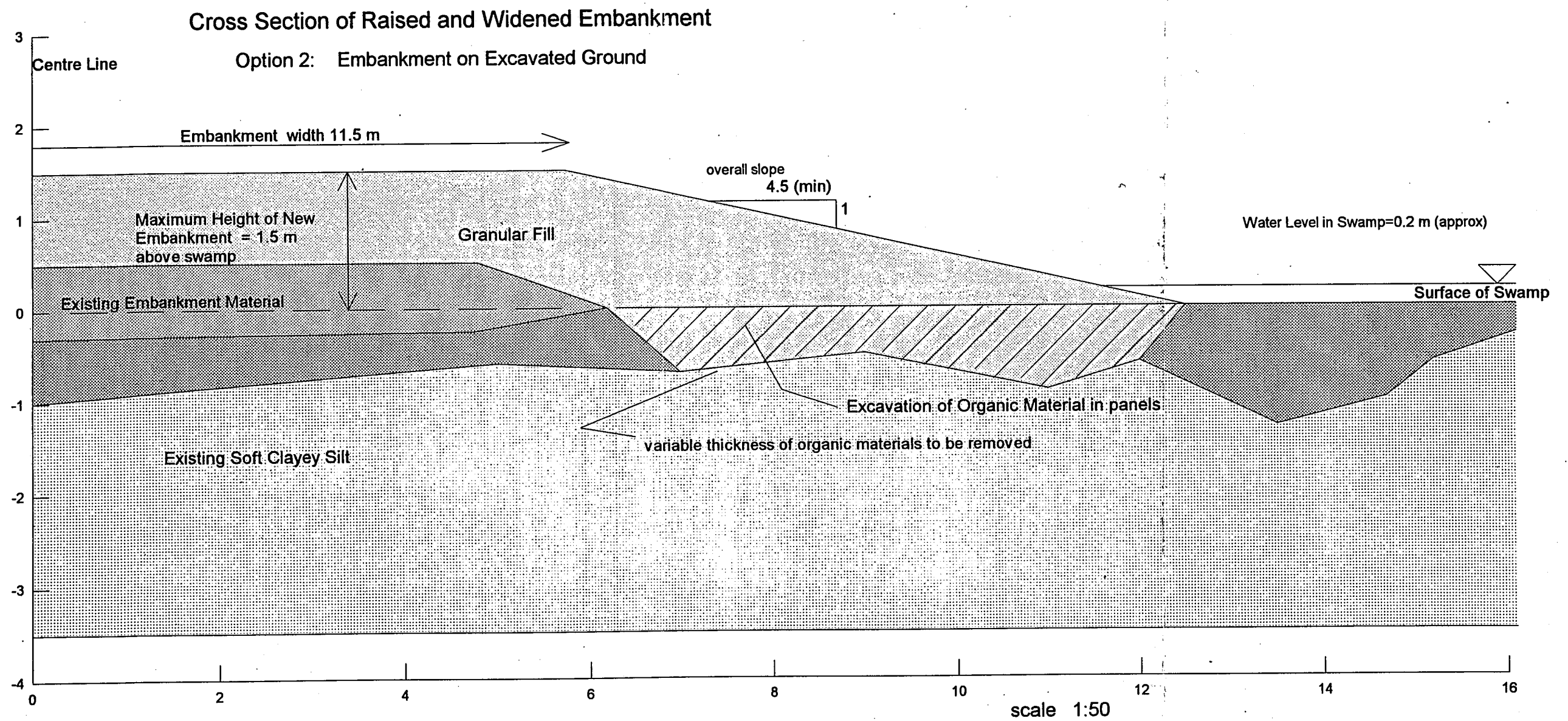
net 8.5-0.26m

0.5-0.4=0.1

0.3-0.3=0

net
gap

Figure 15



Appendix A

Record of Boreholes

RECORD OF BOREHOLE 1

METRIC

W.P: 7508-00-00

LOCATION STA 10+840, 4.0m LT of cl

ORIGINATED BY R.S

DIST Northern Region HWY 607A

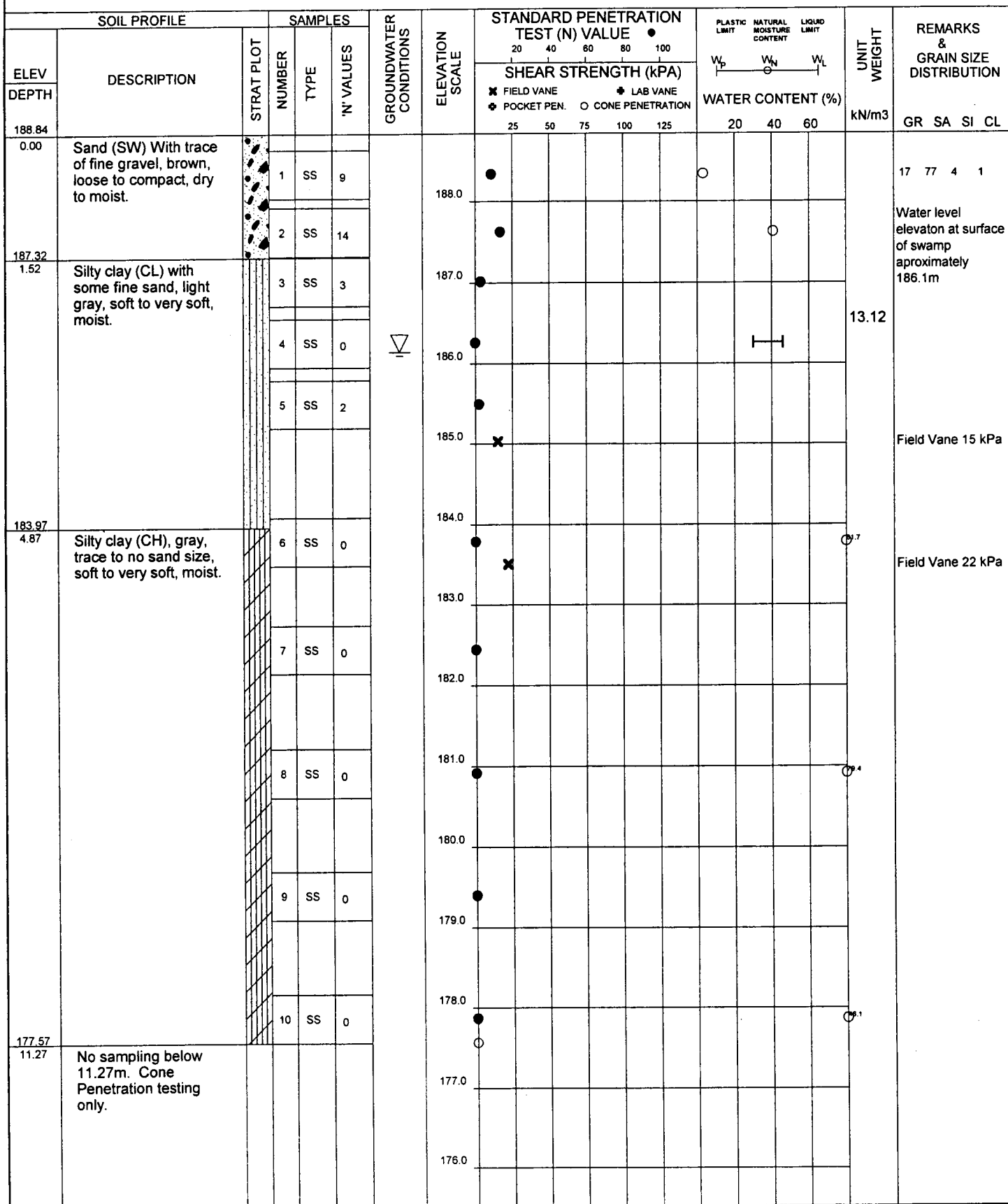
BOREHOLE TYPE Hollow Stem Augers

COMPILED BY R.S

DATUM Geodetic

DATE July 27, 2000

CHECKED BY I.F



RECORD OF BOREHOLE 1

METRIC

W.P: 7508-00-00

LOCATION STA 10+840, 4.0m LT of cl

ORIGINATED BY R.S

DIST Northern Region HWY 607A

BOREHOLE TYPE Hollow Stem Augers

COMPILED BY R.S

DATUM Geodetic

DATE July 27, 2000

CHECKED BY I.F

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	STANDARD PENETRATION TEST (N) VALUE					PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			SHEAR STRENGTH (kPa)					WATER CONTENT (%)					
								25	50	75	100	125	20	40	60			
							175.0											
							174.0											
							173.0											
							172.0											
							171.0											
							170.0											
							169.0											
168.67 20.17	Refusal						END OF BOREHOLE											

Cone Penetration
testing only

METRIC

ORIGINATED BY R.S

COMPILED BY R.S

CHECKED BY I.F

[illegible]

RECORD OF BOREHOLE 2

METRIC

W.P: 7508-00-00

LOCATION STA 10+865, 4.0m RT of cl

ORIGINATED BY R.S

DIST Northern Region HWY 607A

BOREHOLE TYPE Hollow Stem Augers

COMPILED BY R.S

DATUM Geodetic

DATE July 27, 2000

CHECKED BY I.F

SOIL PROFILE		SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	STANDARD PENETRATION TEST (N) VALUE		PLASTIC NATURAL LIQUID LIMIT MOISTURE LIMIT CONTENT			UNIT WEIGHT kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			'N' VALUES	SHEAR STRENGTH (kPa)		WATER CONTENT (%)				
						20	40	60	80	100	W _p	W _N	W _L	
	Cone Penetration testing only					174.0								
							173.0							
							172.0							
							171.0							
							170.0							
							169.0							
						168.0								
						167.0								
						166.0								
						165.0								
						164.0								
163.91 23.77	Refusal						END OF BOREHOLE							

