

**FOUNDATION INVESTIGATION AND DESIGN RECOMMENDATION
FOR COFFERDAM AND UNWATERING AT MOLLIE RIVER
CULVERT
SITE 46-244, NEW LISKEARD AREA
AGREEMENT NO.: 5007-E-0065
ASSIGNMENT No. 8**

**January 21, 2010
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MTO GEOCRES NO. 41P-42

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**FOUNDATION INVESTIGATION AND DESIGN RECOMMENDATION FOR
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PART 1: FACTUAL INFORMATION

1.0 INTRODUCTION

DST Consulting Engineers Inc. (DST) has been retained by the Ministry of Transportation Ontario (MTO) to conduct a geotechnical investigation and provide geotechnical recommendations for the rehabilitation of a culvert located at Mollie River, identified as Site 46-224 New Liskeard Area, located along Highway 144, approx. 2.7 km north of the intersection with highway 560, in Benneweis Township, District of Sudbury, Ontario. This work was carried out under Agreement No.: 5007-E-0065 - Geotechnical Retainer - Assignment No.8.

The purpose of this investigation was to evaluate existing site conditions and provide geotechnical engineering recommendations for cofferdam construction and dewatering of the Mollie River culvert. This report addresses the field investigation, laboratory test program, factual report on conditions (Part 1) and recommendations for the design and construction for the proposed culvert replacement (Part 2).

This report is prepared for the sole use of the MTO. Any use of this report, or any portions thereof, or any reliance on it by any other party, is the responsibility of the parties listed above.

2.0 SITE DESCRIPTION

The culvert section is located on Highway 144, approximately 2.7 km north of Highway 560, in Benneweis Township, District of Sudbury, in the MTO Northeastern Region.

It is understood that the existing culvert is an SPCSPA corrugated steel pipe with dimensions of 7.9 m x 4.9 m x 22.3 m. According to previous report information from William Trow Associates Limited (Trow, 1967) the subsoil at the site consists, at upper levels, of a layer of rounded boulders of approximately 15 to 30 cm in diameter and approximately 3 m in thickness. Beneath this stratum is a compact to very dense alluvial medium to coarse grained sand deposit. A nearby beaver dam to the west of the structure was also identified.

The embankment at the existing culvert location is approximately 7 m in height. The height of cover material above the existing culvert is approximately 2.5 m.

A site visit was made on October 27, 2009 by a geotechnical specialist from DST. There was approximately one inch of snow cover at the site during this visit. The site vegetation consists of shrubs and trees at both sides of culvert inlet and outlet and mixed forest around the river up and downstream as well as at the discharge pond perimeters. The surrounding area is heavily wooded with areas of exposed bedrock. The northeast side of the culvert is difficult to access with a bedrock outcrop at this side. The northwest side of the culvert is heavily vegetated of shrubs and trees on swampy ground and needs excessive clearing to be accessible for construction, however less clearing effort is needed for the southwest side of the culvert. The southeast side slopes upward from the river. Pictures of the site are shown below. The photographs were taken on October 16th and 27th, 2009.



Photo 1: Looking northwest at outlet from southeast bank



Photo 2: Looking southeast at inlet from northwest bank



Photo 3: Looking southwest at outlet from northeast bank



Photo 2: Looking northeast from southwest bank



Photo 5: Looking northeast at outlet (showing Bedrock Outcrop)



Photo 6: Looking southwest at inlet showing vegetation

3.0 INVESTIGATION PROCEDURES AND LABORATORY TESTING

Site work was carried out between October 26 and 28, 2009 utilizing a track mounted CME 850 drill rig equipped for geotechnical drilling, operated by Landcore and supervised by DST. Hand augers were also used to advance boreholes in areas inaccessible to the track mounted equipment at the northeast side of the culvert outlet. A total of three boreholes were advanced to depths ranging from 5.9 to 6.7 m using the CME 850 and one borehole was advanced to a depth of 0.3 m using hand equipment. Termination depths of the boreholes were notified to the MTO during field operations together with difficulties encountered during advancement.

Borehole locations and a stratigraphic section are shown on the Borehole Location Plan, Drawing 1. Borehole 1 is located approximately 4 m south and 2.5 m west of the culvert inlet. Borehole 2 is located approximately 4.5 m south and 10 m east of the culvert outlet. Borehole 3 is located approximately 4 m north and 7 m west of the culvert inlet. Borehole 4 is located approximately 5.3 m north and 4 m east of the culvert outlet. These locations were identified in the terms of reference by the MTO and are consistent with attempts to be advanced near the embankment toe as close as possible to the water and as far as possible from the beaver dam.

Boreholes 1 and 2 were advanced with 108 mm inside diameter hollow stem augers to depths of 3 and 1.5 m and continued with wash boring techniques using diamond drilling bit and NW casing to 6.7 and 6.4 m respectively. Borehole 3 was also advanced with wash boring techniques using diamond drilling bit and NW casing to a depth of 5.9 m. Borehole 4 was advanced using hand operated equipment to a depth of 0.3 m. Boreholes were backfilled with auger cuttings.

Soil samples were obtained from the auger flights as well as sludge return from wash boring and from the split spoon sampler used for the standard penetration test (SPT). The SPT involves driving a 51 mm diameter thick-walled sampler into the soil under the energy of a 63.5 kg weight falling

through 760 mm. The number of blows required to drive the sampler 305 mm is known as the standard penetration blow count (N) which provides an indication of the condition or consistency of the soil. Representative soil samples are obtained from within the sampler.

The ground surface elevations at the borehole locations were surveyed by DST personnel and referenced to MTO BM 748134 located on the exposed bedrock approximately 170 m north of the gravel road to Dividing Lake and 20 m to the east of the centreline. The benchmark has UTM coordinates of Grid 17T, E436474.313 and N5260755.631 with an orthometric elevation of 378.855 m, as reported by the MTO.

The fieldwork was supervised on a full-time basis by DST personnel who located the boreholes in the field, performed sampling and in-situ testing, and logged the boreholes. The soil sample identifications were estimated in the field and placed in labelled containers and transported to DST's laboratory in Ottawa for further analysis.

Classification and index tests were subsequently performed in the laboratory on samples collected from the boreholes to aid in the selection of engineering properties. Laboratory tests included natural moisture contents and particle size analyses. Laboratory test results are presented on the Boreholes Logs in Enclosures 1 to 4, and plotted in Enclosure 5.

Ground profile of the site from a previous investigation and design drawing of the existing culvert (Trow, 1967) are appended to this report.

4.0 DESCRIPTION OF SUBSURFACE CONDITIONS

4.1 Stratigraphy Overview

The general stratigraphy of the proposed culvert site, shown in Drawing 1, is based on the conditions encountered in Boreholes 1 through 4 as well as information previously documented by William Trow Associates Limited (Trow, 1967). The general stratigraphy consists of surficial sands with high concentrations of gravel, cobbles and boulders in the top 4 m. These overly a very loose to dense sand layer with decreasing cobble and boulder size and content. Borehole logs are illustrated in Enclosures 1 to 4.

4.2 Topsoil

Topsoil was noted at surface in Boreholes 1 through 3 up to 50 mm in thickness.

4.3 Sand and Gravel (Containing Cobbles and Boulders)

A stratum of sand and gravel with cobbles and boulders (interstices filled with varying percentages of brown silt, sand and gravel) was encountered in Boreholes 1 through 3. The cobble and boulder content is difficult to accurately assess from borehole data and may be considerable. This layer was found to be approximately 3.7 m thick at Borehole 1 and increased to approximately 5.2 m thick at Borehole 3.

SPT values are between 8 and 47 blows per 0.3 m indicating a loose to dense state of compactness. SPT values of >100 were also encountered in Borehole 1 at 0.8 m, Borehole 2 at 0.8m, 2.3 m and 3.0 m and Borehole 4 at 0.3 m. The variability of the SPT values are likely due to the concentrations of gravel, cobbles and boulders, and they may not be representative of the state of compactness of the soil matrix between the cobbles and boulders.

Gradation analyses conducted on samples from boreholes indicate interstices gravel, sand and fines contents from 1% to 30%, 59% to 62% and 7% to 40% respectively. Grainsize distributions are reported on the Borehole Logs and are plotted in Enclosure 5. The moisture contents of samples range from 10% to 23%.

4.4 Sand

A sand layer with trace to with gravel and trace silt was encountered from underlying the cobbles and boulders to a depth of up to 6.7 m. Within this stratum a higher concentration of cobbles and boulders are found near the top with decreasing size and content as depth increased, based on a qualitative assessment.

SPT values are between 2 and 41 blows per 0.3 m indicating a very loose to dense state of compactness. An SPT value of >100 was also encountered in Borehole 2 at 6.4 m. The variability of the SPT values are likely due to the concentrations of cobbles and boulders.

Gradation analyses conducted on samples from boreholes indicate gravel, sand and fines contents from 1% to 11%, 87% to 96% and 2% to 3% respectively. Grainsize distributions are reported on the Borehole Logs and are plotted in Enclosure 5. The moisture contents of samples range from 9% to 37%.

4.5 Groundwater Levels

The existing culvert invert elevations at the west inlet and east outlet were measured to be 374.63 m and 374.60 m respectively. The river level at the time of the investigation at the culvert inlet and outlet were at elevations 375.68 m and 375.57 m.

The water levels in Boreholes 1 through 3 were 376.58 m, 375.76 m and 375.86 m respectively. The water level in Borehole 4 was not noted.

These levels observed before borehole backfilling are indicated on the Borehole Logs and Drawing 2 and are not intended to represent accurate information with respect to the water table or groundwater flow. The water table is expected to be close to the river level. Groundwater levels will fluctuate seasonally and in response to climatic conditions and river level.

Table 4.1 Groundwater Elevations – October 26th-28th, 2009

Borehole Location	Ground Surface Elevation	Static Groundwater Elevation	Depth to Water Level
BH 09-1	376.90 m	376.58 m	0.32 m
BH 09-2	376.04 m	375.76 m	0.28 m
BH 09-3	376.14 m	375.86 m	0.28 m

**FOUNDATION INVESTIGATION AND DESIGN DRAFT REPORT
COFFERDAM & UNWATERING MOLLIE RIVER CULVERT
SITE 46-244, HIGHWAY 144
BENNEWEIS TOWNSHIP, NEW LISKEARD AREA
AGREEMENT NO.: 5007-E-0065, ASSIGNMENT NO. 8**

PART 2: DESIGN RECOMMENDATIONS

This section presents interpretation of the geotechnical data presented in the factual report and presents geotechnical design recommendations and construction concerns.

5.0 PROJECT DESCRIPTION

The existing culvert is a SPCSPA with 7.9 m X 4.9m X 22.30 m corrugated steel pipe. The height of existing embankment is approximately 7.0 m. MTO has indicated on the basis of previous report information that the subsoil at the site consists, at upper levels, of a rounded boulders layer about 3.0 m thick deposit and beneath above stratum is a compact to very dense alluvial medium to coarse grained deposit. The boulders size ranges from 15 to 30 cm. MTO also has indicated that the two borings in previous investigation were terminated approximately 10.0 meter deep.

Topographic survey has been carried out during soil investigation at the project area. Elevations have been measured at culver invert and obvert, embankment top and toe location at inlet and outlet side. Water surface elevations have also measured during the field investigation.

The centre line elevation of Hwy 144 at culvert location was found to be 381.39 m. Top of the culvert obverts elevation at inlet and outlet side were found 378.93 m and 378.82 m respectively. The difference in elevation between obverts at inlet and outlet side is 0.11 m.

A nearby beaver dam is identified at the west side of culvert. The culvert contains a large amount of water and rehabilitation with concrete liner is required for the culvert reported by MTO in the RFP.

Culvert Inlet

The culvert invert level at inlet side is approximately 374.63 m. During site visit the shallow water depth found at inlet side approximately 0.75 m (Elevation 375.38 m). The river width measured near culvert inlet side is 9.0 m. A gravelly header with a height 0.3 m is found at a 15 m distance from the inlet. A water pond is found at northwest side of inlet of which width and length is approximately 35 m; by over 200 m and velocity of flow in the pond is slow.

The approximate elevation of the top of embankment at inlet side is 381.32 m. The approximate elevation of toe of embankment at inlet northern and southern side is 375.68 m and 377.19 m respectively. Embankment height at inlet is approximately 3.8 m.

Culvert Outlet

The culvert invert level at outlet side is approximately 374.60 m. It was noticed by DST personnel during his site visit that the river width at outlet side is approximately 14.0 m. Water depth within the culvert found to be 1.3 m (Elevation 375.9 m) at outlet side. After the header a water pond width and length approximately 30 m by 27.0 m is found at northeast side of culvert at outlet. The velocity of water is found slow at this time of visit.

The approximate elevation of top of embankment at outlet side is 381.35 m. The approximate elevation of toe of embankment at outlet northern and southern side is 375.57 m. Embankment height at outlet is approximately 5.8 m.

6.0 SOIL CHARACTERISTICS

A total four boreholes were advanced at culvert inlet and outlet side two of them were advanced at culvert inlet side on the river banks, near the toe of the embankment, one at the north bank and another is located at the south bank as close as possible to the water and as far as possible from

the beaver dam. The other two boreholes were advanced at culvert outlet side river banks, near the toe of embankment to verify soil conditions at the culvert outlet. The borehole locations were surveyed with respect to a Bench Mark Orthometric elevation (Elevation 378.855 m) provided by MTO and the elevations are shown in the bore logs. Bedrock outcrop is found at northeast side of culvert.

Based on the information obtained from boreholes and information from previous investigation carried out by Trow Associates in 1967, the river is underlain by 3.7 to 5.2 m thickness of cobbles and boulders which is again underlain by a layer of dense sand up to the auger refusal depth up to 6.71 m.

Groundwater levels were measured between 375.44 m and 376.58 m. Groundwater levels will fluctuate seasonally and in response to climatic conditions. The estimated groundwater level at the culvert location is expected to be close to or above the river bed level and will also vary with the water level in the river.

