Los Angeles County
Metropolitan Transportation Authority

Westside Purple Line Extension Project, Section 2

Contract C1120

Geotechnical Design Memoranda (GDM)

Amendment 8: February 2, 2016
Amendment 3: November 2, 2015

U.S. Department of Transportation
Federal Transit Administration

Metro

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REACHES 4 AND 5

APPENDIX C REACHES 4 AND 5

MEMO

To **Ms. Amanda Elioff, P.E.**
Parsons Brinckerhoff

Date **Amendment 3: November 2, 2015**
Amendment 8: February 2, 2016

Project No.
4953-11-1423
(PB Task 52.05.010.01.01.03)

Subject **Geotechnical Design Memorandum – Section 2, Tunnel Reaches 4 and 5**
Westside Purple Line Extension
Beverly Hills and Los Angeles, California

This Geotechnical Design Memorandum (GDM) for Tunnel Reaches 4 and 5 has been prepared as part of the Advanced Preliminary Engineering (Adv. PE) phase of the Wilshire/La Cienega to Century City Constellation Station portion (Section 2) of the proposed Westside Purple Line Extension (~~WLPE~~**WPLE**) project for the Los Angeles County Metropolitan Transportation Authority (Metro).

The results of the Advanced Conceptual Engineering (ACE), Preliminary Engineering (PE) and ~~limited~~ Adv. PE phase investigations performed for the two tunnel reaches were presented in a Geotechnical Data Report (GDR) dated September **1,** 2015~~. Additional~~ **which is now superseded by GDR-Amendment 8, dated February 2016. The February 2016 GDR included the results from additional** explorations ~~are planned~~ **recently performed** in the Adv. PE phase within the City of Beverly Hills portion of Section 2. ~~A supplemental GDM is planned to incorporate~~**This GDM includes** the additional data **and supersedes the September 2015 GDM**~~ when obtained. The preliminary recommendations and conclusions presented in this GDM may change when additional data from Adv. PE phase are evaluated.~~ **.** In case of any conflict between the interpretation of data or preliminary recommendations presented in this report and the Geotechnical Baseline Report (GBR), the data and preliminary recommendations presented in the GBR will prevail. The Design-Build (D-B) contractor should perform an independent evaluation of the data contained in the GDR and the preliminary recommendations presented herein and provide parameters for final design.

This GDM presents interpretation of the field and laboratory data obtained in the ACE, PE and ~~available~~ Adv. PE phase investigations. This GDM presents preliminary geotechnical recommendations for tunnel design. It should be noted that this report does not include recommendations for the Wilshire/Rodeo Station, which is between Tunnel Reaches 4 and 5**, or for the Century City Constellation Station**; the recommendations for the Wilshire/Rodeo ~~Station~~**and Century City Constellation Stations** are included in a separate GDM.

The geotechnical parameters presented in this report reflect the design team's judgment of subsurface conditions and ground behavior based on the data available and the construction means and methods anticipated. The design data presented herein were established by considering available geologic and

Amec Foster Wheeler
6001 Rickenbacker Road
Los Angeles, Calfiornia 90040, USA
Ph: +1 (323) 889-5300
Fax +1 (323) 721-6700
www.amecfw.com

geotechnical data, together with past construction experience and anticipated construction methods in similar ground conditions. Development of the project design recommendations required interpretation of the data obtained from various sources, including: geologic maps; samples from hollow stem auger, rotary-wash, and core borings; other borings previously conducted for nearby projects; geophysical surveys; and in-situ and laboratory tests, as well as the consideration of information from previous construction projects completed in similar geologic conditions. While actual conditions encountered in the field are expected to be within the range of conditions discussed herein, the earth material and groundwater conditions encountered may vary from those described in this report at locations other than those locations where explorations were performed. In addition to the specific conditions described herein, the ground behavior will also depend on the construction sequence and methods employed, as well as the contractor's equipment and workmanship. The project design, therefore, assumes that the construction methods and level of workmanship will be consistent with those that can reasonably be expected from an experienced and qualified contractor.

It is our understanding that this GDM is being prepared for inclusion in the Request for Proposal Package being prepared for a Design-Build Contract for Section 2.

It is a pleasure to be of continuing professional service to you. -Please call if you have any questions or if we can be of further assistance.

Sincerely,

Amec Foster Wheeler Environment & Infrastructure, Inc.

