



**FOUNDATION DESIGN TECHNICAL MEMORANDUM  
for  
SETTLEMENT ANALYSIS AT WATERMAIN CROSSING  
NEW W-S RAMP  
HIGHWAY 404 AND MAJOR MACKENZIE DRIVE  
TOWN OF RICHMOND HILL, ONTARIO  
AGREEMENT NO. 2015-E-0011-002  
GWP NO. 2227-09-00**

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Figure PP-PC-1– Plasticity Chart

**FOUNDATION DESIGN TECHNICAL MEMORANDUM**

for

Settlement Analysis at New W-S Ramp Crossing  
Highway 404 and Major Mackenzie Drive  
Town of Richmond Hill, Ontario  
Agreement No. 2015-E-0011-002  
GWP No. 2227-09-00

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**1. INTRODUCTION**

The Highway 404 W-S Ramp is proposed to be re-aligned at the interchange with Major Mackenzie Drive. As a result, the re-aligned ramp is expected to cross the existing high pressure watermain along Major Mackenzie Drive for a distance of approximately 75 m. Approximately 1.0 m to 2.0 m high new embankment fill is expected to be placed to accommodate the realigned ramp. The purpose of this technical memorandum is to provide an estimate of settlement of the watermain pipe at the realigned ramp under the proposed embankment fill.

The site is located at the southwest quadrant of Highway 404 and Major Mackenzie Drive interchange in York Region, Ontario.

This technical memorandum is based on the subsoil information obtained during the foundation investigation carried out by PML in November 2016.

AECOM Canada Limited (AECOM) has retained Peto MacCallum Ltd. (PML) to carry out the investigation and preparation of this report on behalf of the Ministry of Transportation of Ontario (MTO) as part of the Retainer Assignment Task No. 2015-E-0011-002. The general terms of reference and scope of work for the foundation engineering services are outlined in MTO's Request for Proposal under Work Item No. 2015-E-0011, dated June 2016.

**2. INVESTIGATION PROCEDURES**

The site investigation consisted of drilling one (1) borehole numbered PP-1 near the existing watermain. This borehole was advanced after locating the alignment of the watermain using a vacuum truck test pit. The borehole was drilled at about 1.5 m north of the pipe edge.



The location of the borehole is appropriately shown on the attached Borehole Location Plan, Drawing PP-1

### **3. SUBSURFACE CONDITION**

The subsoil encountered at this site includes 200 mm of topsoil, which extends to elevation 215.8. The topsoil is immediately followed by 1.3 m of hard clayey silt fill to 1.5 m depth (elevation 214.5). The “N”-values measured within this fill ranged from 32 to 41 blows/300 mm, indicating hard consistency. The fill is immediately underlain by hard clayey silt till, which extends to the maximum investigation depth of 6.2 m (elevation 209.8). The SPT values in this till deposit range from 68 blows/300 mm to 50 blows/80 mm, indicating hard consistency.

The gradation test results indicate that this deposit consists of 3% gravel, 35% sand, 44% silt and 18% clay. One Atterberg limit test was performed on selected sample and the results are provided on Figure PP-PC-1. Based on the Atterberg limit values, the soil may be classified as silts of low plasticity (CL-ML) in the Unified Soil Classification System (USCS).

The borehole was observed to be dry during and upon completion of drilling. The groundwater level may be expected to fluctuate due to the influence of precipitation and seasonal changes.

The subsurface conditions encountered during the course of the investigation, together with the field and laboratory test results are shown on the attached Record of Borehole Sheet.