The design value of coefficient of friction has been determined from “N” value at different depth of soils layer from borehole BH09-1 to 4 applying Wolf (1989) The hydraulic conductivity values were estimated from effective grain size D_{10} (mm) from gradation analysis of soil samples applying Hazen equation (Hazen 1930) and Hazen constant of 1.0 was assumed in this calculation.

The following table shows the values of drained internal coefficient friction and hydraulic conductivity applied to the analyses for this report. In particular, the hydraulic conductivity of the deposits may vary significantly in these types of (alluvial) deposits, and an order of magnitude above and below the values given would not be unusual, .

Table 6.1:

	Sand & Gravel	Sand
Drained internal Friction (Φ) (Degrees)	29 to 42 (35)	28 to 34 (29)
Hydraulic Conductivity (k) in (cm/sec)	2.25×10^{-2}	9×10^{-2}

The following table shows the lateral earth pressure parameters for conventional design of a cofferdam.

Table 6.2:

	Sand & Gravel	Sand
Unit Weight (kN/m^3)	$\gamma = 20$	$\gamma = 19$
Angle of Internal Friction	$\Phi' = 35^\circ$	$\Phi' = 29^\circ$
Active (K_a)	0.27	0.34
Passive (K_p)	3.69	2.88
At Rest (K_o)	0.42	0.51

7.0 DISCUSSION AND RECOMMENDATIONS

7.1.1 Cofferdam

Design of a cofferdam typically requires the following analyses to achieve an adequate design and ensure adequate performance:

1. Stability check for cofferdam sides and base
2. Seepage analysis of flow through and under cofferdam
3. Piping analysis for groundwater seepage below the cofferdam
4. Settlement analysis for a cofferdam constructed as an earth structure
5. Bending moment and lateral displacement analyses for a cofferdam with vertical walls
6. Open channel analysis for diversion channel

A maximum head differential of 2.5 and 1.0 m was applied to the inlet/outlet cofferdams, respectively. This allows for 1.5 m depth of water above the riverbed plus up to 1 m of excavation below the riverbed at up and down stream respectively. At the downstream, MTO has indicated that given the low head a sandbag cofferdam without cutoff wall will be used. The cofferdam design has therefore been applied to the inlet area only. If so required, a cut off wall with same geometry can also be used at the downstream.

Due to the highly permeable nature of the underlying riverbed soils at this site, a sheetpile wall would typically be the preferred option to control the flow. However, due to the significant depth of sand and gravel containing a significant cobble/boulder content with high SPT blow counts, sheet pile installation will require special measures to install. Potential construction procedures will be discussed in a later section.

Alternatively an earth fill structure may be considered. However due to the permeable nature of the underlying riverbed soil, the depth of water, the width of the river and the river discharge this would still require a cut-off wall or excessive earthfill with combined with internal filter. Such a wall (other than sheetpiling) with earthfill would be impractical to install in a flowing river.

A sheetpile wall is therefore recommended. For this a settlement analysis (Item 4) is not applicable. Furthermore, Item 6 (spillway flow analysis) will not be required as discharging of water seepage is expected to be carried out with a pumping system.

The following table shows the advantages and disadvantages between Sheetpile and Earthfill structures.

Table 7.1

Cofferdam	Advantage	Disadvantages
Sheetpile	Well suited for high permeable nature of soil to control the flow	Special equipment is required to install
	Well suited for seepage control	
	No erosion problem	
Earth fill	Easy to construct	Excessive earthfill required
	Available in all places	Cut-off wall required
	No special equipment is required to construct	Or Excessive earthfill width to minimize seepage
		Not well suited for seepage control
		Potential erosion problem

A non standard special provision (NSSP) should be included in the contract documents to alert the Contractor of the possible presence of cobbles and boulders that may affect the installation of temporary excavation support system.

Water level of the Mollie River present seasonal variation and historical fluctuation of water level has been observed by the rust marks at culvert edges during site visit by DST engineer and recorded accordingly. The river surface water levels at inlet and outlet side of culvert were recorded as EL 375.68 m and EL 375.57 m. It is assumed that the highest seasonal creek level required to be controlled during construction would be at the obvert elevation of the culvert. However the possibility of higher flood levels exists.

7.1.2 Seepage Below Cofferdam

As seepage will be a controlling factor for the geometry of the cofferdam, seepage analyses were carried out with various penetration lengths below the excavation, applying finite element modelling using Plaxis Version 8 developed by Plaxis bv. The hydraulic conductivity values described previously were used as input data.

The following table shows calculated seepage volumes and velocities for various geometries of sheetpile cofferdams. In order to minimize the seepage around a cofferdam, extending the cofferdam laterally by a distance at least equal to the penetration depth beyond the river bank on each side is recommended. Based on the calculations, relatively low seepage rates will be experienced within the excavation provided pumping of seepage is exercised within the excavation. However note that given the previously noted possibility of variations in hydraulic conductivity by an order of magnitude, the reported values for flow and velocity could also vary by an order of magnitude up or down.

The condition of penetration length, retained height and water head shown in Table 7.2 and 7.3 were considered in the modelling.

Table 7.2

Type of Sheetpile (API Standard)	Penetration length below excavation (m)	Retained head above excavation (m)	Seepage rate (m ³ /day)	Seepage velocity (m/s)
PU 12*	4	2.5	100-120	1 X 10 ⁻⁴
PU 12*	3	2.5	150	2.3 X 10 ⁻⁴
PU 6*	4	2.5	100-120	1 X 10 ⁻⁴
PU 6*	5	2.5	90-100	5.3 X 10 ⁻⁵

Note: * or equivalent

Piping or heaving occurs when the hydraulic gradient is equal to or greater than critical hydraulic gradient. Analyses on piping potential for three different penetration lengths of sheetpile 3, 4 & 5 meters below the excavation level were carried out. The excavation level has been considered as 1.0 meter below the river bed level. In the analysis, maximum water level at the retained side based on seasonal variation of water level was considered and at the downstream side water level was considered at 1.0 m below.

It was found that the hydraulic gradient is less than critical hydraulic gradient for the all above three cases. Therefore it can be concluded that there is no piping potential associated with groundwater flow below penetrated length of sheelpile. Heave will not be occurred as long as groundwater level is kept below excavation level with a suitable dewatering system discussed earlier.

Piping analyses were carried out based on the effective grain size, the estimated relative density of the riverbed granular soils and the seepage velocities. It was found that the underlying soil has sufficient factor of safety to resist the piping failure for minimum 3 m penetration below the excavation.

7.1.3 Stability of Sheetpile Wall

Stability of a cantilever sheetpile in terms of global stability, horizontal displacements and bending moments were checked for various penetration length of a cantilever (non braced or tied back) sheetpile. Axial stiffness (EA) and bending stiffness (EI) for relevant section modulus for various sheet piles were used as input data in the finite element modeling. Factors of safety for global stability were assessed applying the Phi-C Reduction Method. True limit state analyses were carried out applying stress deformation analyses using the finite element modeling with the help of Plaxis Version 8 developed by Plaxis bv. Soil parameters described in Table 6.1 and 6.2 were used in the Mohr Coulomb model. It was found that a penetration length of at least 3 m of a PU12 sheetpile

section provides sufficient global stability with acceptable horizontal displacements while the bending moments for the selected sections are well below the allowable limit. Bending moment and shear forces profiles are shown in attached Plaxis output in Appendix 'C'. Analyses were repeated with PU 6 sheet pile sections and these found that this sheetpile also provides sufficient stability with deformations and stresses within suitable limits. Results of the calculations are listed below.

Table 7.3:

Type of Sheetpile (API)	Section Modulus (cm ³ /m)	Penetration length (m)	Retained height (m)	Global and sliding (FOS)	Horizontal displacement (mm)	Bending moment (kNm/m)
PU 12	1200	4	2.5	9.4	10	1.1
PU 12	1200	3	2.5	8.3	9	0.85
PU 6	600	4	2.5	9.4	10	0.96
PU 6	600	5	2.5	10.3	10	0.66

Note: * or equivalent

As the structure is temporary, it is not necessary to consider corrosion protection. A typical section of sheet pile wall and excavation can be found in Drawing No. Sheet 2.

7.1.4 Construction Concerns

As indicated in the factual portion of the report, the riverbed is underlain by a 3 to 4 m thickness of granular soil containing a substantial fraction of cobbles and boulders. This will prevent smooth penetration of sheetpiles into the required depth. A suitable vibratory hammer with very high capacity water jetting accessories may be able to install the sheetpiles successfully. Alternatively it will likely be more practical to replace the cobble and boulder material with loose sand of a suitable permeability (construction in the wet) before the installation of sheetpiles. Any cofferdam installation will require mitigation measures to prevent fines in the riverbed soils from affecting aquatic habitat.

8.0 UNWATERING

Unwatering will be required at two locations: one to remove the accumulated river water storage behind the inlet cofferdam with the help of a suitable pump scheme, another to collect seepage into the excavation and/or dewater the groundwater level to below the excavation level (assumed to be up to 1 m below invert). For the former, the pumped water would be discharged downstream of the culvert outlet through a flexible discharge pipe run above the embankment. In order to prevent back up of water from downstream a dyke made of sand bags has been proposed as an hydraulic barrier. However a sheetpile vertical cutoff wall may provide better control of both surface and groundwater.

For the excavation which will collect seepage from under the cofferdam, the sandbags and from groundwater, a suitable sump and pump system, possibly supported by an efficient wellpoint system, will be required to unwater and stabilize the excavation. A well designed well-point system with a suitable diameter of well point at an appropriate spacing will perform better for working under dry conditions and to prevent disturbance of the excavation base through sand boiling and hydraulic heave. Depending upon the proposed excavation level and width, the dewatering design requires an assessment of the radius of influence and discharge rate to achieve a dry and stable condition at the excavated base. The assessment will be for an unconfined aquifer. Hydraulic conductivity values reported in section 6.0 with a range of one order of magnitude above and below this value should be used in order to allow for some degree of variability in a deposit.

Transmissivity of the aquifer may then be estimated by applying the following equation:

$$T = kb$$

where T is transmissivity in m^2/s , k is hydraulic conductivity in m/s and b is saturated thickness of the aquifer in meters. For this location the saturated thickness can be assumed as 10 m.

Specific yield can be conservatively assumed as 0.0003. Alternatively the specific yield (S_y) can be estimated from the following equation:

$$S_y = 1.8 \times 10^{-6} \times b + 8.6 \times 10^{-4} \times b^{0.3}$$

A seepage analysis of the cofferdam and excavation has estimated that the groundwater inflow for the excavation could exceed 100 m³/day. A permit to take water, Category 1 or 2, may be required depending upon volume of the water taking out and the duration of water taking.

Sediment and erosion control measures should be designed by the contractor to address his construction methods and schedule, and installed accordingly during the unwatering process. Suitably designed and located silt fences, straw bales and filter cloths will be required prior to construction activities. Additional sediment and erosion control measures will also be required during construction.

Once all construction activities are completed for the river crossing, the sheetpile cofferdam should be removed together with the decommissioning of the temporary unwatering and dewatering measures. Sediment and erosion control measures must be left in-place until all works are complete.

9.0 CLOSURE

Based on the ground conditions encountered during the ground investigation, a vertical cutoff wall using a cantilever sheet pile will be required upstream of the culvert to dam the water flow. In order to minimize the seepage volume and velocity a sheetpile penetration length of 5 m (total length 7 m) using sheetpile type PU 6 or equivalent is suggested. The tentative location of the alignment is shown in Drawing 1.

Unwatering of the excavation will be required with a suitably designed pumping scheme and well point system.

10.0 LIMITATIONS OF REPORT

A description of limitations which are inherent in carrying out site investigation studies is given in Appendix 'A', and this forms an integral part of this report.

For DST CONSULTING ENGINEERS INC.

Prepared by:

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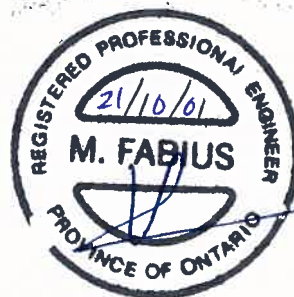
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APPENDIX A

LIMITATIONS OF REPORT

LIMITATIONS OF REPORT

GEOTECHNICAL STUDIES

The data, conclusions and recommendations which are presented in this report, and the quality thereof, are based on a scope of work authorized by the Client. Note that no scope of work, no matter how exhaustive, can identify all conditions below ground. Subsurface and groundwater conditions between and beyond the testholes may differ from those encountered at the specific locations tested, and conditions may become apparent during construction which were not detected and could not be anticipated at the time of the site investigation. Conditions can also change with time. It is recommended practice that DST Consulting Engineers be retained during construction to confirm that the subsurface conditions throughout the site do not deviate materially from those encountered in the testholes. The benchmark and elevations used in this report are primarily to establish relative elevation differences between the testhole locations and should not be used for other purposes, such as grading, excavation, planning, development, etc.

The design recommendations given in this report are applicable only to the project described in the text and then only if constructed substantially in accordance with details stated in this report. Since all details of the design may not be known, we recommend that we be retained during the final stage to verify that the design is consistent with our recommendations, and that assumptions made in our analysis are valid.

Unless otherwise noted, the information contained herein in no way reflects on environmental aspects of either the site or the subsurface conditions.

The comments given in this report on potential construction problems and possible methods are intended only for the guidance of the designer. The number of testholes may not be sufficient to determine all the factors that may affect construction methods and costs, e.g. the thickness of surficial topsoil or fill layers may vary markedly and unpredictably. The contractors bidding on this project or undertaking the construction should, therefore, make their own interpretation of the factual information presented and draw their own conclusion as to how the subsurface conditions may affect their work.

Any results from an analytical laboratory or other subcontractor reported herein have been carried out by others, and DST Consulting Engineers Inc. cannot warranty their accuracy. Similarly, DST cannot warranty the accuracy of information supplied by the client.