Hari Ponnaboyina, P.E.
Senior Engineer

Martin B. Hudson, Ph.D., G.E.
Principal Engineer / Project Manager

Perry A. Maljian, G.E.
Senior Principal Engineer/
Senior Vice President

SUMMARY OF REVISIONS TO THE NOVEMBER 2, 2015 GDM (Amd 3)

Chapter/Figure/Table	Revisions	Page Nos.
Cover page	Added a note to state that September 2015 GDR and GDM are superseded by February 2016 versions	
	Added a note to state separate GDM is submitted for Constellation Station	
1.0	Rewrote description of Reach 5 limits	1
	Revision to clarify that stated tunnel interior diameter is the minimum diameter	1
	Changed reference of tunnel profile from September to December 2015	1
2.0	Capitalized geologic formation names	1, 2
	Noted that groundwater data reported is from ACE, PE and Adv. PE phase investigations	1
	Corrected hydrostatic head above tunnel invert in Reaches 4 and 5	2
3.0	Changed term bulk density to total density	2
Table 3-1	Revised engineering parameters to include Adv. PE phase investigation data	5
Table 3-2	Revised engineering parameters to include Adv. PE phase investigation data	6, 7
4.0	Revised section heading and added a note that tunnel should be designed for potential fault offset	9
4.1	Revisions to state suspension logging data was used to evaluate dynamic soil properties	9
	Defined abbreviations for ODE and MDE events; removed full names for dynamic soil properties and used abbreviations instead	9
4.2	Revisions to state suspension logging data was used in ground motion evaluation	9
	Used abbreviations for PGA and PGV	9
	Defined abbreviation GMPE	10
	Revised sentence for clarity	10
Table 4-1	Revised table with new values for the revised tunnel depths per December 2015 profile and added estimated values for boring with new shear wave data	10
	Revised footnotes for clarity	10
4.3	Added new section for fault displacement	11
5.0	Revised extensometers to say multi-point borehole extensometers	11
7.0	Added 2016 GDR and EDR references to bibliography	13
Plates	Revised plates to show December 2015 tunnel profile and data collected from 2015 Adv. PE phase borings in Beverly Hills	

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Plate 4: Seismic Design Parameters (Reaches 4 and 5)

1.0 TUNNEL REACH DESCRIPTIONS

This Geotechnical Design Memorandum (GDM) has been prepared for Tunnels Reaches 4 and 5 within Section 2 of the Metropolitan Transportation Authority (Metro) Westside Purple Line Extension (WPLE) project, which is about 2.19 miles long and runs from the proposed Tail Tracks at the west end of the Wilshire / La Cienega station at the western end of the WPLE Section 1 to the proposed Century City Constellation Station. Section 2 lies within two local jurisdictions: the City of Los Angeles and the City of Beverly Hills. The tunnels generally follow an east-west alignment beneath Wilshire Boulevard ~~and~~ **from Tail Tracks in Section 1 to Linden Drive and then sweeps westward into Century City beneath residential buildings along Lasky Drive, the Beverly Hills High School campus and** Constellation Boulevard ~~with two stations: the Wilshire/Rodeo Station and~~ **to the proposed** Century City Constellation Station. ~~The northeast-southwest tending portion of tunnel alignment between Wilshire and Constellation Boulevards roughly follows Lasky Drive and also runs below the Beverly Hills High School campus.~~

The dual tunnels will have ~~an~~**a minimum** interior diameter of 18-foot-10 inches. For the purpose of this GDM, the excavated tunnel bore diameter was considered to be about 22 feet. The tunnel alignment considered for this GDM is based on plans dated ~~September~~**December** 2015 and included in the Geotechnical Data Report (Metro, ~~September 2015~~**February 2016**).

A tunnel reach is defined as the tunnel extending between any two stations. Section 2 of the WPLE project has two tunnel reaches. A description of the two reaches is presented below:

- Tunnel Reach 4 is the portion of the tunnel alignment between the proposed Tail Tracks at the west end of Section 1 of the WPLE (just west of the proposed Wilshire/La Cienega Station) and the proposed Wilshire/Rodeo Station. This reach is about 1.09 miles long with the depth to tunnel invert varying from about 65 to 110 feet below ground surface (bgs).
- Tunnel Reach 5 is the portion of the tunnel alignment between the proposed Wilshire/Rodeo and Century City Constellation Stations. This reach is about 1.1**0** miles long with the depth to tunnel invert varying from 80 to 135 bgs.

In addition, tunnel cross-passages that connect eastbound and westbound tunnels are typically spaced at about 800 feet along the tunnel alignment.

2.0 GEOTECHNCIAL INPUT FOR TUNNEL DESIGN

Reach 4

Along Tunnel Reach 4, the tunnel will be excavated in the ~~older alluvium~~**Older Alluvium** and San Pedro Formation and mixed-face conditions of these two materials. The anticipated ground conditions in the tunnel excavation along different stretches of Reach 4 are presented on Plate 1-1.

Based on groundwater conditions measured during the ACE**, PE** and **Adv.** PE **investigations** phases (2009 through **2015)**~~2011) and in the 2015 limited Adv. PE phase investigation,~~**),** and considering the planned

tunnel diameter and tunnel invert depth, the tunnel invert is expected to be under a hydrostatic head of about ~~15~~**35** to 85 feet **using the shallowest groundwater depth based on either perched water or potentiometric surface**.