100 blows for 0.20m

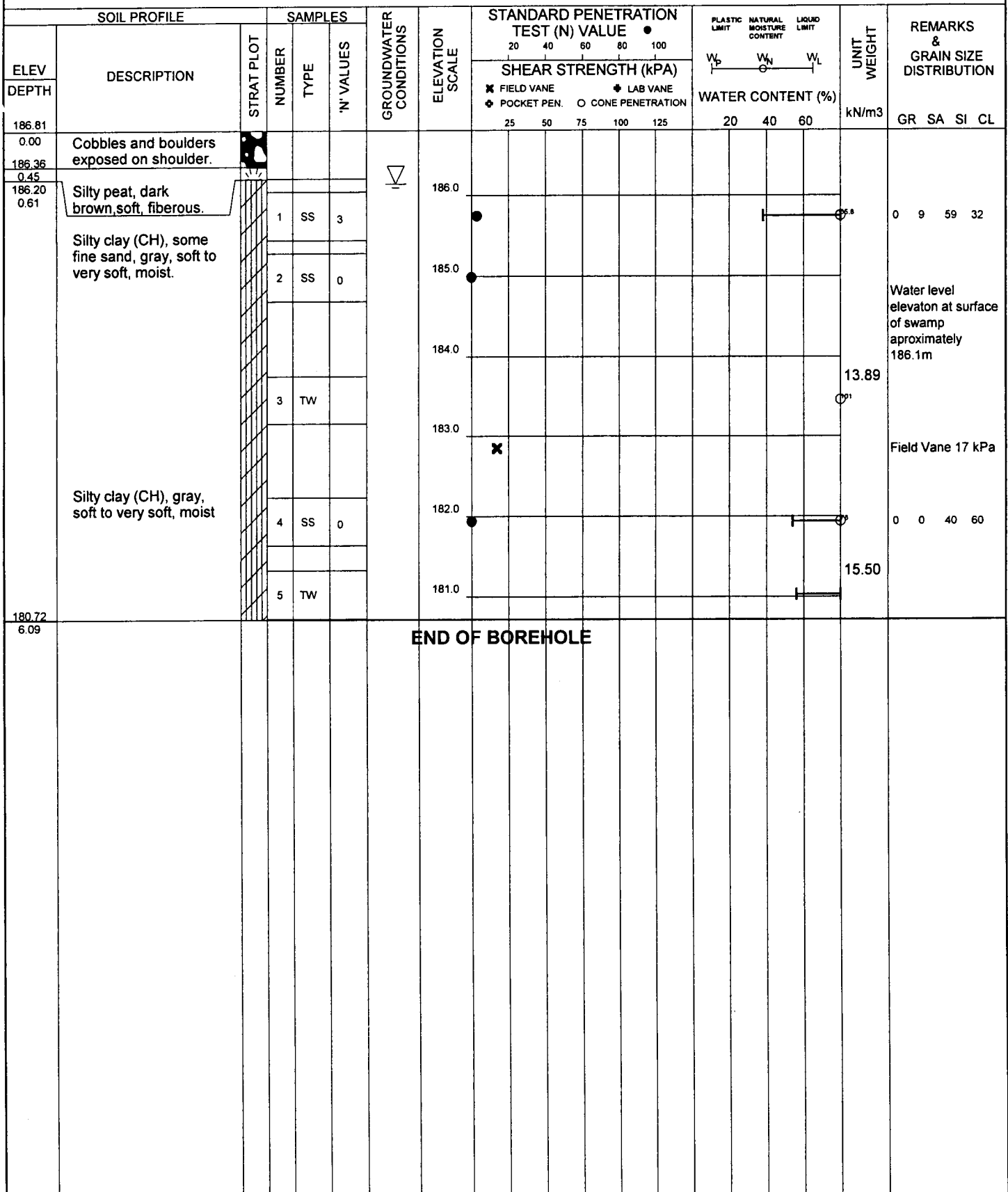
RECORD OF BOREHOLE 3

METRIC

W.P: 7508-00-00
 DIST Northern Region HWY 607A
 DATUM Geodetic

LOCATION STA 10+890, 7.5m LT of cl
 BOREHOLE TYPE Hollow Stem Augers
 DATE July 27, 2000

ORIGINATED BY R.S
 COMPILED BY R.S
 CHECKED BY I.F



RECORD OF BOREHOLE 4

METRIC

W.P: 7508-00-00

LOCATION STA 10+915, 6.7m RT of cl

ORIGINATED BY R.S

DIST Northern Region HWY 607A

BOREHOLE TYPE *Sampled by hand.

COMPILED BY R.S

DATUM Geodetic

DATE July 28,2000

CHECKED BY I.F

SOIL PROFILE		SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	STANDARD PENETRATION TEST (N) VALUE		PLASTIC NATURAL LIQUID LIMIT MOISTURE LIMIT CONTENT			UNIT WEIGHT kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			'N' VALUES	20 40 60 80 100	100	W _p	W _N		
186.10 0.00 185.80 .3	Fibrous organic material.												Water level elevation at surface of sawmp approximately 186.1m
184.90 1.20	Silty sand and decomposed organic debris, dark brown, very soft and wet.		1	TW									