### **4. SETTLEMENT ANALYSIS**

The natural moisture content (6.7%) of the hard clayey silt till below the watermain is observed to be on the dry side of optimum (OMC) of the material and lower than that of the plastic limit (11). This type of soils are considered over consolidated and brittle in nature. In the absence of groundwater, the clayey silt fill or the glacial till is not expected to undergo any consolidation settlement. The total settlement under the proposed embankment will result from the elastic settlements of the approximately 4.0 m deep pipe trench fill and of the glacial till subgrade. The fill above the pipe was assumed to be in a stiff to very stiff condition for the purpose of the settlement calculation. The elastic settlements of the fill and subgrade  $S_i$ , is calculated as follows.



$$S_i = q_o \times B \times (I_i/E)$$

Where,  $S_i$  = Immediate or elastic settlement (m)  
 $q_o$  = average pressure imposed by the proposed embankment, (kPa)  
 $B$  = width of the new embankment (m)  
 $I_i$  = Influence factor  
 $E$  = undrained modulus of ground (MPa)

MATERIAL	MODULUS OF ELASTICITY (MPa)	POISSON RATIO	EMBANKMENT WIDTH (m)	INFLUENCE FACTOR
Stiff to Very Stiff Clayey Silt Fill	20	0.3	8.7	0.4
Hard Clayey Silt Till	50	0.3	8.7	0.4

Based on the analysis, the elastic settlement of the subgrade below the watermain is estimated to be about 5 mm.

The existing trench fill is expected to undergo a compression of 8 mm. It is also noted that the proposed 1.0 m to 2.0 m high embankment fill may be expected to settle by about 0.5% to 1.0% of the fill height.

In general, the differential settlement between the loaded and the unloaded parts of the pipe is 5 mm and will occur within distance of about 30 m.



## **5. DISCUSSION**

We recommend that the pipe stress due to the estimated settlement be evaluated by the pipe supplier/designer.

It is our understanding that MTO requires that watermains be steel lined where they cross beneath highway traffic including the ramps. Consequently, the use of alternative pipe protection methods, or no protection, should be determined by MTO.

The tolerance or acceptable limit for the watermain in place will depend on the condition and type of pipe and associated connections. The supplier of the product or the designer should be consulted for this information.

The elastic compression is expected to occur upon completion of placement of new fill. The existing water main is in place for a longtime and the condition of the pipe should be assessed by a mechanical engineer or the product supplier. However, the failure of the pipe may lead to closure of the ramp. The risk of the pipe failure is failure of embankment and lose of property/life. At the minimum, the ramp would be closed for the pipe replacement/repair.



## 6. CLOSURE

This Foundation Technical Memorandum was prepared by Mr. M. Khorsand, BSc, EIT., and reviewed by Mr. M. Vasavithasan, M.Sc.Eng., P.Eng., Senior Engineer. Mr. C. M. P. Nascimento, P. Eng., Project Manager and MTO Designated Principal Contact, conducted an independent review of the technical memo.

Yours very truly

Peto MacCallum Ltd.

Mansoor Khorsand, BSc, EIT.  
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NOTE: Mr. Vasavithasan, P.Eng.  
is currently on vacation and  
will sign this document  
upon his return

*Chase instant*  
Feb 2, 2017



Carlos M.P. Nascimento, P.Eng  
Project Manager and  
MTO Designated Principal Contact

## EXPLANATION OF TERMS USED IN REPORT

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

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

SOILS ARE DESCRIBED BY THEIR COMPOSITION AND CONSISTENCY OR DENSENESS.

**COMPOSITION:** SECONDARY SOIL COMPONENTS ARE DESCRIBED ON THE BASIS OF PERCENTAGE BY MASS OF THE WHOLE SAMPLE AS FOLLOWS:

PERCENT BY MASS	0 - 10	10 - 20	20 - 30	30 - 40	> 40
	TRACE	SOME	WITH	ADJECTIVE (SILTY)	AND (AND SILT)

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

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

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

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

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

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

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

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

**JOINTING AND BEDDING:**

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

## ABBREVIATIONS AND SYMBOLS

### FIELD SAMPLING

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

### STRESS AND STRAIN

$u_w$	kPa	PORE WATER PRESSURE
$u$	1	PORE PRESSURE RATIO
$\sigma$	kPa	TOTAL NORMAL STRESS
$\sigma'$	kPa	EFFECTIVE NORMAL STRESS
$\tau$	kPa	SHEAR STRESS
$\sigma_1, \sigma_2, \sigma_3$	kPa	PRINCIPAL STRESSES
$\epsilon$	%	LINEAR STRAIN
$\epsilon_1, \epsilon_2, \epsilon_3$	%	PRINCIPAL STRAINS
E	kPa	MODULUS OF LINEAR DEFORMATION
G	kPa	MODULUS OF SHEAR DEFORMATION
$\mu$	1	COEFFICIENT OF FRICTION