Reach 5

Along Tunnel Reach 5, the tunnel will be excavated predominantly in ~~older alluvium~~**Older Alluvium** and to some extent in Lakewood Formation as well as in mixed-face conditions of ~~older alluvium/San Pedro~~**Older Alluvium/Lakewood** Formation and Lakewood/San Pedro Formations. The anticipated ground conditions in the tunnel excavation along different stretches of Reach 5 are presented in Plate 1-2.

Based on groundwater conditions measured during the ACE**, PE** and **Adv.** PE **investigations** phases (2009 through **2015)**~~2011) and in the 2015 limited Adv. PE phase investigation,~~**,** and considering the planned tunnel diameter and tunnel invert depths, the tunnel invert is expected to be under a hydrostatic head of about ~~15~~**40** to ~~95~~**100** feet **using the shallowest groundwater depth based on either perched water or potentiometric surface**.

3.0 PRELIMINARY ENGINEERING PROPERTIES OF PRINCIPAL GEOLOGIC UNITS

Preliminary engineering properties were compiled in the principal geologic units anticipated in the tunnel excavations and a statistical analysis was performed to estimate the lower bound, upper bound and recommended values for the properties. The properties were evaluated by sub-dividing each geologic unit into fine-grained and coarse-grained materials before performing the statistical analysis. The preliminary engineering and index properties of interest for Tunnel Reaches 4 and 5 are listed below.

- SPT Blow Counts
- Moisture Content
- Dry Density
- ~~Bulk~~**Total** Density
- Void Ratio
- Degree of Saturation
- Fines Content
- Specific Gravity
- Liquid Limit
- Plasticity Index
- Compression Index

- Recompression Index
- Expansion/Collapse
- At-rest Lateral Earth Pressure Coefficient (K_0) (in-situ measured earth pressure condition)
- Effective Cohesion and Friction Angle
- Undrained Cohesion and Friction Angle
- Elastic Parameters – Young's Modulus and Poisson's Ratio
- Hydraulic Conductivity
- Soil Abrasion Test Value
- Corrosion Potential (Minimum Resistivity, pH, Chloride Content, Sulfate Content)

The estimated range (lower bound, upper bound) and recommended values of the properties listed above for Tunnel Reaches 4 and 5 are presented in Tables 3-1 and 3-2, respectively. More detailed information is found in the Geotechnical Data Report (GDR) for Tunnel Reaches 4 and 5.

3.1 Particle Size Distribution and Clogging Potential of Materials in Tunnel Zone

The particle size distribution curves from the gradation tests performed on materials anticipated within the tunnel excavation for Tunnel Reach 4 are presented on Plates 2-1 through 2-3. The corresponding gradation curves for materials anticipated within tunnel excavation for Tunnel Reach 5 are presented on Plates 3-1 through 3-4.

Using the Atterberg limit tests, an evaluation was made for clogging potential of soils (Thewes and Burger, 2005) anticipated in tunnel excavation for Tunnel Reaches 4 and 5. The results of the clogging potential analysis for Tunnel Reaches 4 and 5 are presented in Plates 2-4 and 3-5, respectively. Based on the evaluation, the materials expected in tunnel excavation for Tunnel Reaches 4 and 5 are anticipated to have medium to high clogging potential.

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Table 3-1: Preliminary Engineering Properties of Principal Geologic Units for Tunnel Reach 4