183.36 2.74	Silty clay with decomposed organics (CH), some fine sand, dark gray to brown, soft, moist.											13.13	
END OF BOREHOLE													

RECORD OF BOREHOLE 5

METRIC

W.P: 7508-00-00

LOCATION STA 10+940, 8.2m LT of cl

ORIGINATED BY R.S

DIST Northern Region HWY 607A

BOREHOLE TYPE *Sampled by hand.

COMPILED BY R.S

DATUM Geodetic

DATE July 28,2000

CHECKED BY I.F

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	STANDARD PENETRATION TEST (N) VALUE					PLASTIC NATURAL LIQUID LIMIT MOISTURE LIMIT			UNIT WEIGHT kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			SHEAR STRENGTH (kPa)					WATER CONTENT (%)				
						20 40 60 80 100 X FIELD VANE + LAB VANE * POCKET PEN. O CONE PENETRATION					W _p W _N W _L						
						25 50 75 100 125					20 40 60						
186.10																	
0.00 185.80 .3	Fibrous organic material.																
184.90 1.20	Silty sand and decomposed organic debris, dark brown, very soft and wet.		1	TW													
183.82 2.28	Clayey silt (CH) with some fine sand and decomposed organics, dark gray to brown, very soft to soft, moist.																
END OF BOREHOLE																	