### MECHANICAL PROPERTIES OF SOIL

$m_v$	kPa <sup>-1</sup>	COEFFICIENT OF VOLUME CHANGE
$C_c$	1	COMPRESSION INDEX
$C_s$	1	SWELLING INDEX
$C_\alpha$	1	RATE OF SECONDARY CONSOLIDATION
$c_v$	m <sup>2</sup> /s	COEFFICIENT OF CONSOLIDATION
H	m	DRAINAGE PATH
$T_v$	1	TIME FACTOR
U	%	DEGREE OF CONSOLIDATION
$\sigma'_{v0}$	kPa	EFFECTIVE OVERBURDEN PRESSURE
$\sigma'_p$	kPa	PRECONSOLIDATION PRESSURE
$\tau_f$	kPa	SHEAR STRENGTH
$c'$	kPa	EFFECTIVE COHESION INTERCEPT
$\phi'$	-°	EFFECTIVE ANGLE OF INTERNAL FRICTION
$c_u$	kPa	APPARENT COHESION INTERCEPT
$\phi_u$	-°	APPARENT ANGLE OF INTERNAL FRICTION
$\tau_R$	kPa	RESIDUAL SHEAR STRENGTH
$\tau_r$	kPa	REMOULDED SHEAR STRENGTH
$S_i$	1	SENSITIVITY = $\frac{c_u}{\tau_r}$

### PHYSICAL PROPERTIES OF SOIL

$\rho_s$	kg/m <sup>3</sup>	DENSITY OF SOLID PARTICLES	n	1, %	POROSITY	$e_{max}$	1, %	VOID RATIO IN LOOSEST STATE
$\gamma_s$	kN/m <sup>3</sup>	UNIT WEIGHT OF SOLID PARTICLES	w	1, %	WATER CONTENT	$e_{min}$	1, %	VOID RATIO IN DENSEST STATE
$\rho_w$	kg/m <sup>3</sup>	DENSITY OF WATER	$S_r$	%	DEGREE OF SATURATION	$I_D$	1	DENSITY INDEX = $\frac{e_{max} - e}{e_{max} - e_{min}}$
$\gamma_w$	kN/m <sup>3</sup>	UNIT WEIGHT OF WATER	$w_L$	%	LIQUID LIMIT	D	mm	GRAIN DIAMETER
$\rho$	kg/m <sup>3</sup>	DENSITY OF SOIL	$w_p$	%	PLASTIC LIMIT	$D_n$	mm	n PERCENT - DIAMETER
$\gamma$	kN/m <sup>3</sup>	UNIT WEIGHT OF SOIL	$w_s$	%	SHRINKAGE LIMIT	$C_u$	1	UNIFORMITY COEFFICIENT
$\rho_d$	kg/m <sup>3</sup>	DENSITY OF DRY SOIL	$I_p$	%	PLASTICITY INDEX = $w_L - w_p$	h	m	HYDRAULIC HEAD OR POTENTIAL
$\gamma_d$	kN/m <sup>3</sup>	UNIT WEIGHT OF DRY SOIL	$I_L$	1	LIQUIDITY INDEX = $\frac{w - w_p}{I_p}$	q	m <sup>3</sup> /s	RATE OF DISCHARGE
$\rho_{sat}$	kg/m <sup>3</sup>	DENSITY OF SATURATED SOIL	$I_C$	1	CONSISTENCY INDEX = $\frac{w_L - w}{I_p}$	v	m/s	DISCHARGE VELOCITY
$\gamma_{sat}$	kN/m <sup>3</sup>	UNIT WEIGHT OF SATURATED SOIL	DTPL		DRIER THAN PLASTIC LIMIT	i	1	HYDRAULIC GRADIENT
$\rho'$	kg/m <sup>3</sup>	DENSITY OF SUBMERGED SOIL	APL		ABOUT PLASTIC LIMIT	k	m/s	HYDRAULIC CONDUCTIVITY
$\gamma'$	kN/m <sup>3</sup>	UNIT WEIGHT OF SUBMERGED SOIL	WTP		WETTER THAN PLASTIC LIMIT	j	kN/m <sup>3</sup>	SEEPAGE FORCE
e	1, %	VOID RATIO						