Parameter	2009 through 2015 Geotechnical and Environmental Investigations Estimated Range of Engineering Parameters							
Geologic Unit	Quaternary Older Alluvium (Qalo)				San Pedro Formation (Qsp)			
	Fine-Grained		Coarse-Grained		Fine-Grained		Coarse-Grained	
USCS Soil Classification	CL, CH, ML		SW,SW-SM,SP,SP-SM,SM,SC		CL, CH, CL-ML, ML		SW-SM, SP, SP-SM, SM	
Engineering Properties	**Range[1]**	**Recommended[1]**	**Range[1]**	**Recommended[1]**	**Range[1]**	**Recommended[1]**	**Range[1]**	**Recommended[1]**
SPT Blowcounts "N"-Value[2]	~~19~~**12** to 100	~~33~~**30**	28 to 60	~~43~~**40**	~~13~~**11** to 93	~~44~~**37**	~~23~~**20** to 100	50
Moisture Content (%)	12 to 38	~~20~~**21**	~~5~~**1** to 27	13	6 to 44	~~23~~**22**	~~13~~**10** to 33	~~20~~**18**
Dry Density (pcf)	97 to 121	108	93 to 123	~~111~~**110**	83 to ~~123~~**126**	106	93 to 120	~~106~~**108**
Total Density (pcf)	~~117~~**123** to ~~138~~**139**	~~129~~**130**	106 to ~~137~~**139**	~~125~~**127**	115 to 142	128	118 to 136	128
Void Ratio	0.~~57~~**35** to 0.~~66~~**67**	0.~~63~~**58**	0.33 to 0.54	0.44	0.~~51~~**34** to 1.02	0.~~76~~**66**	0.39 to 0.79	0.~~59~~**57**
Degree of Saturation (%) #	69 to ~~97~~**100**	~~86~~**91**	~~58~~**80** to 100	~~84~~**89**	~~87 to 100~~*	~~95~~*	~~65 to 100~~*	~~91~~*
Fines Content (%)	50 to ~~72~~**89**	~~63~~**67**	7 to ~~45~~**46**	~~26~~**28**	53 to 99	75	~~18~~**1** to 48	~~32~~**31**
Specific Gravity	2.~~76~~**49** to 2.98	2.~~87~~**74**	2.56 to 2.~~70~~**72**	~~2.63~~**3**	2.51 to 2.72	2.62	2.66 to 2.82	2.73
Liquid Limit (%)	32 to ~~47~~**49**	~~38~~**39**	~~29~~**28** to 39	~~34~~**32**	~~35~~**31** to 84	~~48~~**43**	33 to ~~35~~**38**	~~34~~**35**
Plasticity Index (%)	15 to ~~23~~**33**	~~19~~**21**	~~NP~~**10** to 16	13	11 to 56	~~25~~**23**	~~NP~~**11** to ~~19~~**22**	~~15~~**17**
Modified Compression Index (~~Cc~~**Cce**)	**0.09**~~***~~**	**0.09**~~***~~**	~~0.098***~~	~~0.098***~~	~~*~~**0.09 to 0.13**	**0.11**~~*~~**	~~*~~**0.07****	**0.07**~~*~~**
Modified Recompression Index (~~Cr~~**Cre**)	~~*~~**0.02****	~~*~~**0.02****	~~0.007***~~	~~0.007***~~	~~*~~**0.02**	~~*~~**0.02**	~~*~~**0.01****	~~*~~**0.01****
Collapse Potential (%)	*	*	~~0.03***~~	~~0.03***~~	*	*	~~0.01 to 0.17*~~	~~0.07*~~
Expansion Potential (%)	*	*	*	*	*	*	~~-*0.09**~~	~~-*0.09**~~
At-Rest Lateral Earth Coefficient, K_o	0.~~45~~**57** to 0.~~68**~~**69**	0.~~57**~~**63**	~~*~~**0.60****	~~*~~**0.60****	0.~~62 to 0.79~~**55****	0.~~71~~**55****	~~*~~**0.66****	~~*~~**0.66****
Effective Cohesion from Direct Shear Test [3] (psf)	100 to 400	250	950**	950**	**100** to 2,**400**	1,130	**350** to 1,~~100)~~**200**	758
Effective Friction Angle from Direct Shear Test [3] (degrees)	25 to 28	27	**34****	34**	21 to 33	28	**25** to 36	32
Effective Cohesion from Triaxial Test [4] (psf)	400~~**~~ **to 1,400**	~~400**~~**900**	~~*~~**1,300****	~~*~~**1,300****	*	*	*	*
Effective Friction Angle from Triaxial Test [4] (degrees)	28~~**~~ **to 33**	~~28**~~**31**	**31**~~***~~**	**31**~~***~~**	*	*	*	*
Undrained Cohesion from Triaxial Test [4] (psf)	50~~**~~ **to 700**	~~50**~~**375**	~~*~~**100****	~~*~~**100****	*	*	*	*
Undrained Friction Angle from Triaxial Test [4] (degrees)	24~~**~~ **to 30**	~~24**~~**27**	~~*~~**28****	~~*~~**28****	*	*	*	*
Young's Modulus from **Empirical** Correlations [5] (ksf)	~~869~~**1,375** to ~~8,505~~**3,369**	~~3,893~~**1,891**	1,754 to 3,759	2,~~757~~**623**	~~2,085~~**1,100** to ~~6,864~~**5,569**	~~4,210~~**2,708**	1,817 to 6,266	3,~~273~~**348**
Young's Modulus from Triaxial Test [6] (ksf)	1,810~~**~~ **to 3,240**	~~1,810**~~**2,525**	~~*~~**3,682****	~~*~~**3,682****	*	*	*	*
Poisson's Ratio	0.~~35~~**33** to 0.~~42~~**37**	0.~~38~~**35**	0.31 to 0.~~40~~**31**	0.~~35~~**31**	0.~~34~~**31** to 0.~~45~~**39**	0.~~39~~**35**	0.~~30~~**29** to 0.~~45~~**37**	0.~~34~~**32**
Hydraulic Conductivity (ft/day) [7]	10^{-7} to 10^{-1} ^	10^{-4} ^	10^{-2} to 10^{3} ^	10 ^	10^{-7} to 10^{-1} ^	10^{-4} ^	10^{-1} to 10^{2} ^	10^
Soil Abrasion Test Value	~~5***~~	~~5***~~	~~8~~**14** to ~~14~~**38**	~~11~~**26**	~~*~~**9 to 13**	~~*~~**11**	~~*~~**9 to 25**	~~*~~**16**
Corrosivity Results [8]**:**								
Minimum Resistivity (ohm-cm)	~~1,560~~**811** to 2,800	~~1,560~~**811**	3,440 to 4,400	3,440	880 to 2,360	880	1,~~920**~~**130 to 2,886**	1,~~920**~~**130**
pH	~~8.0~~**7.5** to 8.4	~~8~~**7.5**	7.8~~**~~ **to 7.8**	7.8~~**~~	7.6 to 8.2	7.6	**7.3 to** 7.9~~**~~	7.~~9**~~**3**
Chloride Content (ppm or mg/kg)	~~14~~**3** to ~~35~~**180**	~~35~~**180**	~~62~~**9** to ~~104~~**23**	~~104~~**23**	~~11~~**3** to ~~405~~**119**	~~405~~**119**	~~36**~~**10 to 111**	~~36**~~**111**
Sulfate Content (ppm or mg/kg)	~~31~~**4** to ~~38~~**56**	~~38~~**56**	~~96~~**2** to ~~23~~**104**	~~23~~**104**	~~31~~**1** to ~~39~~**415**	~~39~~**415**	~~10**~~**36 to 181**	~~10**~~**181**