GR SA SI CL
Water level
elevaton at surface
of swamp
approximately
186.1m

METRIC

ORIGINATED BY R.S

COMPILED BY R.S

CHECKED BY I.F

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	STANDARD PENETRATION TEST (N) VALUE ●		PLASTIC NATURAL LIQUID LIMIT MOISTURE LIMIT CONTENT			UNIT WEIGHT kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			SHEAR STRENGTH (kPa)		WATER CONTENT (%)				
								✕ FIELD VANE ◆ POCKET PEN.	◆ LAB VANE ○ CONE PENETRATION	20	40	60		
187.06 0.00	Sand (SW) With trace of fine gravel, cobbles and boulders, brown, loose to compact, dry to moist.		1	SS			187.0						Water level elevation at surface of swamp approximately 186.1m	
							186.0							
							185.0							
							184.0							
184.03 3.05	Silty clay (CI-CH), gray, soft to very soft, moist.		2	TW			183.0							
			3	TW			182.0							
			4	TW			181.0							
						180.0	✕					16.17		
						179.0	●					○ ⁴	Field Vane 21 kPa	
						178.0								
			5	SS	0		177.0							
							176.0	●						
175.81 11.27			6	SS	0									
			7	SS	0									
END OF BOREHOLE														

RECORD OF BOREHOLE 7

METRIC

W.P: 7508-00-00
 DIST Northern Region HWY 607A
 DATUM Geodetic

LOCATION STA 10+990, on cl
 BOREHOLE TYPE Hollow Stem Augers
 DATE July 29,2000

ORIGINATED BY R.S
 COMPILED BY R.S
 CHECKED BY I.F

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	STANDARD PENETRATION TEST (N) VALUE		PLASTIC NATURAL LIQUID LIMIT MOISTURE CONTENT			UNIT WEIGHT kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			SHEAR STRENGTH (kPa)		W _p	W _N	W _L		
							20 40 60 80 100							
							25 50 75 100 125							
187.11 0.00	Sand (SW) With trace of fine gravel, brown, loose to compact, dry to moist.						187.0							Water level elevation at surface of swamp approximately 186.1m
186.20 0.91	Cobble and boulder sub-base not sampled.						186.0							
							185.0							
184.06 3.05	Silty clay (CH with some fine sand and decomposed organic debris, dark brown, very soft and wet.		1	SS	?		184.0							0 18 68 14
							183.0							Cannot push shelly tube
182.51 4.60	Silty clay (CH), gray, soft to very soft, moist.		2	SS	1		182.0							Try shelly tube, but lost sample. Got sample with split spoon.
							181.0							13.40
				3	TW		180.0							Field Vane 7 kPa
				4	TW		179.0							Field Vane 13 kPa
							178.0							
177.36 9.75			5	TW										
END OF BOREHOLE														

RECORD OF BOREHOLE 8

METRIC

W.P: 7508-00-00 LOCATION STA 11+015, 6.4m LT of cl ORIGINATED BY R.S
 DIST Northern Region HWY 607A BOREHOLE TYPE *Sampled by hand. COMPILED BY R.S
 DATUM Geodetic DATE July 28,2000 CHECKED BY I.F

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	STANDARD PENETRATION TEST (N) VALUE		PLASTIC NATURAL LIQUID LIMIT MOISTURE LIMIT CONTENT			UNIT WEIGHT kN/m3	REMARKS & GRAIN SIZE DISTRIBUTION
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			SHEAR STRENGTH (kPa)		WATER CONTENT (%)				
							20 40 60 80 100							
							25 50 75 100 125							
186.10														
0.00	Fibrous organic material.													Water level elevation at surface of swamp approximately 186.1m
185.50														
0.6	Silty sand and decomposed organic debris, dark brown, very soft and wet.		1	TW										
184.50														
1.60	Silty clay (CH) with some fine sand and decomposed organics (CH), dark gray to brown, soft to very soft, moist.													
183.36														
2.74														
END OF BOREHOLE														