**RECORD OF BOREHOLE No PP-1**

1 of 1

**METRIC**

G.W.P. 2227-09-00 LOCATION Co-ords: 4 860 257.7 N ; 314 231.6 E ORIGINATED BY S.A.  
DIST Central BOREHOLE TYPE Continuous Flight Solid Stem Augers COMPILED BY M.Kh.  
DATUM Geodetic HWY 404 DATE November 25, 2016 CHECKED BY M.V.

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS *	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT w <sub>p</sub>	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa									
216.0	Ground Surface							20	40	60	80	100					
215.8	Topsoil																
0.2	Clayey silt, with sand rootlets		1	SS	41		215										
	Hard      Grey/      Moist brown (FILL)		2	SS	32												
214.5	Clayey silt, sandy trace gravel		3	SS	68		214										
1.5	Hard      Brown      Moist		4	SS	50/10cm												
	(TILL)		5	SS	50/10cm		213										
							212										
			6	SS	50/8cm		211										
209.8	End of borehole		7	SS	50/13cm		210										
6.2																	
	*      Borehole dry upon completion of drilling																



LEGEND

- Borehole
- Cone
- Borehole and Cone
- N Blows/0.3m (Std. Pen Test, 475 J/blow)
- CONE Blows/0.3m (60 Cone, 475 J/blow)
- WL at time of investigation October 2016
- WH Penetration due to weight of hammer and rod
- \* Water level not established
- Head
- ARTESIAN WATER Encountered
- PIEZOMETER

BH No	ELEVATION	NORTHINGS	EASTINGS
PP-1	216.0	4 860 257.7	314 231.6

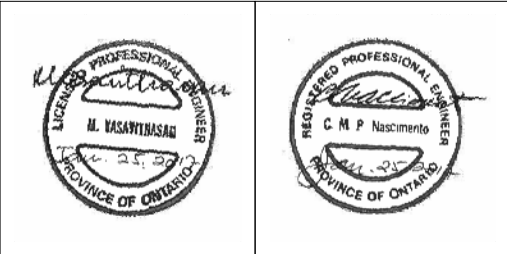
NOTE

The boundaries between soil strata have been established only at Borehole locations. Between Boreholes the boundaries are assumed from geological evidence.