EXPLANATION OF TERMS USED IN THIS REPORT

Soil Classification (Based on Amounts by Weight)

Noun	Gravel, sand, silt, clay	>35% and main fraction
“and”	And gravel, and silt, etc.	>35%
Adjective	Gravely, sandy, silty, clayey, etc.	20% - 35%
“some”	Some sand, some silt, etc.	10% - 20%
“trace”	Trace sand, trace silt, etc.	1% - 10%

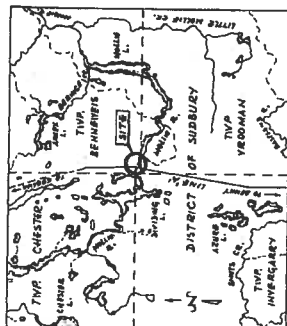
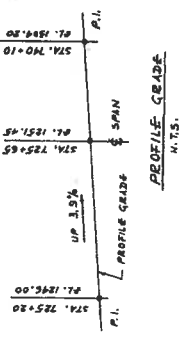
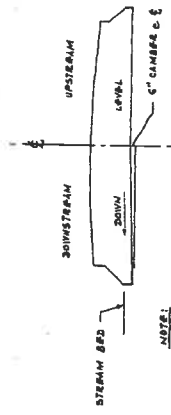
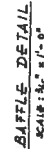
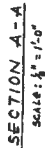
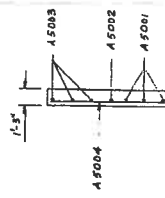
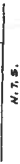
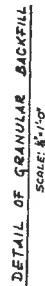
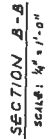
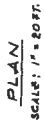
Consistency and Shear Strength of Cohesive Soils

CONSISTENCY	UNDRAINED SHEAR STRENGTH (kPa)
Very Soft	<12
Soft	12 - 25
Firm	25 - 50
Stiff	50 - 100
Very stiff	100 - 200
Hard	>200

Compactness Condition of Sands from Standard Penetration Tests

COMPACTNESS CONDITION	SPT N-INDEX (blows per 0.3 m)
Very loose	0 - 4
Loose	4 - 10
Compact	10 - 30
Dense	30 - 50
Very dense	Over 50

APPENDIX B
EXISTING DRAWINGS



KEY PLAN
SCALE: 1" = 2 MI.

NOTES:

Q. B. M. N^o 2320 ELEV. 1156.875
HUBBARD BAY CO. STORE, TABLE IN SOUTH CONCRETE
FOUNDATION WALL, 15 FT. FROM SOUTHWEST CORNER
1 FT. BELOW WORK.
PUBLICATION 20, PAGE 74. "GOCAMA"

CLASS OF CONCRETE


3000 P.S.I.
CLEAR COVER ON REINFORCING STEEL
3" EXCEPT AS NOTED

CONSTRUCTION NOTICE

HEAVY CONSTRUCTION EQUIPMENT SHALL NOT USE THE
STRUCTURE UNTIL THE 7 FT. OF COVER HAS BEEN PLACED

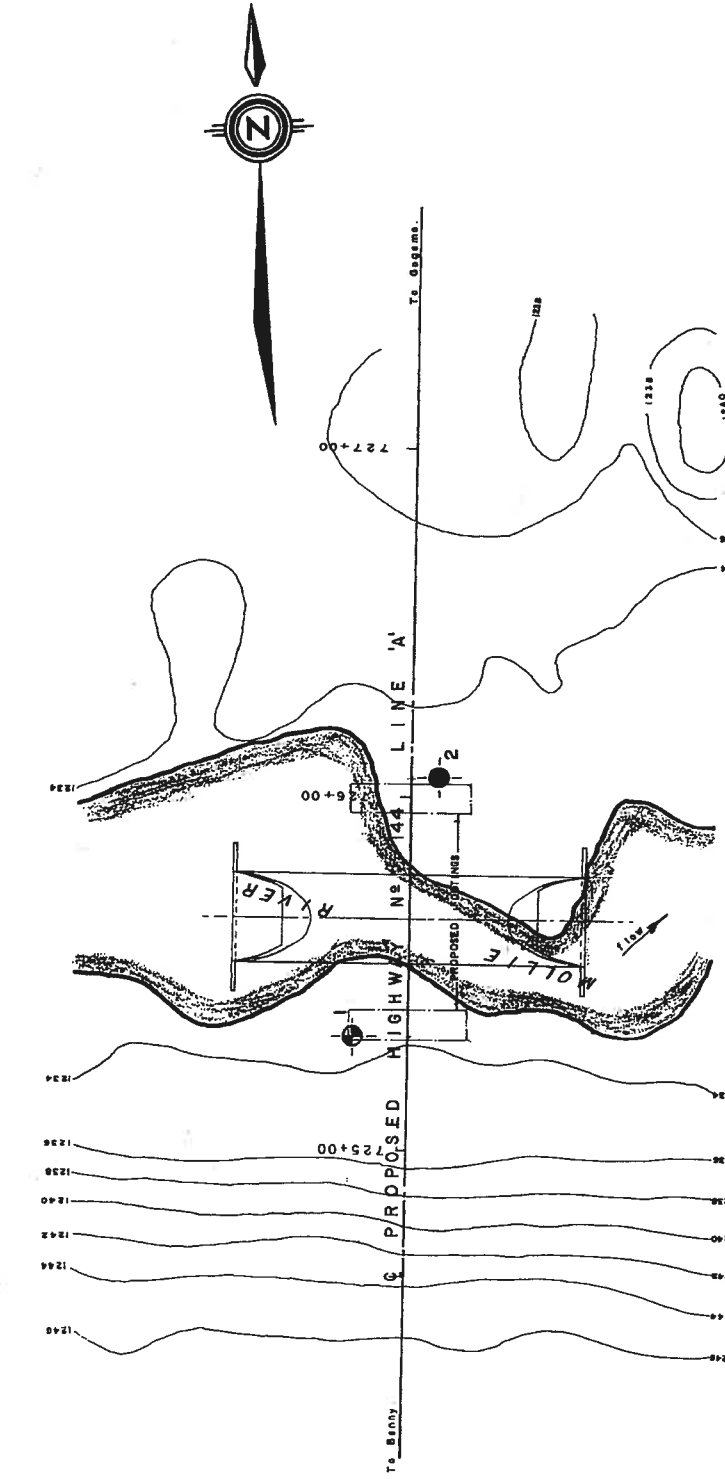
LIST OF DRAWINGS
D-GIBI-1 GENERAL PLAN
-2 BOB# HOLE LOCATIONS & SOIL STRATA

[illegible][illegible]

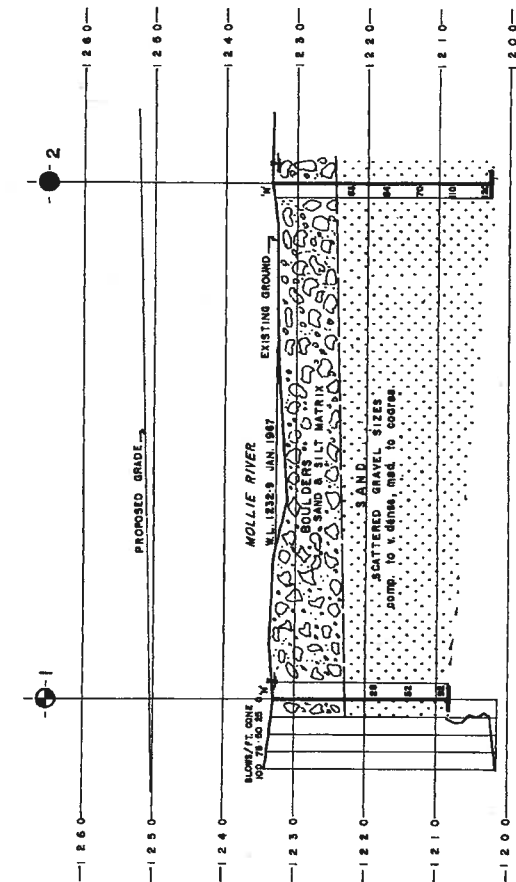
DEPARTMENT OF HIGHWAYS, ONTARIO		BRIDGE DIVISION	
<p style="text-align: center;"><u>MOLLIE RIVER PIPE ARCH</u></p> <p style="text-align: center;">SOUTH OF COCAMA</p>			
KING'S HIGHWAY No. 144		LINE 'A'	
S.S. DIST. OF SUBURBY		LOT 458 (SENIOR) SQ. UNDIVIDED	
TWP. BRANTFORD		GENERAL PLAN	
APPROVED 		SHEET NO. 45-244	W.D. NO. 287-06
DESIGN	D. S. M.	CONTRACT	
DRAWING	P. A.	POST	67-214
DATE	JULY 1907	DRAWING No.	B-6781-7
			ISSUED 10-2-07

M.W.C.L. TRANSLATION 300-2-16

69211 # 1320-244-1-A



P L A N
 1" = 40 FT
 0 20 40



PROFILE LINE 'A'
 1" = 40 FT
 0 20 40

LEGEND

- Bore Hole
- Cone Penetration Hole
- Bore & Cone Penetration Hole
- Water Levels established at time of field investigation

NO.	ELEVATION	STATION	OFFSET
1	1238.9	725+32	18' L
2	1235.6	726+05	6' RL

NOTE
 The boundaries between soil strata have been established only at Bore Hole locations. Between Bore Holes the boundaries are assumed from geological evidence and may be subject to considerable error.

PRINT RECORD

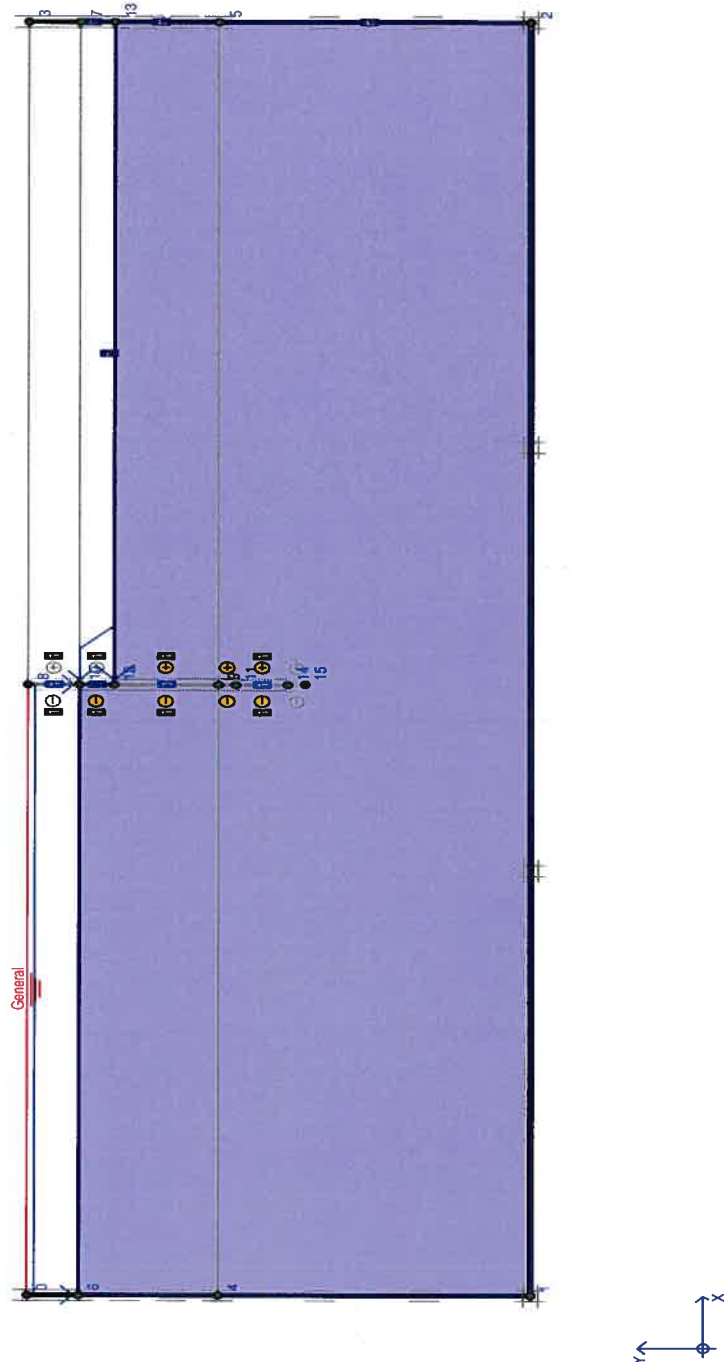
NO.	DATE
705	1987

WILLIAM TROW ASSOCIATES LIMITED
 DEPARTMENT OF HIGHWAYS - ONTARIO
 MATERIALS & TESTING DIVISION - FOUNDATION SECTION
PROPOSED CROSSING
MOLLIE RIVER
 KING'S HIGHWAY NO. 144 LINE 'A' DIST. NO. 14
 TWP. BENNEWIS LOT CON.
BORE HOLE LOCATIONS & SOIL STRATA
 SURVEY D.C. CHECKED E.P. NO. 287-64 DRAWING NO. 3415
 DRAWN E.F.K. CHECKED J.M.M. NO. 1000
 DATE FEB. 1987 SITE NO. 74-244 BRIDGE DRAWING NO. 66451-2
 APPROVED *[Signature]* ENGINEER DIST. NO. 67-214
 69212 #1320-244-2-A