* No test data
** Limited data
^ No test data; reported values are based on published data in literature, and/or based on prior experience
"NP" indicates non-plastic material
# Estimated using a specific gravity of 2.65 when a specific gravity test was not performed
pcf = pounds per cubic foot; psf = pounds per square foot; psi = pounds per square inch; cm = centimeter; ppm = parts per million; mg = milligrams; kg = kilograms; DS = direct shear

Notes:
1. Data presented here are based on ACE, PE and ~~limited~~ Adv. PE phase explorations as well as applicable prior explorations as discussed in Tunnel GDR.
2. Blow counts from ACE and PE phase environmental hollow-stem-auger borings were not considered
3. Effective cohesion and friction angle are based on peak strength values from slow direct shear tests.
4. Cohesion and friction angle are based on peak shear strength values from Triaxial consolidated-undrained tests. Effective values are based on effective stress results, and undrained values are based on total stress results.
5. Based on relationship between elastic modulus and SPT N-value from Stroud (1989) and Duncan Bursey (2007)
6. Based on secant modulus computed at 0.1+0.05% axial strain from Triaxial consolidated-undrained tests
7. Hydraulic conductivity values were based on published data (Department of Water Resources Bulletin 118, California's Groundwater Update, 2003)
8. For soil corrosivity, the recommended values correspond to minimum resistivity, lowest pH and highest values for chloride and sulfate content

Table 3-2: Preliminary Engineering Properties of Principal Geologic Units for Tunnel Reach 5