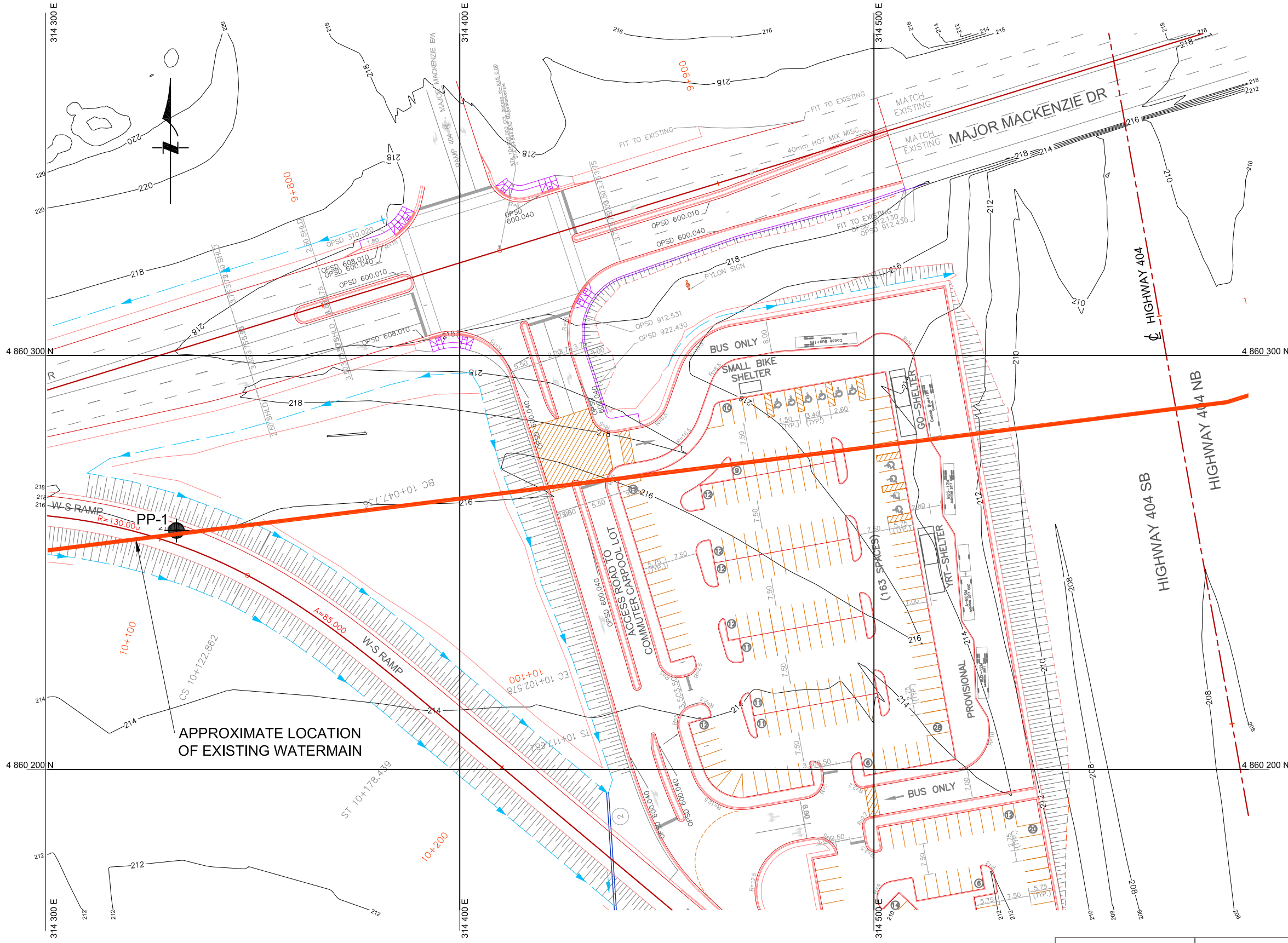
REVISIONS	DATE	BY	DESCRIPTION

HWY No	404	DIST	CENTRAL
SUBM'D	NA	CHECKED	M.Kh.
DRAWN	NA	CHECKED	M.V.
DATE	JAN. 25, 2017	APPROVED	C.N.
SITE		DWG	PP-1

Geocres No. 30M14-461

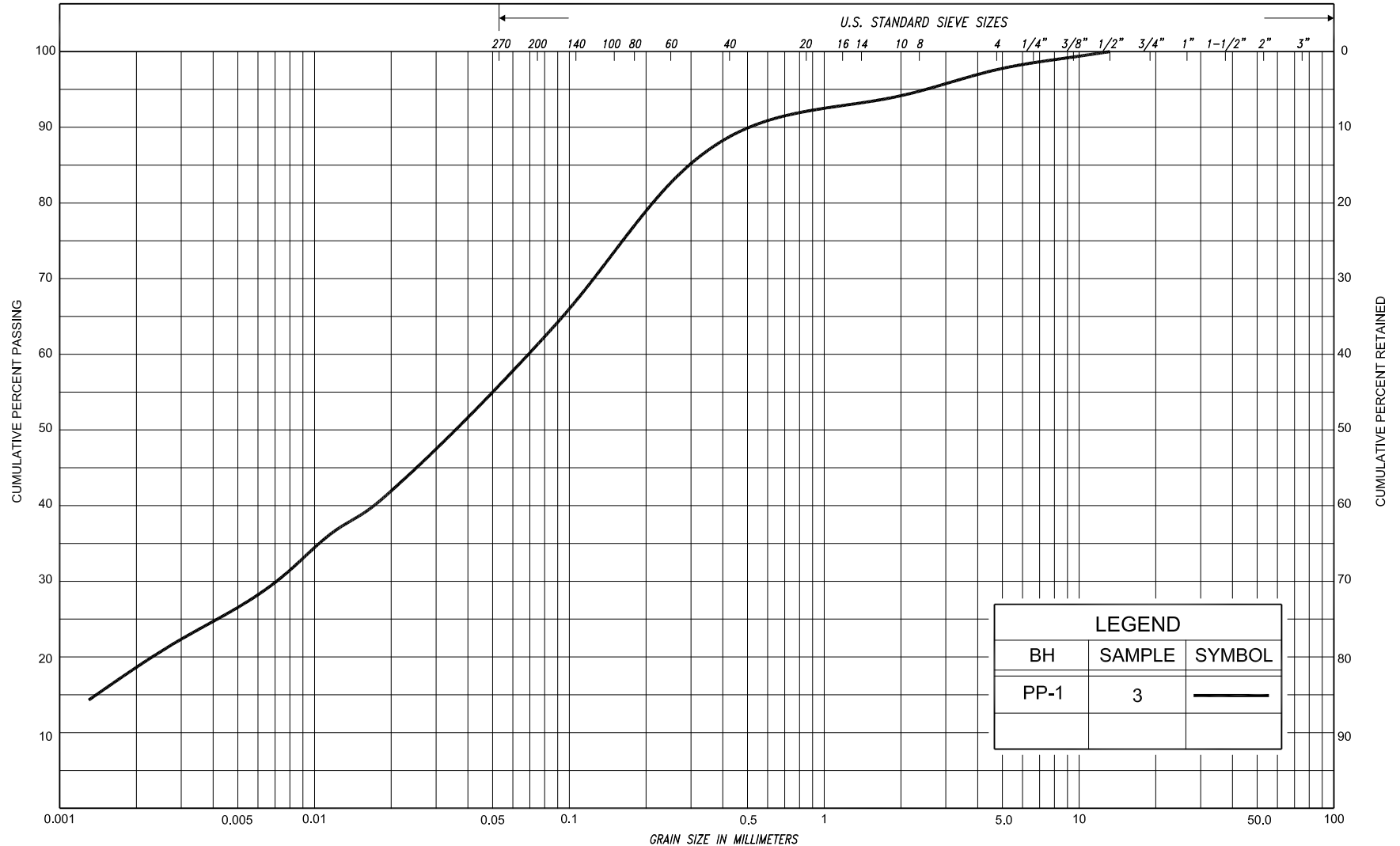


REF AECOM Drawings: ACAD-404 MM CCL\_plan.dwg and ACAD-404-MM CCL\_add BHs\_foundations.dwg undated



NOTES:

- THIS DRAWING SHOULD BE READ IN CONJUNCTION WITH THE TEXT OF REPORT AND RECORD OF BOREHOLE LOGS.
- THIS DRAWING IS FOR SUBSURFACE INFORMATION ONLY. SURFACE DETAILS AND FEATURES ARE FOR CONCEPTUAL ILLUSTRATION.
- DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS ARE IN KILOMETRES AND METRES.



SILT & CLAY					FINE		MEDIUM		COARSE	GRAVEL				COBBLES	UNIFIED		
					SAND												
CLAY	FINE		MEDIUM		COARSE	FINE		MEDIUM		COARSE		GRAVEL				COBBLES	M.I.T.
	SILT																
CLAY		SILT			V. FINE	FINE	MED.	COARSE		GRAVEL							U.S. BUREAU
					SAND												