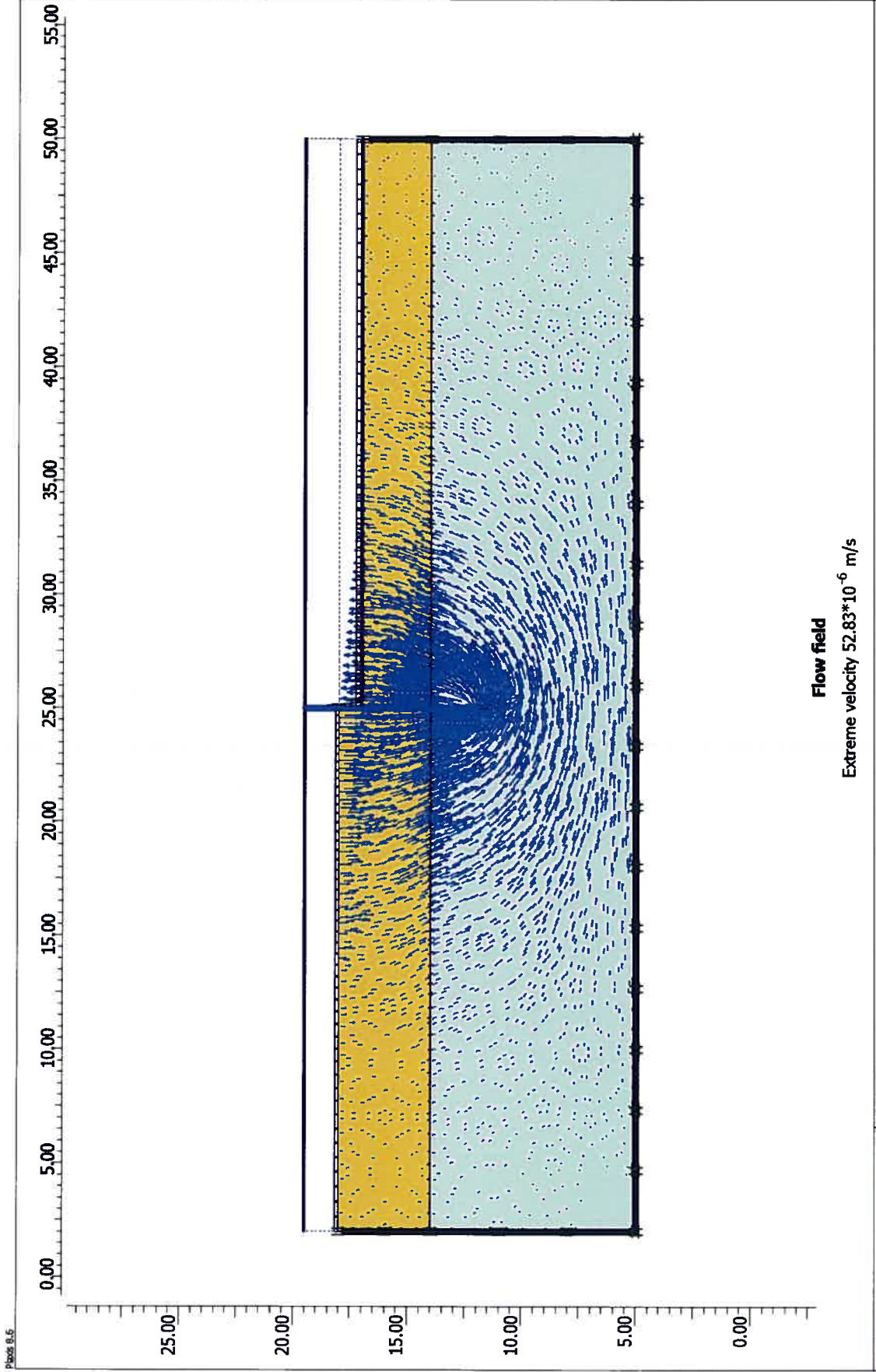
APPENDIX “C”


PLAXIS FINITE ELEMENT MODELLING

INPUT MODEL FOR COFFERDAM ANALYSIS

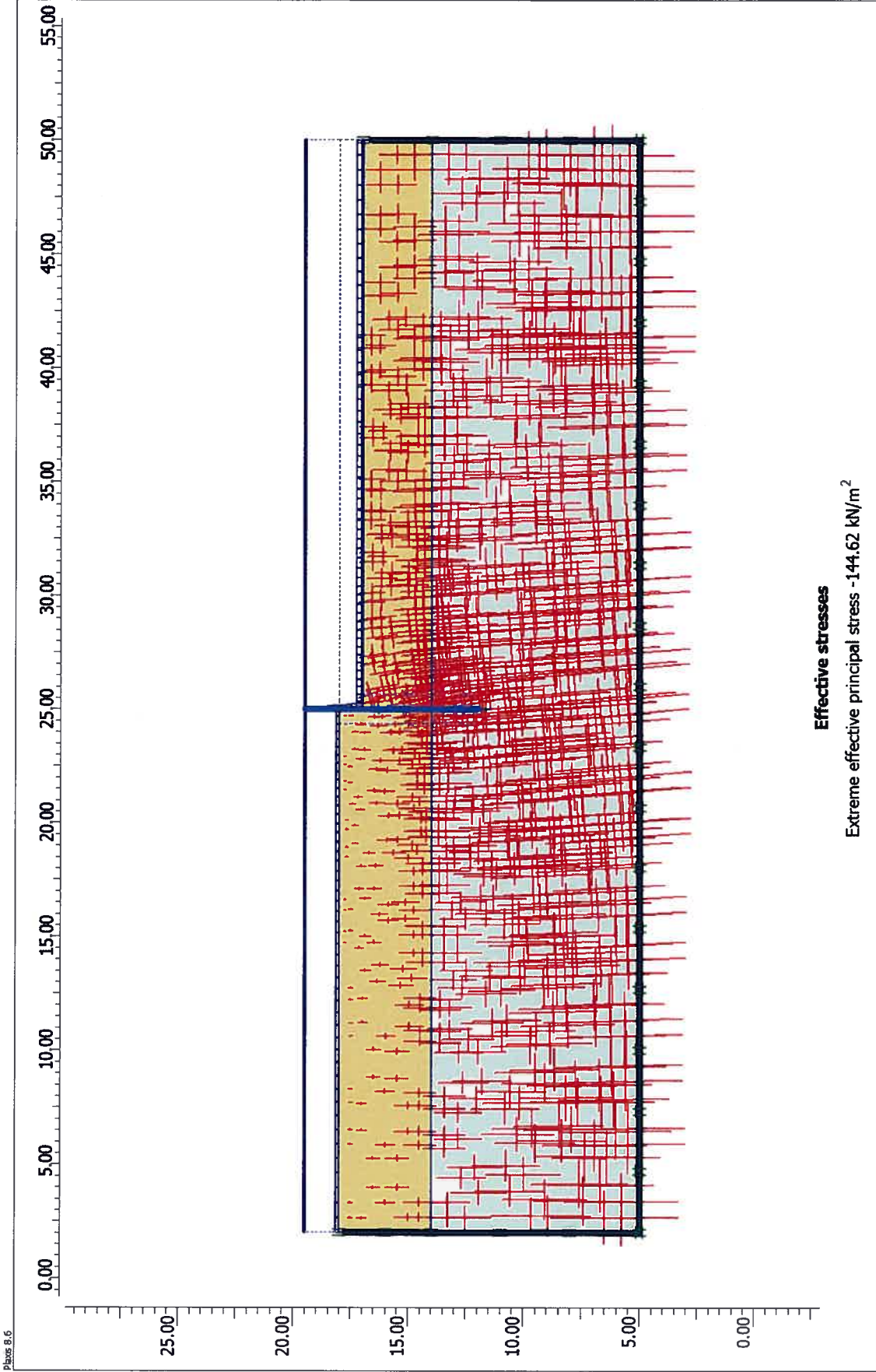


SEEPAGE ANALYSIS OF COFFERDAM WITH PU12 SHEET PILE (5m PENETRATION)



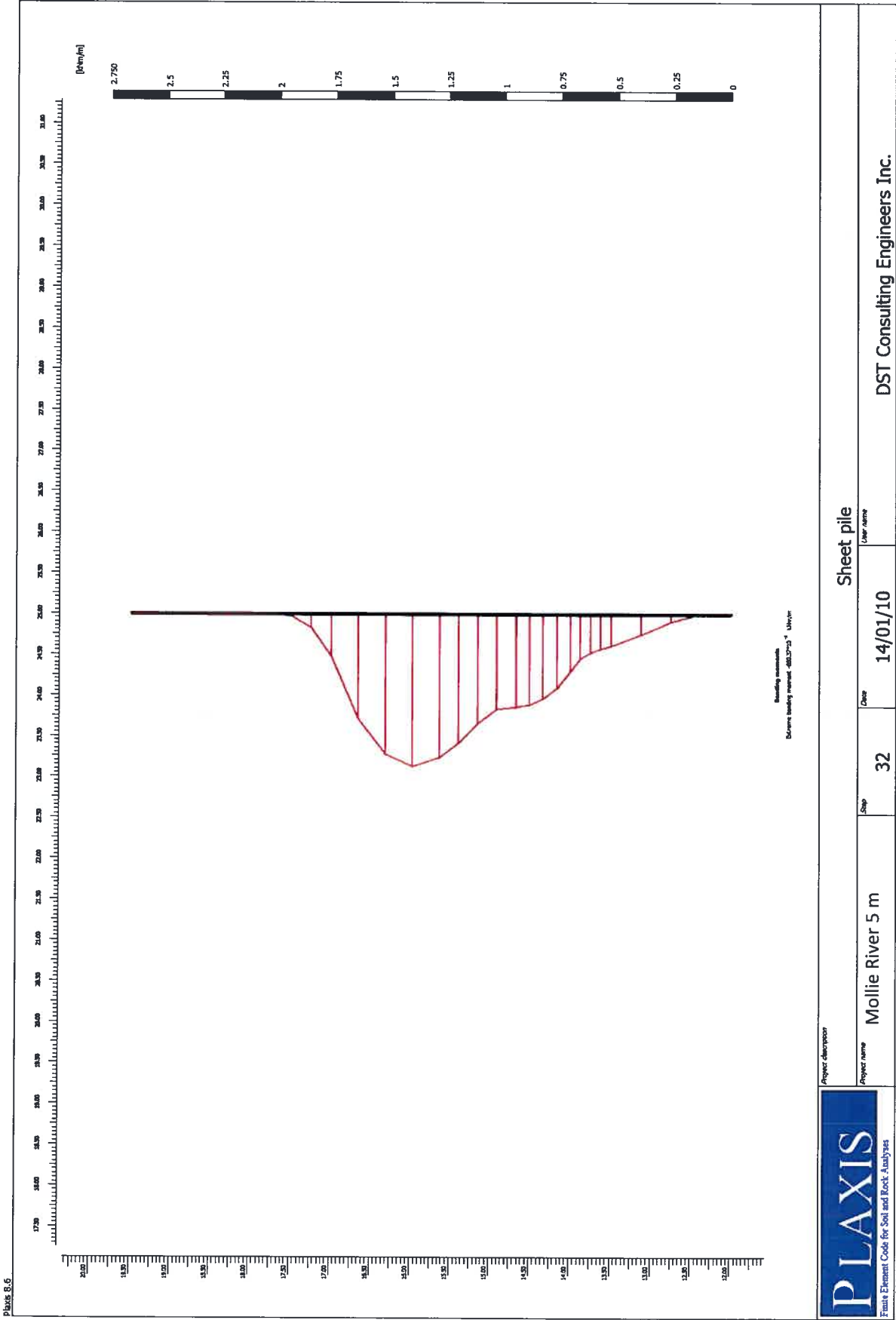
		Project description		Sheet pile	
Project name	Mollie River 5 m	Date	14/01/10	User name	DST Consulting Engineers Inc.

EFFECTIVE STRESS DIAGRAM WITH PU12 SHEET PILE (5m PENETRATION)

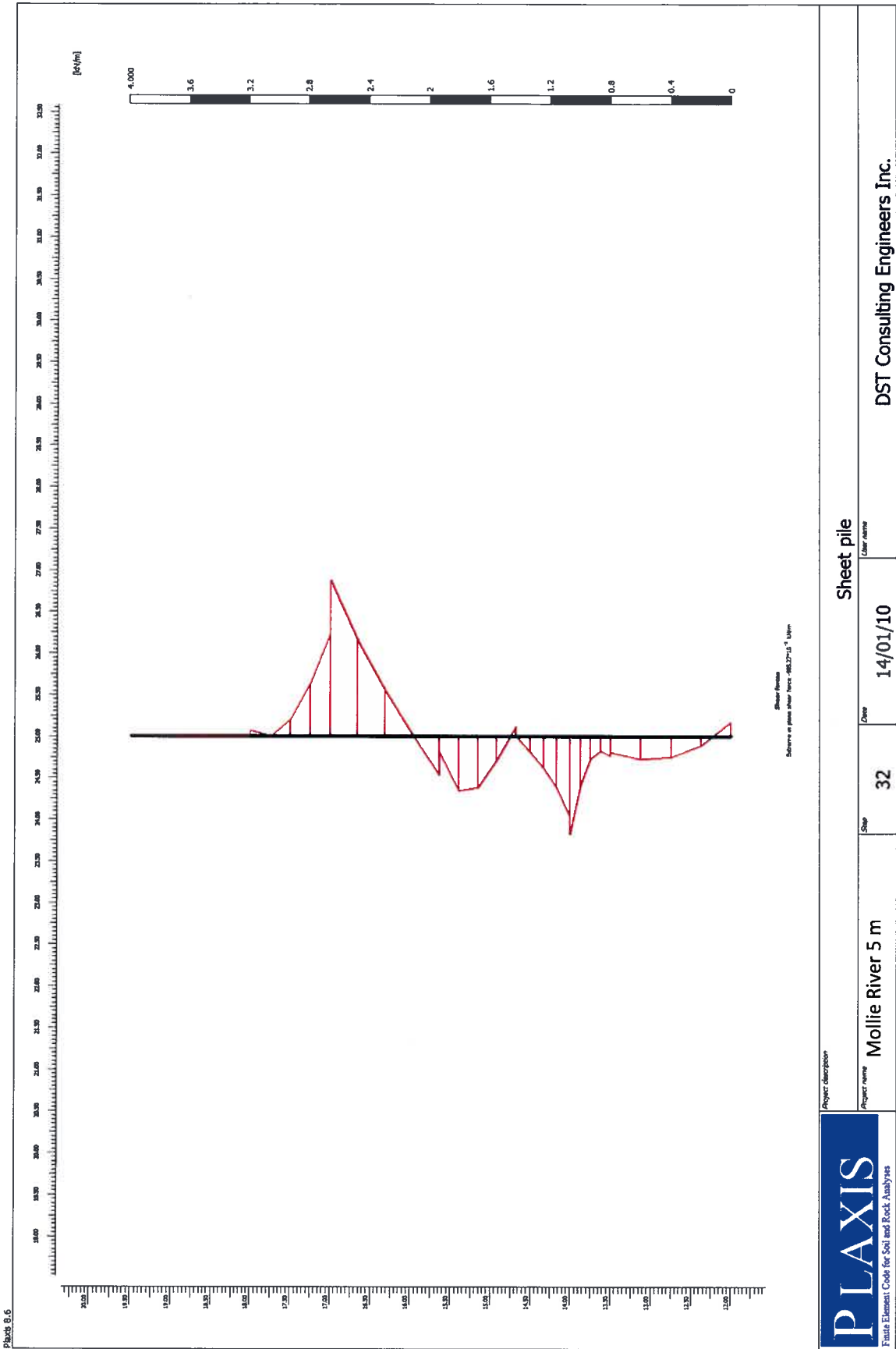


Project description		Sheet pile	
Project name	Mollie River 5 m	Order	14/01/10
Order	32	Order	
DST Consulting Engineers Inc.		DST Consulting Engineers Inc.	