Parameter	2009 through 2015 Geotechnical and Environmental Investigations Estimated Range of Engineering Parameters											
Geologic Unit	Quaternary Older Alluvium (Qalo)				Lakewood Formation (Qlw)				San Pedro Formation (Qsp)			
	Fine-Grained		Coarse-Grained		Fine-Grained		Coarse-Grained		Fine-Grained		Coarse-Grained	
USCS Soil Classification	CL, CH, ML		SM, SC-SM, GC, SC		CL, CH, ML		SW,SW-SM,SP,SP-SM,SM,SC		CL, CH, CL-ML, ML		SW-SM, SP, SP-SM, SM	
Engineering Properties	Range[1]	Recommended[1]	Range[1]	Recommended[1]	Range[1]	Recommended[1]	Range[1]	Recommended[1]	Range[1]	Recommended[1]	Range[1]	Design
SPT Blowcounts "N"-Value[2]	15 to 100	40	42 to 100	76	100**	100**	66 to 100	97	39**	39**	55 to 100	73
Moisture Content (%)	8 to 57	21	6 to 24	14	16 to 24	20	1 to 24	14	25**	25**	4 to 21	11
Dry Density (pcf)	66 to 126	108	101 to 130	114	101 to 111	106	89 to 109	101	*	*	98 to 116	105
Total Density (pcf)	103 to 142	130	121 to 143	132	125 to 130	127	99 to 128	116	*	*	103 to 127	115
Void Ratio	0.34 to 1.51	0.60	0.34 to 0.65	0.50	*	*	0.53 to 0.84	0.66	*	*	0.58 to 0.72	0.66
Degree of Saturation (%) #	72 to 100	93	33 to 100	81	*	*	19 to 95	69	*	*	16 to 88	49
Fines Content (%)	53 to 99	71	10 to 46	28	*	*	10 to 28	16	84**	84**	10 to 49	33
Specific Gravity	2.61 to 2.82	2.73	2.57 to 2.75	2.67	*	*	2.61 to 2.67	2.63	2.77**	2.77**	2.65 to 2.66	2.66
Liquid Limit (%)	28 to 82	44	28 to 30	29	*	*	*	*	*	*	*	*
Plasticity Index (%)	13 to 39	23	7 to 14	11	*	*	*		*	*	*	*
Modified Compression Index (Cce)	0.045 to 0.123	0.080	0.042 to 0.065	0.057	*	*	0.026 to 0.050	0.039	*	*	0.079**	0.079**
Modified Recompression Index (Cre)	0.012 to 0.026	0.019	0.007 to 0.013	0.010	*	*	0.004 to 0.007	0.006	*	*	0.007**	0.007**
Collapse Potential (%)	*	*	-0.05**	-0.05**	*	*	*	*	*	*	-1.38 to -0.21	-0.80
Expansion Potential (%)	0.27 to 0.62	0.45	0.02 to 0.23	0.11	*	*	0.01 to 0.14	0.07	*	*	*	*
At-Rest Lateral Earth Coefficient, K_o	0.68 to 0.73	0.71	0.68**	0.68**	*	*	*	*	*	*	*	*
Effective Cohesion from Direct Shear Test [3] (psf)	350 to 500	450	100 to 900	413	*	*	450 to 700	575	*	*	750**	750**
Effective Friction Angle from Direct Shear Test [3] (degrees)	29 to 31	30	30 to 33	32	*	*	30 to 32	31	*	*	32**	32**
Effective Cohesion from Triaxial Test [4] (psf)	600*	600**	*	*	*	*	*	*	*	*	*	*
Effective Friction Angle from Triaxial Test [4] (degrees)	30**	30**	*	*	*	*	*	*	*	*	*	*
Undrained Cohesion from Triaxial Test [4] (psf)	150**	150**	*	*	*	*	*	*	*	*	*	*
Undrained Friction Angle from Triaxial Test [4] (degrees)	27**	27**	*	*	*	*	*	*	*	*	*	*
Young's Modulus from Empirical Correlations [5] (ksf)	1,031 to 3,988	2,236	2,632 to 6,266	4,878	3,600**	3,600**	4,135 to 6,266	6,081	2,145**	2,145**	3,446 to 6,266	4,574
Young's Modulus from Triaxial Test [6] (ksf)	2,621**	2,621**	*	*	*	*	*	*	*	*	*	*
Poisson's Ratio	0.33 to 0.35	0.34	0.31 to 0.32	0.32	*	*	0.32 to 0.33	0.33	*	*	0.32**	0.32**
Hydraulic Conductivity (ft/day) [7]	10^{-7} to 10^{-1} ^	10^{-4} ^	10^{-2} to 10^{3} ^	10 ^	10^{-7} to 10^{-4} ^	10^{-5} ^	10^{-1} to 10^{2} ^	10 ^	10^{-3} to 10^{-1} ^	10^{-2} ^	10^{-1} to 10^{2} ^	10 ^
Soil Abrasion Test Value	26 to 44	32	27 to 33	30	*	*	*	*	*	*		*
Corrosivity Results [8]:												
Minimum Resistivity (ohm-cm)	600 to 2,778	600	1,176 to 4,051	1176	*	*	2,214 to 3,280	2,214	*	*	*	*
pH	7.0 to 8.0	7.0	7.2 to 7.8	7.2	*	*	7.5 to 7.9	7.5	*	*	*	*
Chloride Content (ppm or mg/kg)	3 to 172	172	12 to 56	56	*	*	20 to 34	34	*	*	*	*
Sulfate Content (ppm or mg/kg)	9 to 134	134	56 to 86	86	*	*	40 to 61	61	*	*	*	*

Table 3-2 (continued): Preliminary Engineering Properties of Principal Geologic Units for Tunnel Reach 5

Parameter	2009 through 2015 Geotechnical and Environmental Investigations Estimated Range of Engineering Parameters					
Geologic Unit	Quaternary Older Alluvium (Qalo)		Lakewood Formation (Qlw)		San Pedro Formation (Qsp)	
	Fine-Grained	Coarse-Grained	Fine-Grained	Coarse-Grained	Fine-Grained	Coarse-Grained

** Limited data
^ No test data; reported values are based on published data in literature, and/or based on prior experience
"NP" indicates non-plastic material
# Estimated using a specific gravity of 2.65 when a specific gravity test was not performed
pcf = pounds per cubic foot; psf = pounds per square foot; psi = pounds per square inch; cm = centimeter; ppm = parts per million; mg = milligrams; kg = kilograms; DS = direct shear

Notes:
1. Data presented here are based on ACE, PE and limited Adv. PE phase explorations as well as applicable prior explorations as discussed in Tunnel GDR.
2. Blow counts from ACE and PE phase environmental hollow-stem-auger borings were not considered
3. Effective cohesion and friction angle are based on peak strength values from slow direct shear tests.
4. Cohesion and friction angle are based on peak shear strength values from Triaxial ~~Test[4] (psf)~~consolidated-undrained tests. Effective values are based on effective stress and undrained values are based on total stress
5. Based on relationship between elastic modulus and SPT N-value from Stroud (1989) and Duncan Bursey (2007)
6. Based on secant modulus computed at 0.1+0.05% axial strain from Triaxial consolidated-undrained tests
7. Hydraulic conductivity values were based on published data (Department of Water Resources Bulletin 118, California's Groundwater Update, 2003)
8. For soil corrosivity, the recommended values correspond to minimum resistivity, lowest pH and highest values for chloride and sulfate content