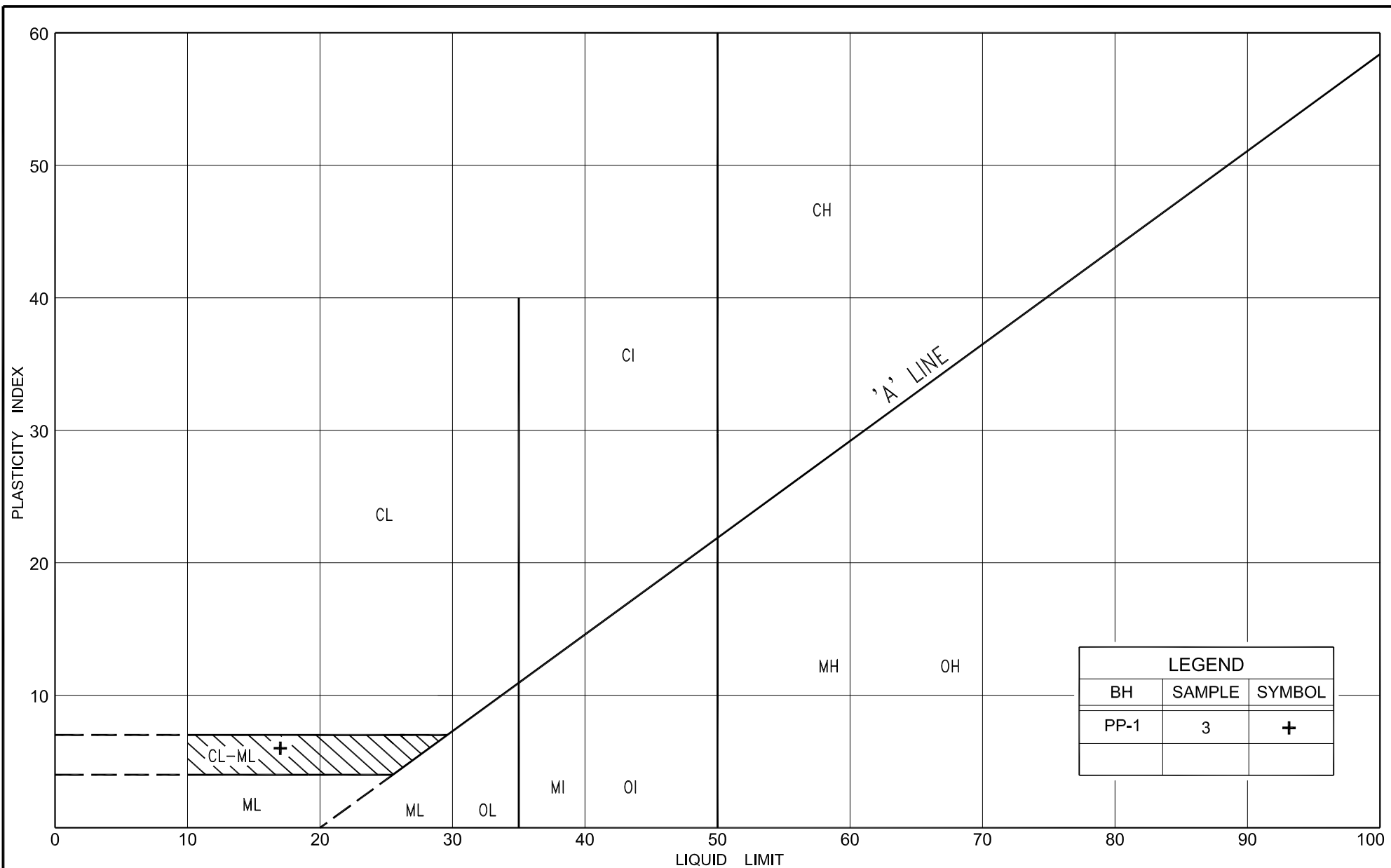
## GRAIN SIZE DISTRIBUTION

CLAYEY SILT, SANDY, trace gravel (CL-ML)

FIG No. PP-GS-1

HWY 404

TASK # 2015-E-0011 - 002



**PLASTICITY CHART**  
CLAYEY SILT, SANDY, trace gravel (CL-ML)

FIG No. PP-PC-1

HWY 404

TASK # 2015-E-0011 - 002