RECORD OF BOREHOLE 9

METRIC

W.P: 7508-00-00 LOCATION STA 10+978, 7.3m LT of cl ORIGINATED BY R.S
 DIST Northern Region HWY 607A BOREHOLE TYPE *Sampled by hand. COMPILED BY R.S
 DATUM Geodetic DATE July 28,2000 CHECKED BY I.F

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	STANDARD PENETRATION TEST (N) VALUE		PLASTIC LIMIT	NATURAL MOISTURE CONTENT	LIQUID LIMIT	UNIT WEIGHT kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			SHEAR STRENGTH (KPA)						
186.10								20 40 60 80 100						
0.00	Fibrous organic material.							25 50 75 100 125						Water level elevation at surface of swamp approximately 186.1m
185.60														
0.50	Silty sand and decomposed organic debris, dark brown, very soft and wet.		1	TW										
184.30														
1.80	Silty clay with decomposed organics (CH), dark gray to brown, soft, moist.													
183.36														
2.74														
END OF BOREHOLE														

RECORD OF BOREHOLE 11

METRIC

W.P: 7508-00-00 LOCATION STA 11+090, 3.5m RT of cl ORIGINATED BY R.S
 DIST Northern Region HWY 607A BOREHOLE TYPE Hollow Stem Augers COMPILED BY R.S
 DATUM Geodetic DATE July 28,2000 CHECKED BY I.F

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	STANDARD PENETRATION TEST (N) VALUE					PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	N' VALUES			SHEAR STRENGTH (KPA)					WATER CONTENT (%)				
								20	40	60	80	100	W _p	W _N	W _L		
186.89																	
0.00	Sand (SW) With trace of fine gravel, cobbles and boulders, brown, loose to compact, dry to moist.															Water level elevation at surface of swamp approximately 186.1m	
185.99 .90																	
185.37 1.52	Silty sand with decomposed organic debris, dark brown, soft and wet.		1	SS	3												
	Silty clay (CH) with fibrous roots and organics, dark gray to brown, soft to very soft, moist.		2	SS	4												
183.79 3.10	Refusal																
END OF BOREHOLE																	

METRIC

ORIGINATED BY R.S

COMPILED BY R.S

CHECKED BY I.F

[illegible]

RECORD OF BOREHOLE 12

METRIC

W.P: 7508-00-00

LOCATION STA 10+937, 3.5m LT of cl

ORIGINATED BY R.S

DIST Northern Region HWY 607A

BOREHOLE TYPE Hollow Stem Augers

COMPILED BY R.S

DATUM Geodetic

DATE August 15, 2000

CHECKED BY I.F

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	STANDARD PENETRATION TEST (N) VALUE		PLASTIC NATURAL LIQUID LIMIT MOISTURE LIMIT CONTENT			UNIT WEIGHT kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			SHEAR STRENGTH (kPa)		W _p	W _N	W _L		
							20 40 60 80 100							
	Cone Penetration testing only						173.0							
							172.0							
							171.0							
							170.0							
							169.0							
							168.0							
							167.0							
							166.0							
							165.0							
							164.0							
							163.0							
							162.0							
							161.0							

METRIC

ORIGINATED BY R.S

COMPILED BY R.S

CHECKED BY I.F

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	STANDARD PENETRATION TEST (N) VALUE ●		PLASTIC NATURAL LIQUID LIMIT MOISTURE LIMIT CONTENT			UNIT WEIGHT kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION						
ELEV	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			SHEAR STRENGTH (kPA)							WATER CONTENT (%)					
DEPTH								× FIELD VANE ♦ LAB VANE ♦ POCKET PEN. ○ CONE PENETRATION							W _p W _N W _L					
							20	40	60	80	100	20	40	60	GR	SA	SI	CL		
	Cone Penetration testing only						160.0													
							159.0													
158.06																		100 blows for .060m		
28.95	Refusal						END OF BOREHOLE													