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4.0 ~~DYNAMIC SITE~~SEISMIC CHARACTERISTICS

As stated in Section 3B6.0 of the Metro Supplemental Seismic Design Criteria of the Metro Rail Design Criteria (MRDC) dated November 2014, the underground tunnel structures undergo three primary modes of deformation during seismic shaking: ovaling/racking, axial, and curvature deformation. In order to evaluate the response of the tunnel to these deformation modes using simplified empirical methods, ground motion parameters and dynamic characteristics of the material at tunnel depths are required. The ground motion parameters namely the peak ground acceleration (PGA) and peak ground velocity (PGV) are needed at the tunnel depths; the dynamic properties such as shear wave velocity (V_s), elastic Young's modulus (E_s) and shear modulus (G_s) should be obtained for the materials at the tunnel depths and should be strain compatible for the design earthquake considered. **In addition to the deformations due to ground shaking as described above, the tunnel should be designed for offset due to potential fault deformation.**

4.1 Dynamic Soil Properties

Dynamic properties of geologic formations anticipated in the tunnel zone were evaluated using the shear-wave data from seismic cone penetration tests (SCPTs~~).~~**) and suspension logging testing in borings.** The small strain elastic Young's modulus (E_s) and shear modulus (G_s) were estimated from the shear-wave velocity (small strain) of these materials (V_s).

For the **Operating Design Earthquake (**ODE**)** and **Maximum Design Earthquake (**MDE**)** events, small-strain shear wave velocity was degraded using the guidelines provided in Table 19.2-1 of FEMA P- 750 (2009). The computed shear-wave velocity, ~~elastic Young's modulus (~~E_s~~)~~ and ~~shear modulus (~~G_s~~)~~ for small-strain and for ~~Operating Design Earthquake (~~ODE~~)~~ and ~~Maximum Design Earthquake (~~MDE~~)~~ events are shown on Plate ~~3~~**4** and Table ~~5~~**4**-1.

4.2 Ground Motion Parameters

Ground motion parameters were estimated for seismic design of the tunnel using the available small-strain shear wave velocity measurements from the SCPTs~~. Peak ground acceleration (PGA) and peak ground velocity (PGV)~~ **and suspension logging testing in borings. PGA and PGV** were estimated in accordance with Section 2.3.1 of the MRDC (Metro, 2014). Two hazard levels were evaluated as listed below, based on a design life of 100 years for the subway per the Metro Design Criteria.

- ODE – defined as an earthquake event likely to occur once in the design life, where structures are designed to respond without significant structural damage. The current Metro Seismic Design Criteria of the MRDC defines ODE as an event with 50% probability of exceedence in 100 years (corresponding to a return period of 150 years).
- MDE – defined as an earthquake event with a low probability of occurring in the design life, where structures are designed to respond with repairable damage and to maintain life safety. The current Metro Seismic Design Criteria of the MRDC defines MDE as an event with 4% probability of exceedence in 100 years (corresponding to a return period of 2,475 years~~)~~**).**

The PGA at ground surface for the ODE and MDE events were estimated using the 2009 USGS Interactive Probabilistic Seismic Hazard Analysis (PSHA) Deaggregation tool on the USGS website (USGS, 2011). The USGS deaggregation tool uses the Next Generation Attenuation (NGA) relationships of Boore-Atkinson (2008), Campbell-Bozorgnia (2008) and Chiou-Youngs (2008) for the ground motion prediction equations~~.~~ **(GMPEs).** Based on the available combinations of exceedence probability and exposure time, ground motions for the MDE event were computed for a probability of exceedence of 2% in 50 years (equivalent to the 4% in 100 year) criteria stated in Metro Seismic Design Criteria of the MRDC. The PGV at ground surface was computed using the relationship between PGV-S_1 presented in the FHWA-NHI-10-034 manual (2009).

~~Ground~~**The GMPEs provide an estimate of ground** motions ~~are~~**at ground surface, however, ground motions** generally ~~smaller~~**reduce** with depth and therefore ground motions at the tunnel depths are lower than the ground motions at ground surface. The ground motion parameters (PGA, PGV) at the tunnel depths were estimated by using attenuation reduction factors presented in Table 13-1 of FHWA-NHI-10-034 manual (2009). The small strain shear wave velocity, PGA and PGV and those for ODE and MDE levels at tunnel elevation are presented in Plate 4 for Reaches 4 and 5. In summary, the PGA and PGV estimated at each discrete boring/CPT location with shear-wave data, are presented in Table 4-1.