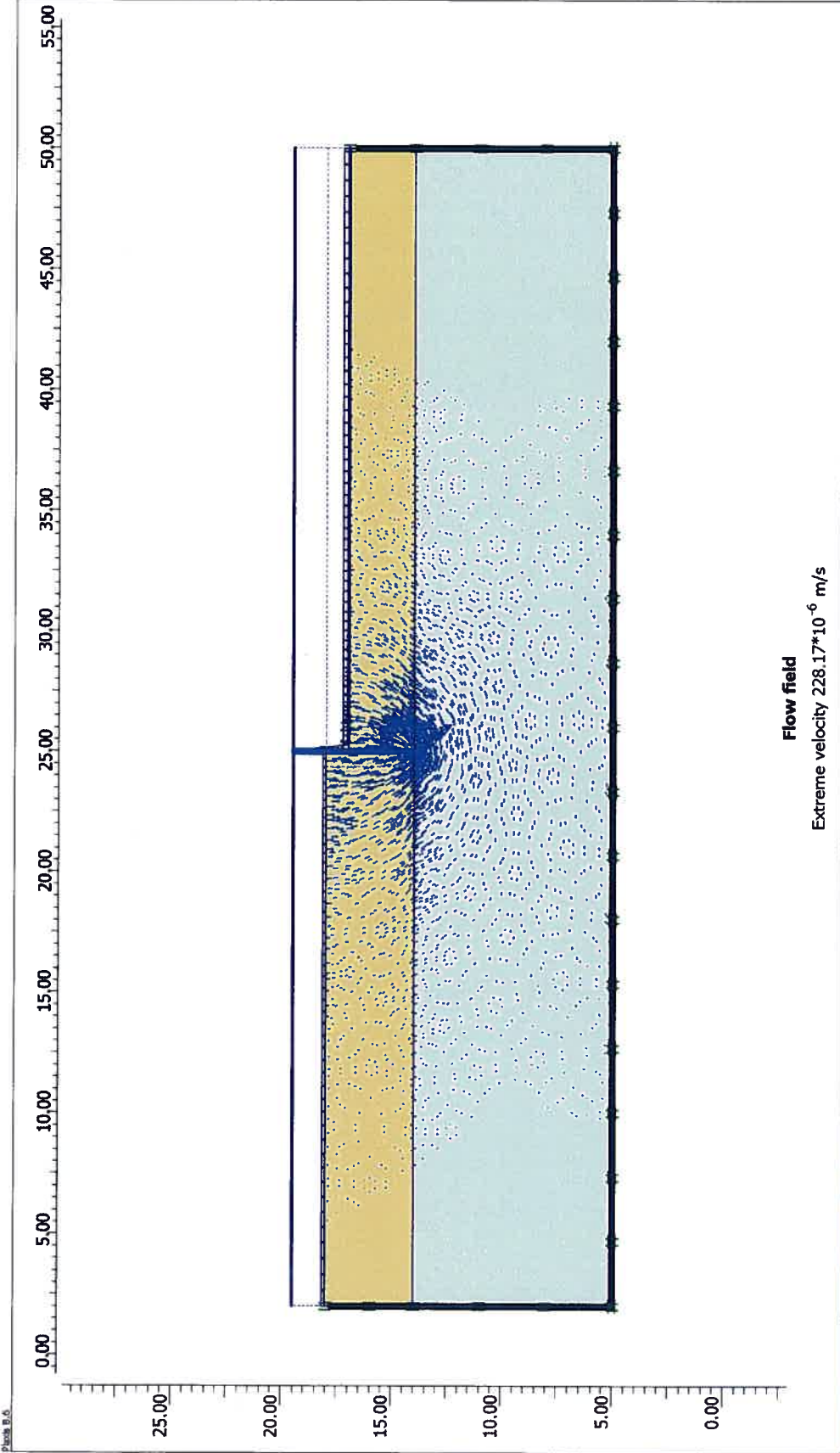
BENDING MOMENT PROFILE WITH PU12 SHEET PILE (5m PENETRATION)



SHEAR FORCES PROFILE WITH PU12 SHEET PILE (5m PENETRATION)

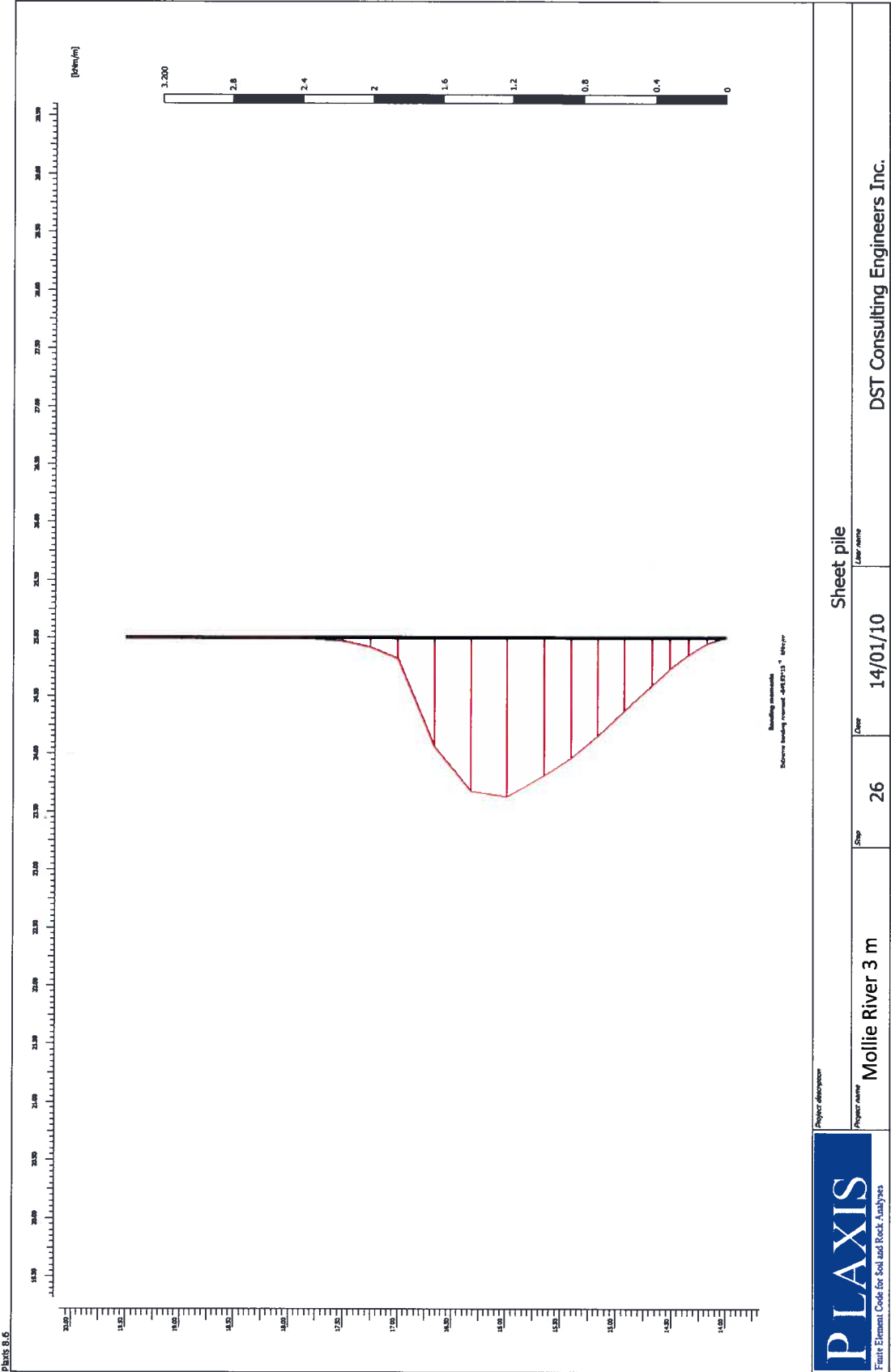


SEEPAGE ANALYSIS OF COFFERDAM WITH PU12 SHEET PILE (3m PENETRATION)

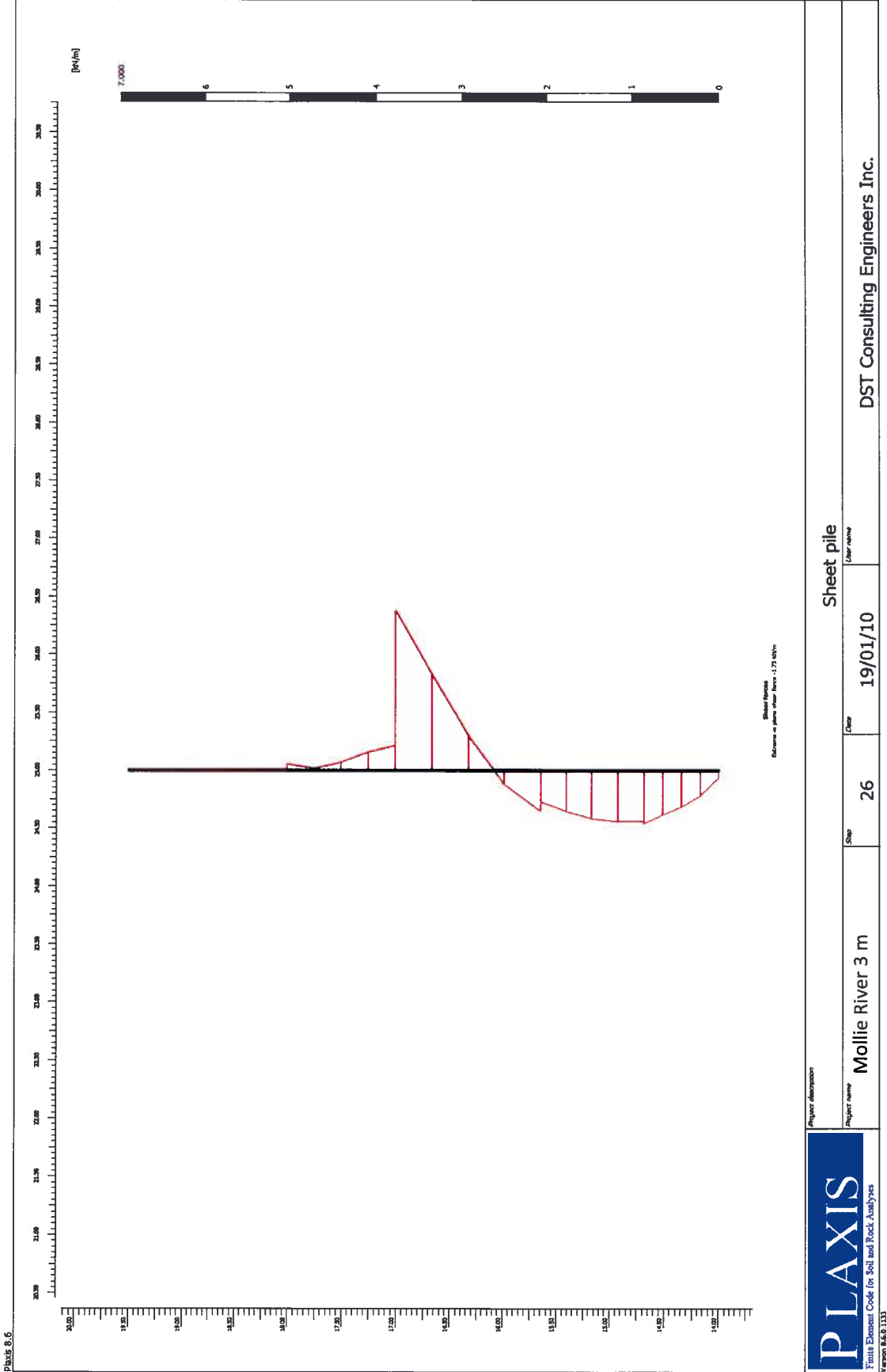


PLAXIS Finite Element Code for Soil and Rock Analyses Version 8.6.13.37	Project description		Sheet pile	
	Project name	Date	User name	
	Mollie River 3 m	14/01/10		DST Consulting Engineers Inc.