METRIC

ORIGINATED BY R.S

COMPILED BY R.S

CHECKED BY I.F

[illegible]

METRIC

CHECKED BY I.F

[illegible]

METRIC

ORIGINATED BY R.S

COMPILED BY R.S

CHECKED BY I.F

[illegible]

RECORD OF BOREHOLE 14

METRIC

W.P: 7508-00-00

LOCATION STA 10+902, 3.5m LT of cl

ORIGINATED BY R.S

DIST Northern Region HWY 607A

BOREHOLE TYPE Hollow Stem Augers

COMPILED BY R.S

DATUM Geodetic

DATE August 15, 2000

CHECKED BY I.F

SOIL PROFILE			SAMPLES			GROUNDWATER CONDITIONS	ELEVATION SCALE	STANDARD PENETRATION TEST (N) VALUE		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	'N' VALUES			SHEAR STRENGTH (kPa)		WATER CONTENT (%)				
						20 40 60 80 100 X FIELD VANE ♦ LAB VANE ♦ POCKET PEN. O CONE PENETRATION		W _p W _n W _L 20 40 60				GR SA SI CL		
171.89			3	SS	0		173.0							
15.24	Clayey silt, (ML-MH), grey, soft, moist.		4	SS	6		171.0							0 2 85 13
171.29	No sampling below 15.84m. Cone penetration testing only.						170.0							
15.84							169.0							
							168.0							
							167.0							
							166.0							
							165.0							
							164.0							
							163.0							
							162.0							
							161.0							

Explanation of Terms Used in Report

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 31mm 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 (31mm 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 (RQD), 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
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_2	kPa	RESIDUAL SHEAR STRENGTH
τ_r	kPa	REMOULDED SHEAR STRENGTH
S_i	1	SENSITIVITY = $\frac{c_u}{\tau_r}$

PHYSICAL PROPERTIES OF SOIL

ρ_s	kg/m ³	DENSITY OF SOLID PARTICLES	e	1, %	VOID RATIO	e_{min}	1, %	VOID RATIO IN DENSEST STATE
γ_s	kN/m ³	UNIT WEIGHT OF SOLID PARTICLES	n	1, %	POROSITY	I_D	1	DENSITY INDEX = $\frac{e_{max} - e}{e_{max} - e_{min}}$
ρ_w	kg/m ³	DENSITY OF WATER	w	1, %	WATER CONTENT	D	mm	GRAIN DIAMETER
γ_w	kN/m ³	UNIT WEIGHT OF WATER	S_r	%	DEGREE OF SATURATION	D_n	mm	n PERCENT - DIAMETER
ρ	kg/m ³	DENSITY OF SOIL	w_L	%	LIQUID LIMIT	C_u	1	UNIFORMITY COEFFICIENT
γ	kN/m ³	UNIT WEIGHT OF SOIL	w_p	%	PLASTIC LIMIT	h	m	HYDRAULIC HEAD OR POTENTIAL
ρ_d	kg/m ³	DENSITY OF DRY SOIL	w_s	%	SHRINKAGE LIMIT	q	m ³ /s	RATE OF DISCHARGE
γ_d	kN/m ³	UNIT WEIGHT OF DRY SOIL	I_p	%	PLASTICITY INDEX = $w_L - w_p$	v	m/s	DISCHARGE VELOCITY
ρ_{sat}	kg/m ³	DENSITY OF SATURATED SOIL	I_L	1	LIQUIDITY INDEX = $\frac{w - w_p}{I_p}$	i	1	HYDRAULIC GRADIENT
γ_{sat}	kN/m ³	UNIT WEIGHT OF SATURATED SOIL	I_C	1	CONSISTENCY INDEX = $\frac{w_L - w}{I_p}$	k	m/s	HYDRAULIC CONDUCTIVITY
ρ'	kg/m ³	DENSITY OF SUBMERGED SOIL	e_{max}	1, %	VOID RATIO IN LOOSEST STATE	j	kN/m ²	SEEPAGE FORCE
γ'	kN/m ³	UNIT WEIGHT OF SUBMERGED SOIL						