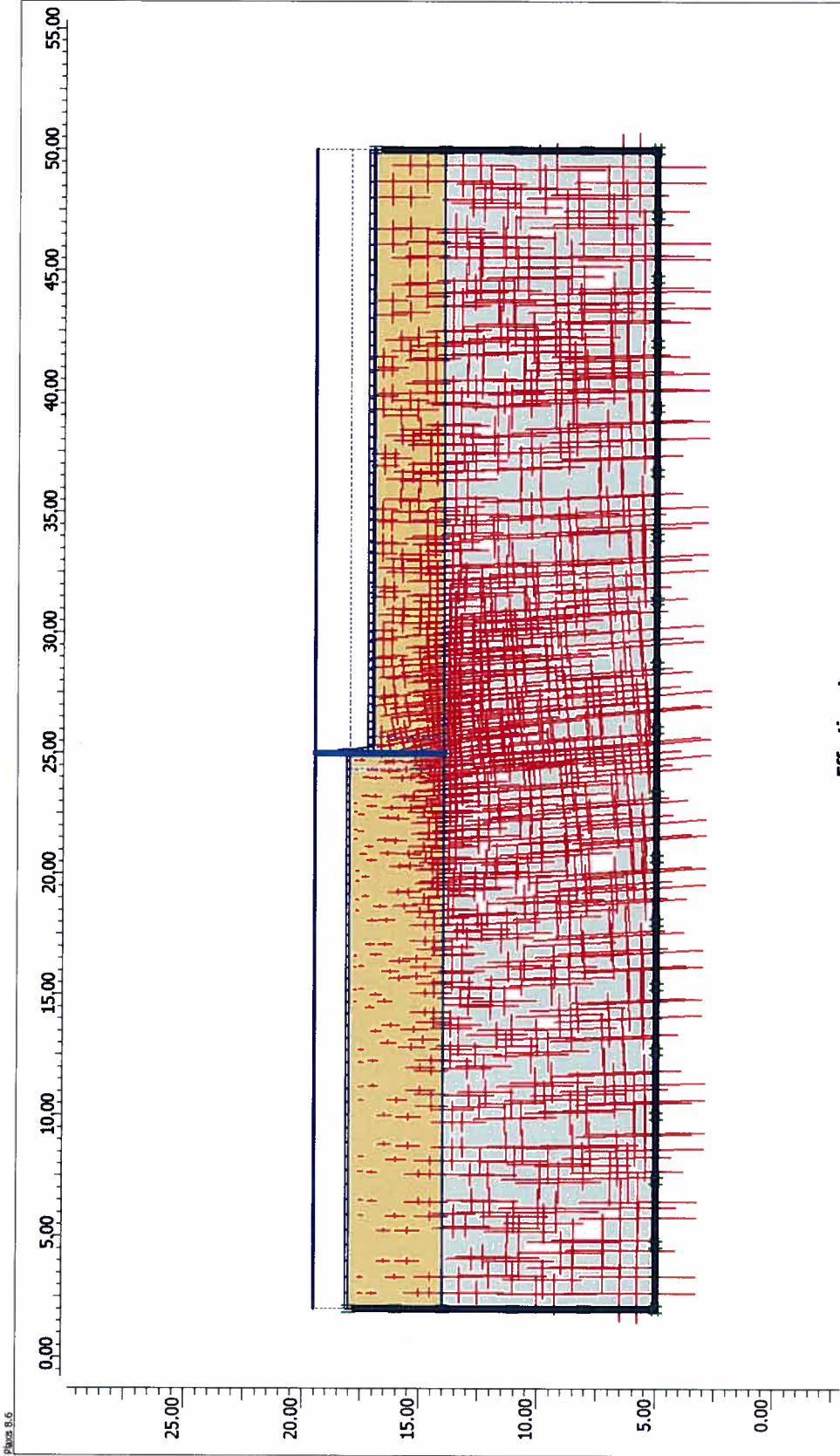
BENDING MOMENT PROFILE WITH PU12 SHEET PILE (3m PENETRATION)



SHEAR FORCE PROFILE WITH PU12 SHEET PILE (3m PENETRATION)

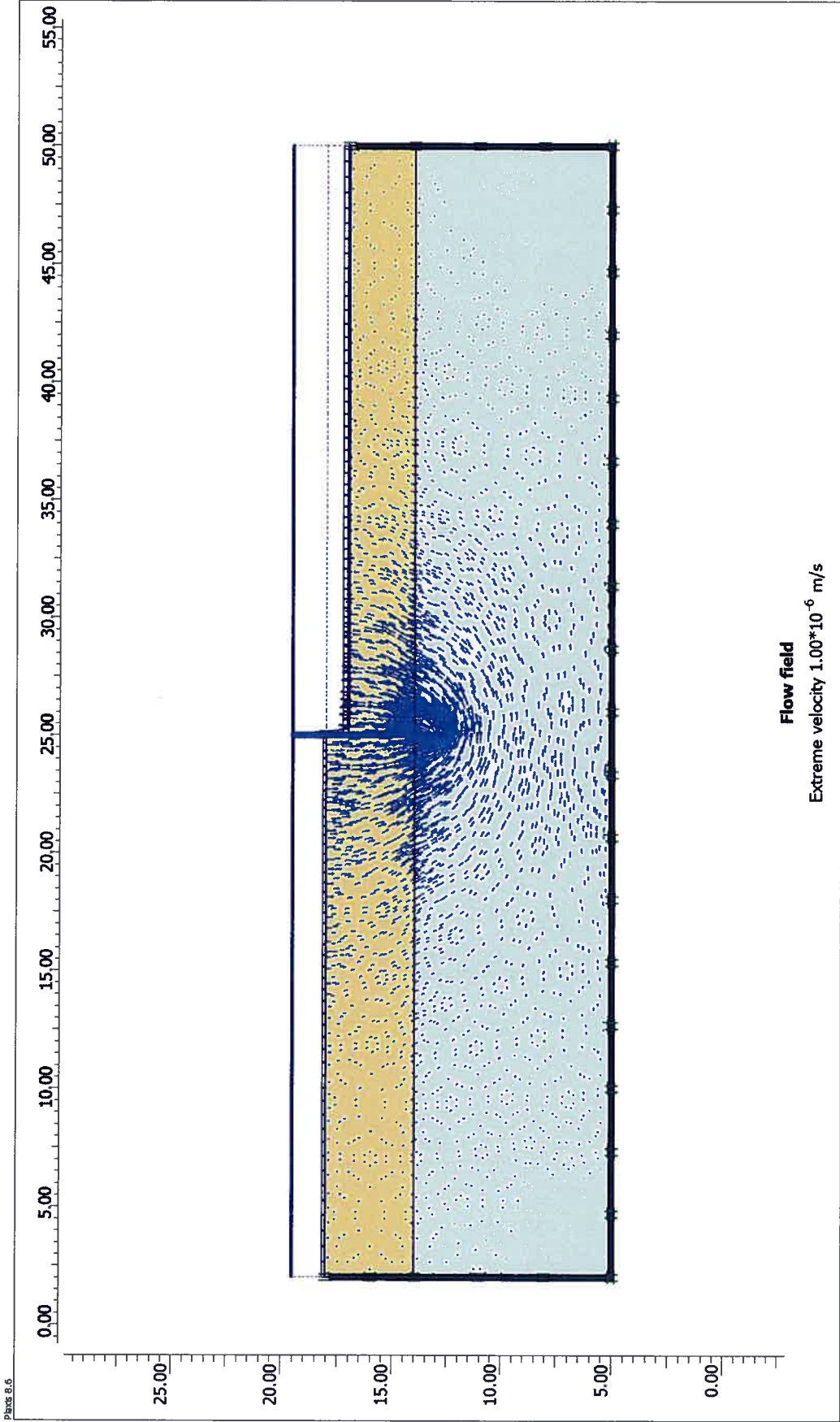


EFFECTIVE STRESS DISTRIBUTION WITH PU12 SHEET PILE (3 m PENETRATION)



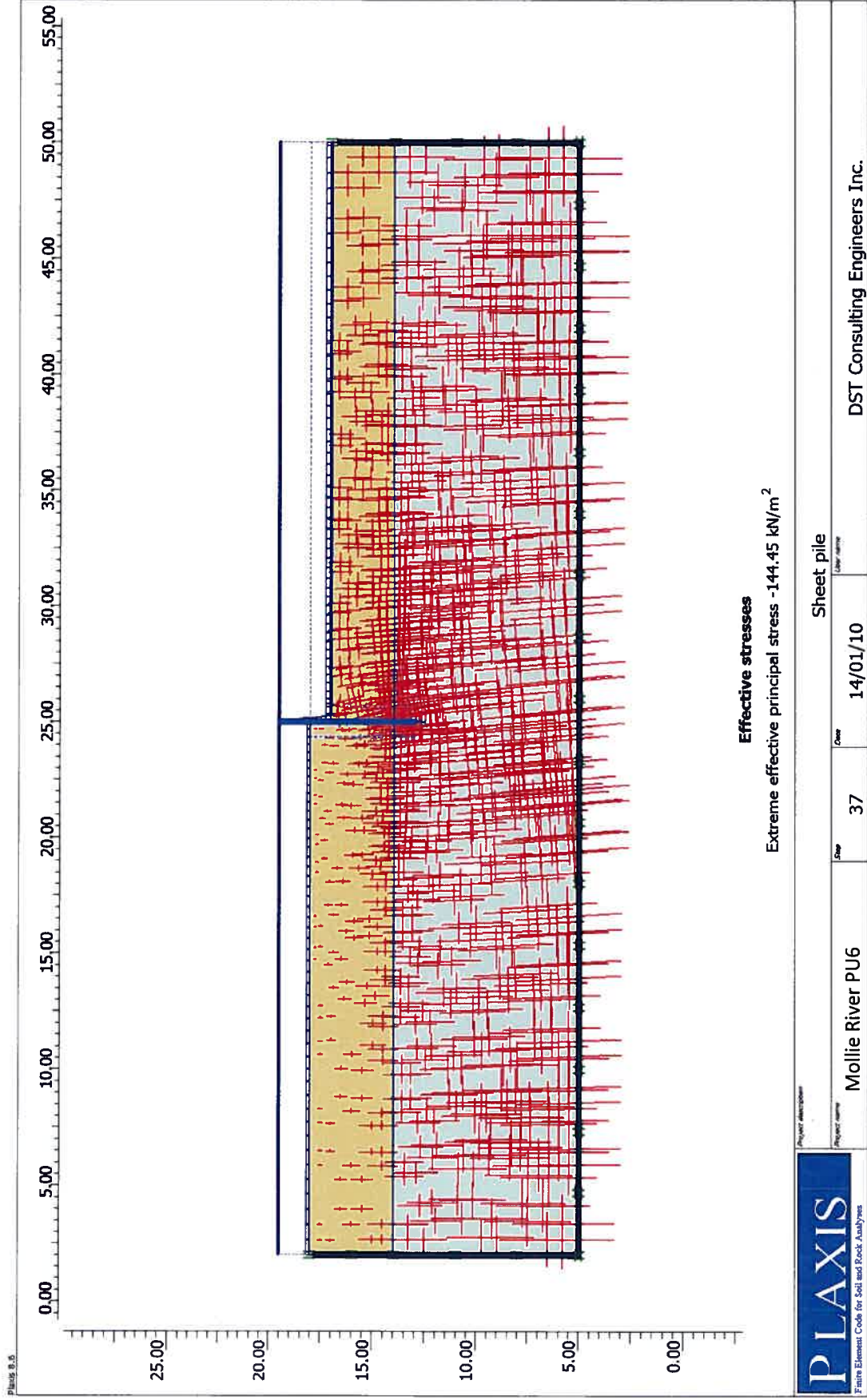
Project description		Sheet pile	
Project name	Mollie River 3 m	Date	14/01/10
Project number	26	Client name	DST Consulting Engineers Inc.

SEEPAGE ANALYSIS OF COFFERDAM WITH PU 6 SHEET PILE (4m PENETRATION)

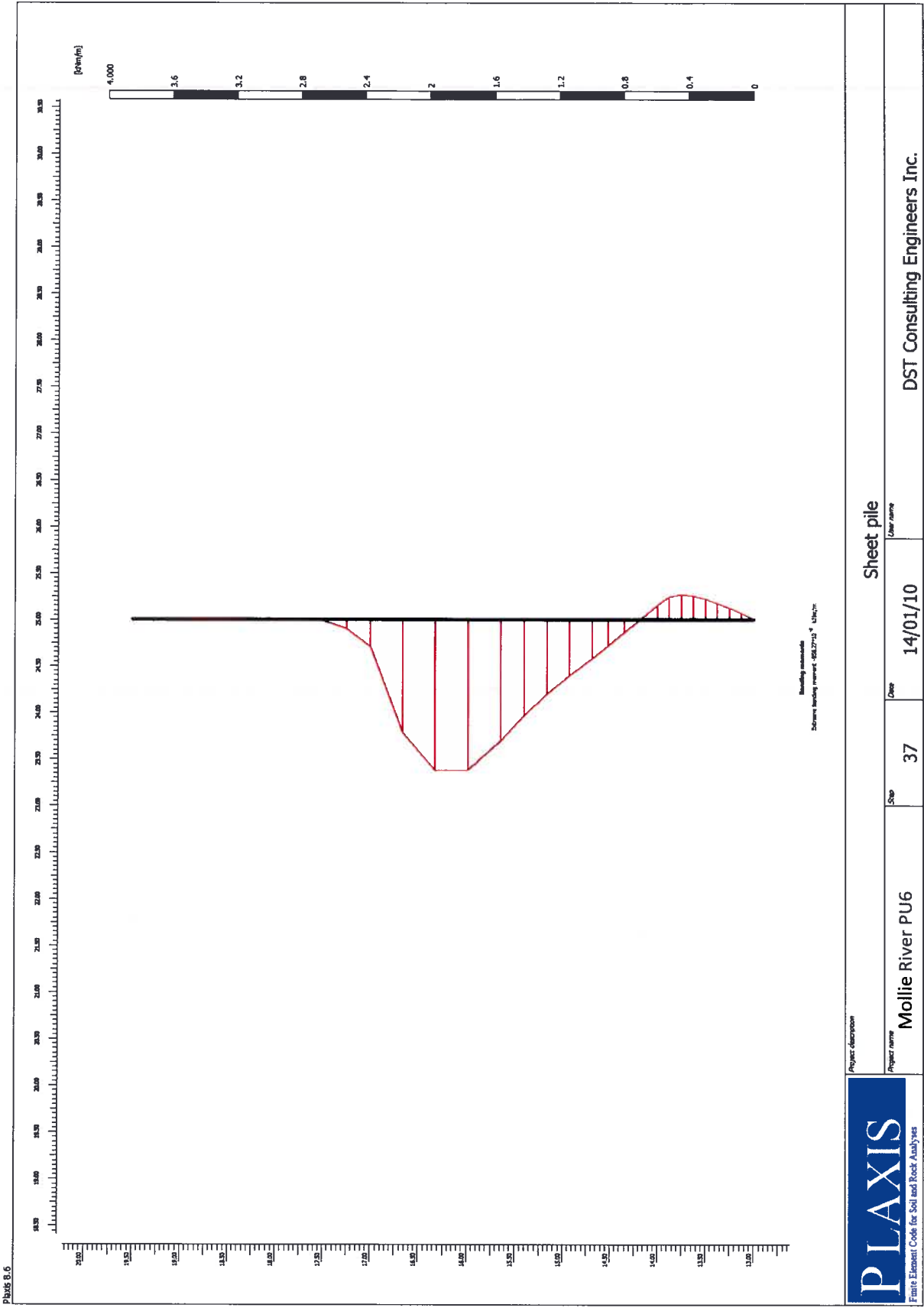


Project description		Sheet pile	
Project name	Mollie River PU6	Date	14/01/10
Finite Element Code for Soil and Rock Analyses		DST Consulting Engineers Inc.	
Version 8.6.6.1133			

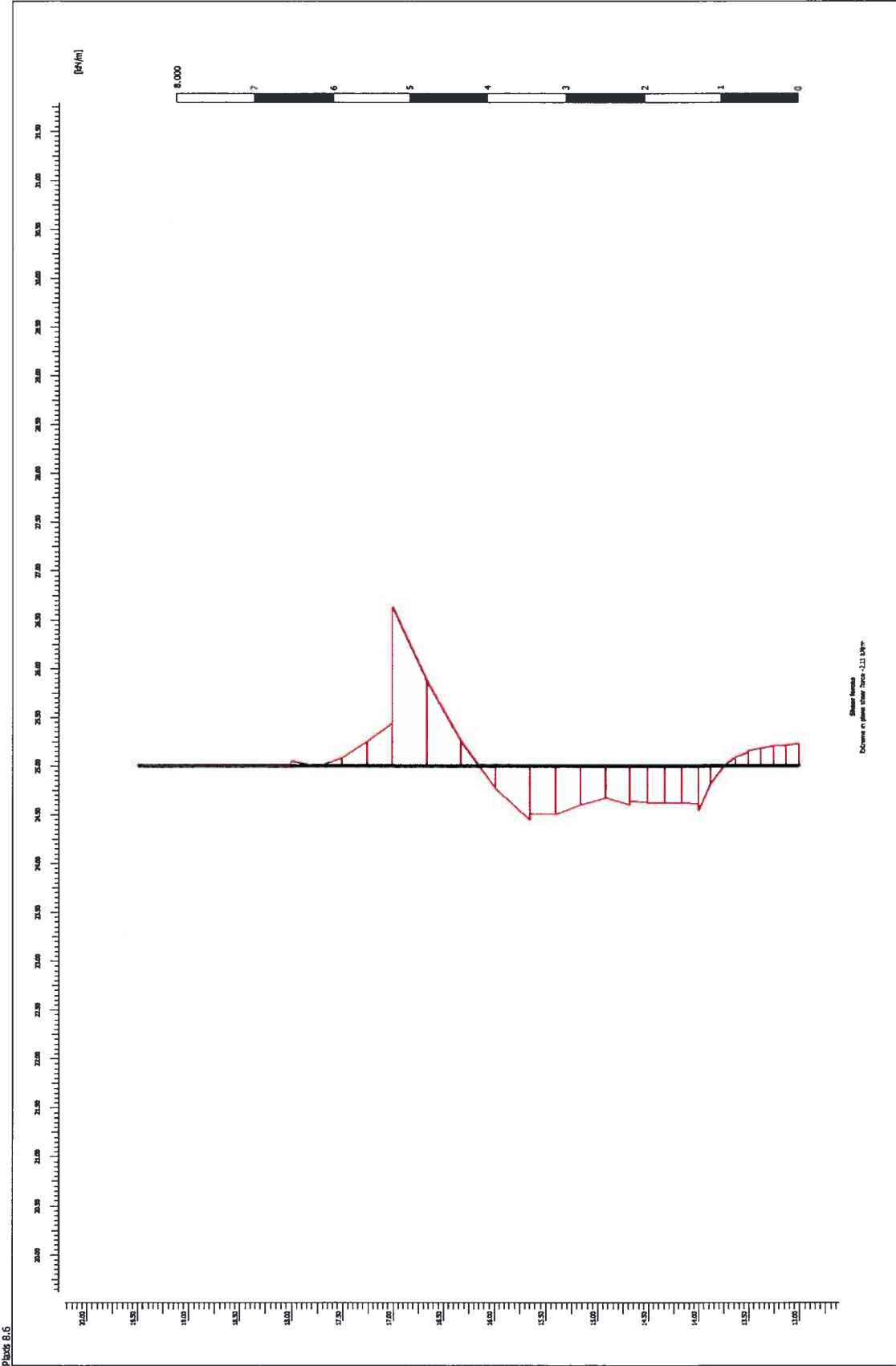
EFFECTIVE STRESS DISTRIBUTION WITH PU6 SHEET PILE (4m PENETRATION)



BENDING MOMENT PROFILE WITH PU6 SHEET PILE (4m PENETRATION)



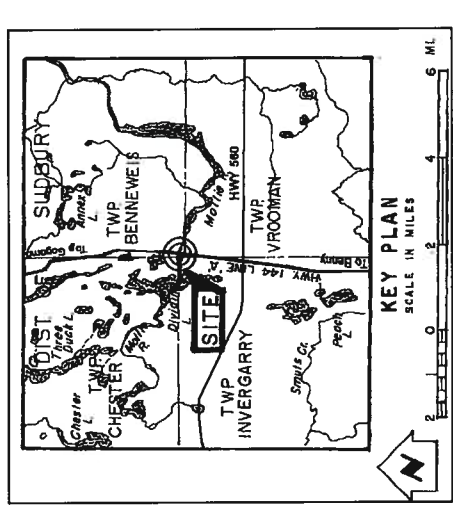
SHEAR FORCES PROFILE WITH PU6 SHEET PILE (4m PENETRATION)


















PLAXIS Finite Element Code for Soil and Rock Analysis Version 8.6 & 8.11.13	Project description			Sheet pile	
	Mollie River PU6			Date	User name
	37			14/01/10	DST Consulting Engineers Inc.

DRAWINGS

SHEET
1



LEGEND			
	Borehole		
	Dynamic Cone Penetration Test (DCPT)		
	Borehole with DCPT		
	Blows/0.3m (Std. Pen Test, 475 J/Blow)		
	Water level at time of investigation.		
	Benchmark		
	Fill		Sand
	Organics		Silt
	Topsoil		Clay
	Till		Sand & Gravel
	Boulders & Cobbles		
No.	Elevation	Station	Offset
1	376.80	10+000	15.0 m LT
2	376.04	10+002	27.0 m RT
3	376.14	10+020	23.0 m LT
4	375.72	10+019	21.5 m RT

NOTES

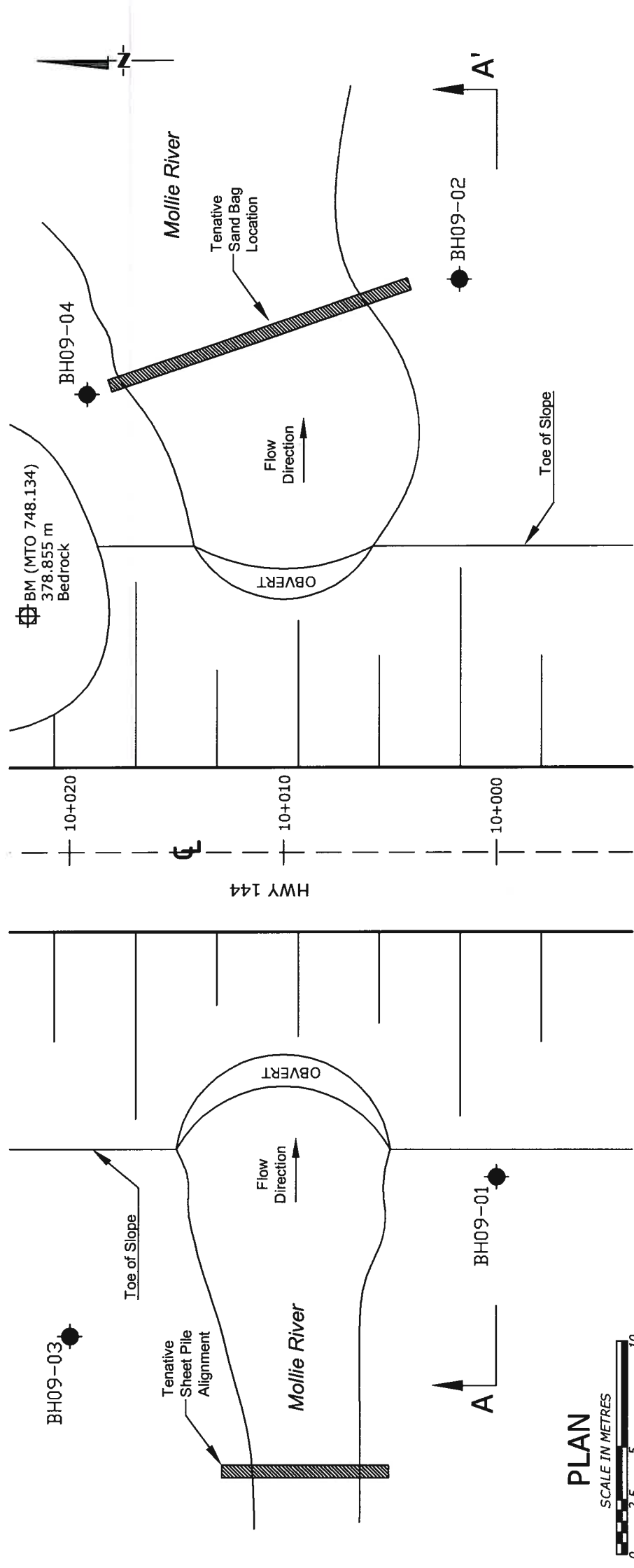
1. The cofferdam design should account for basal heave due to flow of water beneath the sheet piling
2. The presence of cobbles and boulders that may affect the installation of temporary excavation support system
3. Water level of the Molle River presents the seasonal variation
4. Historical fluctuation of water level observed from the evidence at inlet and outlet side is EL.376.18 m and EL.376.07 m

NOTE:
The boundaries between soil strata have been established only at borehole locations. Between boreholes the boundaries are assumed by interpolation and may not represent actual conditions.

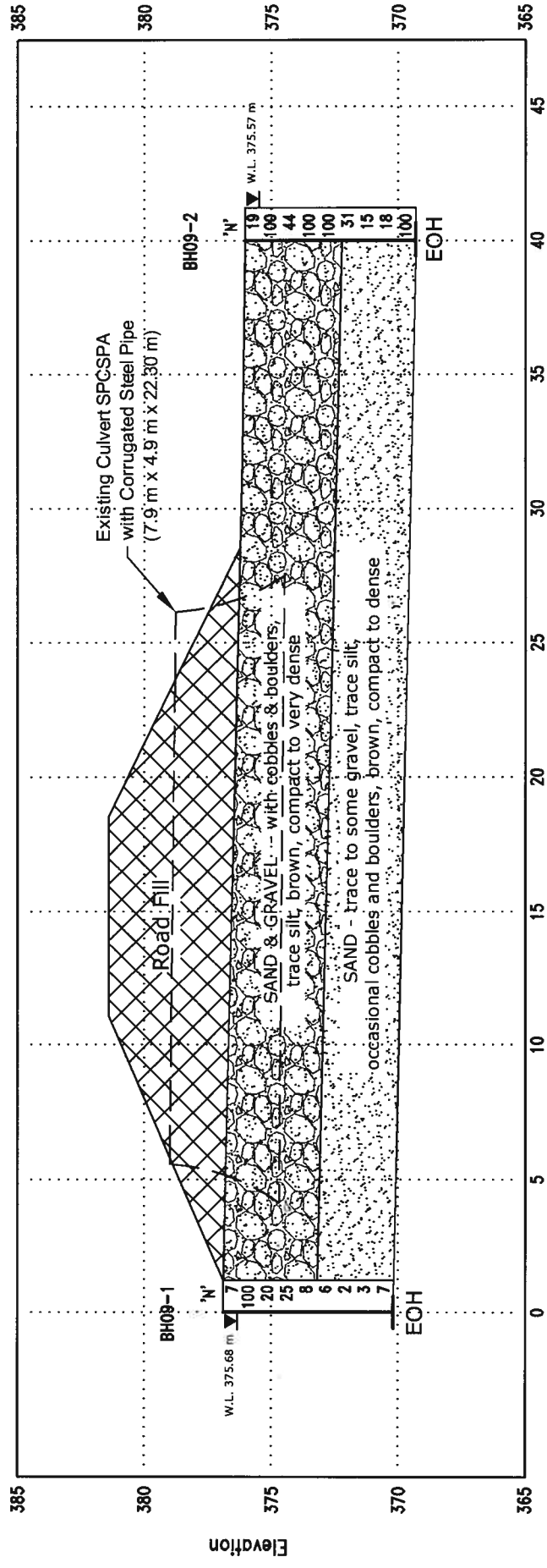
DST
CONSULTING ENGINEERS INC.

DRAWING

METRIC



SECTION A-A'
Scale 1H:1V



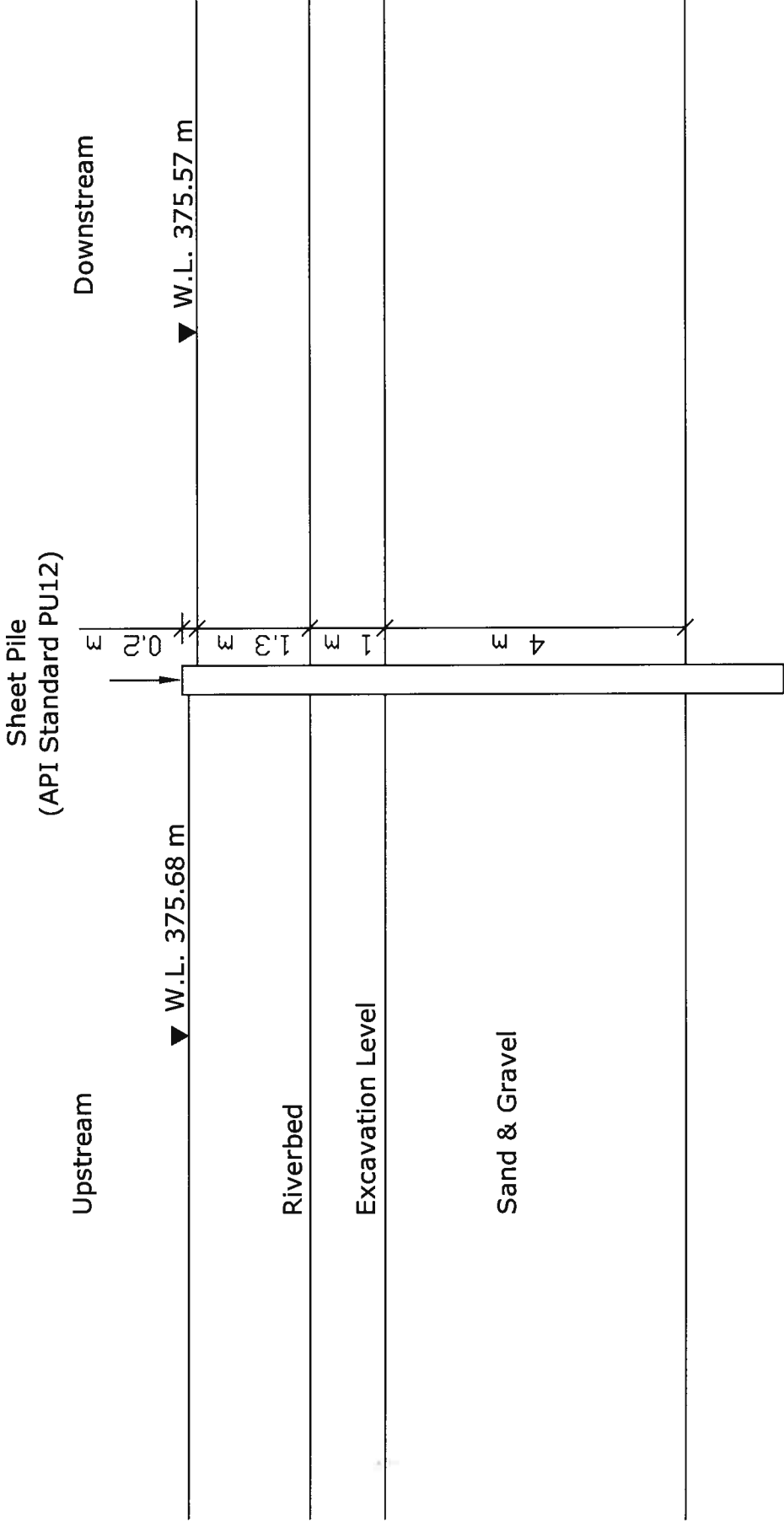
METRIC
DIMENSIONS ARE IN METERS
AND/OR MILLIMETERS UNLESS
OTHERWISE SHOWN. SUGGEST
IN PARENTHESES → METERS

CONT No. 5007-E-0065
GEOGRES No. 41P-42
ASSIGNMENT No. 8

















HIGHWAY 144
Mollie River Culvert Replacement
Cofferdam Geometry

Cofferdam Geometry



NOTES

1. The cofferdam design should account for basal heave due to flow of water beneath the sheet piling
2. The presence of cobbles and boulders that may affect the installation of temporary excavation support system
3. Water level of the Mollie River presents the seasonal variation
4. Historical fluctuation of water level observed from the evidence at inlet and outlet side is EL.376.18 m and EL.376.07 m

LEGEND				
	Borehole			
	Dynamic Cone Penetration Test (DCPT)			
	Borehole with DCPT			
'N'	Blows/0.3m (Std. Pen Test, 475 J/Blow)			
	Water level at time of investigation.			
	Benchmark			
	Fill		Sand	
	Organics		Silt	
	Topsoil		Clay	
	Till		Sand & Gravel	
	Boulders & Cobbles			
No.	Elevation	Station	Offset	
1	376.90	10+000	15.0 m LT	
2	376.04	10+002	27.0 m RT	
3	376.14	10+020	23.0 m LT	
4	375.72	10+019	21.5 m RT	

NOTE:
The boundaries between soil strata have been established only at borehole locations. Between boreholes the boundaries are assumed by interpolation and may not represent actual conditions.

DST
CONSULTING ENGINEERS

DST Consulting Engineers Inc.
605 Hewitson Street
Thunder Bay, ON P7B 5V5
Ph: (807) 623-2929
Fx: (807) 623-1792
Email: thunderbay@dstgroup.com

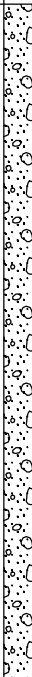


ENCLOSURES

RECORD OF BOREHOLE No BH09-1

1 OF 1

METRIC

W.P. 5007-E-0065 (Assignment #8) LOCATION 10+000 (15 m LT) ORIGINATED BY CS
 DIST 20 m HWY 144 BOREHOLE TYPE Hollow Stem Auger/Washbore COMPILED BY ML
 DATUM Geodetic DATE 2009 10 26 CHECKED BY WS

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W _P	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL				
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa										WATER CONTENT (%)			
								○ UNCONFINED □ QUICK TRIAXIAL	✕ FIELD VANE ★ LAB VANE												
376.9	SAND & GRAVEL - with cobbles and boulders, trace silt, brown, loose to compact		1	SS	7		376										Water level at 0.32 m on Nov. 3, 2009				
																			SPT Value 100 blows/75 mm		
			2	SS	100+																
			3	SS	20														24 69 (7)		
			4	SS	25														30 62 (8)		
	5	SS	8																		
373.2	SAND - trace to some gravel and silt, occasional cobbles and boulders, brown, very loose to loose							373											Auger Refusal at 3.7 m. Start Washboring.		
3.7			6	SS	6																1 96 (3)
			7	SS	2																
			8	SS	3																
			9	SS	7																
370.2	End of Borehole at 6.71 m																				
6.7																					

ON_MOT_CS-TB-011097 MTO ASS#8 - MOLLIE RIVER.GPJ DST_MIN.GDT 31/12/09

✕³, ★³: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

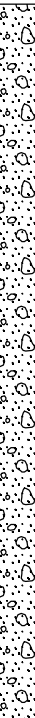

ENCLOSURE 1

RECORD OF BOREHOLE No BH09-2

1 OF 1

METRIC

W.P. 5007-E-0065 (Assignment #8) LOCATION 10+002 (27 m RT) ORIGINATED BY CS
 DIST 20 m HWY 144 BOREHOLE TYPE Hollow Stem Auger/Washbore COMPILED BY ML
 DATUM Geodetic DATE 2009 10 27 CHECKED BY WS

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
								20	40	60	80	100																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	
376.0	SAND & GRAVEL - with cobbles and boulders, trace silt, brown, compact to very dense		1	SS	19		376																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						

ON_MOT_CS-TB-011097 MTO ASS#8 - MOLLIE RIVER.GPJ DST_MIN.GDT 31/12/09

✕³, ★³: Numbers refer to Sensitivity ○ 3% STRAIN AT FAILURE

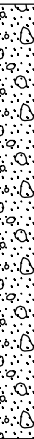


ENCLOSURE 2

RECORD OF BOREHOLE No BH09-3

1 OF 1

METRIC

W.P. 5007-E-0065 (Assignment #8) LOCATION 10+020 (23 m LT) ORIGINATED BY CS
 DIST 20 m HWY 144 BOREHOLE TYPE Hollow Stem Auger/Washbore COMPILED BY ML
 DATUM Geodetic DATE 2009 10 28 CHECKED BY WS

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT w _p	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w _L	UNIT WEIGHT γ 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						20	40	60
376.1	SAND & GRAVEL - with cobbles and boulders, trace silt, brown, compact to dense		1	SS	19		376										Water level at 0.28 m below original surface grade on Nov. 3, 2009 SPT Values 10 blows/150 mm 9 blows/150 mm 10 blows/150 mm 10 blows/0 mm			
																			1 59 (40)	
			2	SS	47		375													
			3	SS	13		374													
373.8	SAND - trace to some gravel, trace silt, occasional cobbles and boulders, brown, compact to dense						374													
2.3																				
					4	SS	17													
					5	SS	30	373												
					6	SS	32	372												
			7	SS	26	371														
			8	SS	41															
370.2	End of Borehole at 5.94 m																			
5.9																				

\times^3, \star^3 : Numbers refer to Sensitivity \bigcirc 3% STRAIN AT FAILURE

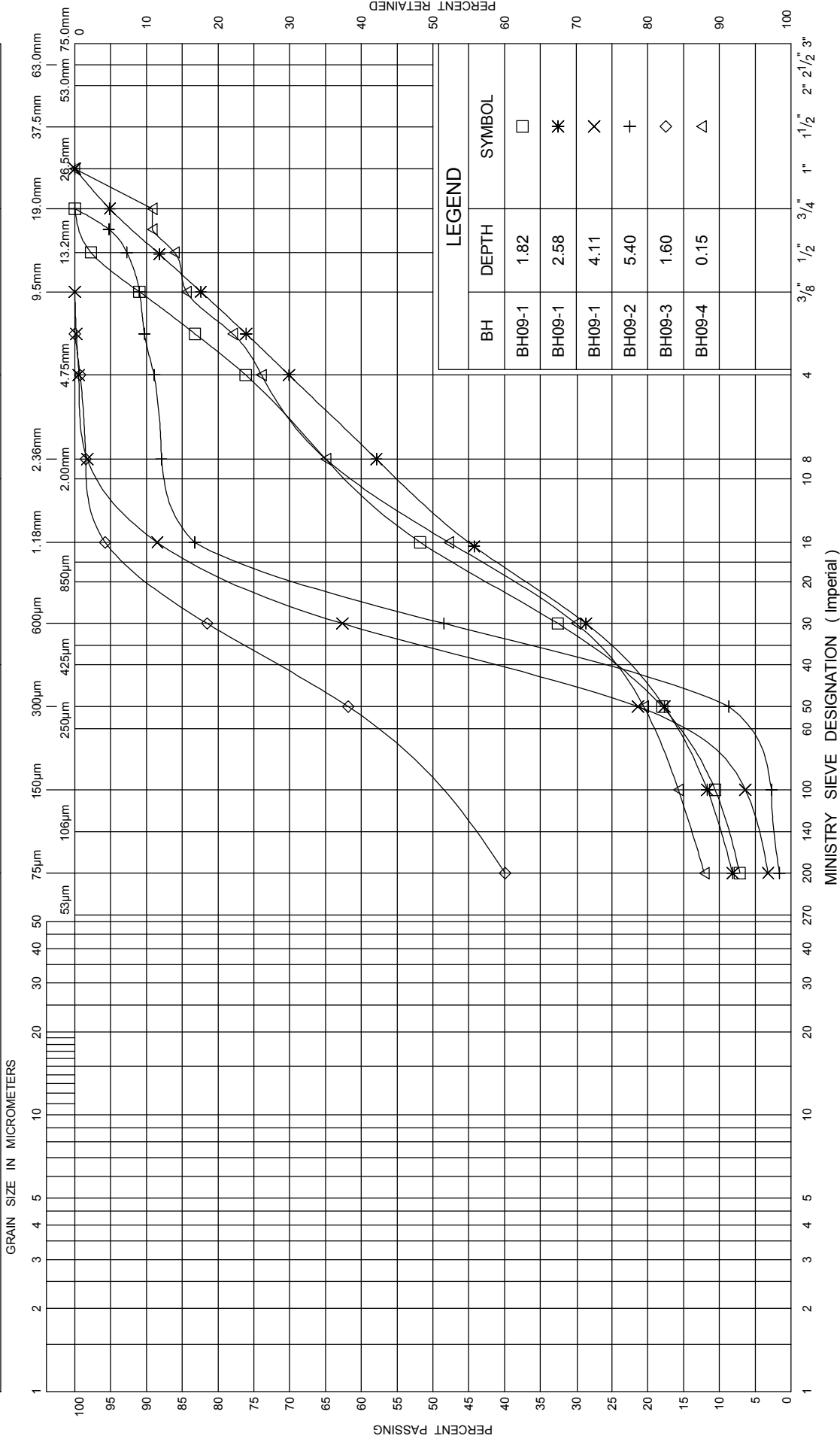
METRIC

✕³, ★³: Numbers refer to Sensitivity ○^{3%} STRAIN AT FAILURE

ON_MOT GS-TB-011097 MTO ASS#8 - MOLLIE RIVER.GPJ DST_MIN.GDT 31/12/09

UNIFIED SOIL CLASSIFICATION SYSTEM

CLAY & SILT		SAND			GRAVEL	
		Fine	Medium	Coarse	Fine	Coarse



GRAIN SIZE DISTRIBUTION

ENCLOSURE 5

5007-E- 0065 (Assignment #8)

HIGHWAY 144