Table 4-1: PGA and PGV for ODE and MDE Events

Reaches	CPT No.	Small-strain shear-wave Velocity in ft/sec*	Strain-compatible shear-wave Velocity in ft/sec		Peak Ground Acceleration (PGA) at tunnel depth, in g		Peak Ground Velocity (PGV) at tunnel depth, in ft/sec	
			ODE	MDE	ODE	MDE	ODE	MDE
Reach 4	C-~~112~~[1]**112**[1)]	~~988~~**981**	~~817~~**812**	~~414~~**411**	0.23	0.66	1.18	4.10
	G-406	**1,342**	**1,110**	**521**	**0.23**	**0.68**	**1.14**	**4.14**
	C-113A	~~1324~~**1,322**	~~1217~~**1,215**	~~1026~~**1,024**	0.22	0.70	0.98	3.~~97~~**76**
Wilshire/Rodeo Station	**G-408**[2)]	**1,267**	**1,164**	**990**	**0.23**	**0.70**	**1.12**	**4.20**
Reach 5	**G-409**	**1,409**	**1,172**	**613**	**0.23**	**0.67**	**1.24**	**4.81**
	C-117	~~1365~~**1,376**	~~1134~~**1,143**	~~442~~**446**	0.22	0.70	1.05	4.~~71~~**17**
	C-118	~~1060~~**1,060**	882	335	0.22	0.70	1.02	4.12
	C-119	~~1003~~**1,003**	836	384	0.~~22~~**23**	0.68	1.~~4~~**413**	4.34
	C-119B	~~1003~~**1,017**	~~833~~**844**	~~346~~**351**	0.~~22~~**23**	0.~~70~~**69**	1.08	4.24
	C-120	~~1164~~**1,218**	~~970~~**1,015**	~~459~~**480**	0.~~22~~**23**	0.68	2.27	4.38
	C-120A	~~977~~**923**	~~813~~**768**	~~309~~**292**	0.22	0.70	1.02	4.12
	C-120A1	743	617	251	0.~~22~~**23**	0.70	1.~~06~~**07**	4.22
	C-120B	~~784~~**752**	~~651~~**625**	~~262~~**251**	0.~~22~~**23**	0.70	1.06	4.21
Recommended Values for Section 2					0.23	0.70	2.27	4.~~38~~**81**

* **Average** velocity within tunnel zone defined as tunnel bore diameter and 10 feet above crown and 10 feet below invert; tunnel elevations based on plans dated ~~June~~**December** 2015 included in **the** GDR.

1) CPT performed at Wilshire/La Cienega station
2) Boring performed at Wilshire/Rodeo station; **Remaining** CPTs performed along Reaches 4 and 5

4.3 Fault Displacement

The Tunnel in Reach 5 should be designed to accommodate offset due to potential fault rupture. The preliminary fault displacement values for the tunnel may be taken as up to 9 centimeters (cm) for the same annual probability of exceedance as defined for ground shaking at the ODE level, and 33 cm for the same annual probability of exceedance as defined for ground shaking at the MDE level. It is recommended that these values are confirmed in Final Design, including the specific location, amount, and nature of displacement that may occur on fault crossings.

5.0 GEOTECHNICAL INSTRUMENTATION AND MONITORING

A geotechnical instrumentation and monitoring program should be planned and implemented to monitor ground movements and any potential distress during tunnel excavation in the adjacent buildings, other structures and critical utilities. The following instrumentation should be considered:

- Ground surface settlement points
- Building settlement reference points
- Inclinometer casings
- **Multi-point Borehole** Extensometers **(MPBX)**
- Piezometers and observation wells (water and subsurface gas)
- Tiltmeters and crackmeters on sensitive buildings or structures
- Construction vibration monitoring near sensitive buildings or structures
- Photo documentation of the baseline/preconstruction survey in existing buildings

Depending on the features of the adjacent structures (age of the building, construction type, sensitivity of the structures to noise and vibration), a more detailed and site-specific instrumentation and monitoring program may need to be developed.

In addition, tieback anchors from adjacent building constructions with deep basements could extend into the tunnel excavation. Near tall buildings with deep basements, geophysical surveys or other exploratory methods should be performed to locate the tieback anchors.

6.0 LIMITATIONS AND BASIS FOR PRELIMINARY RECOMMENDATIONS

The professional services have been performed using the degree of care and skill ordinarily exercised, under similar circumstances, by reputable geotechnical consultants practicing in this or similar localities. No other warranty, expressed or implied, is made as to the professional advice included in this GDM.

This GDM has been prepared for the Los Angeles County Metropolitan Transportation Authority (Metro) and its design consultants to be used solely for the evaluation for Tunnel Reaches 4 and 5 in Section 2 planned as part of the proposed WPLE project. The GDM has not been prepared for use by other parties, and may not contain sufficient information for purpose of other parties or other uses.

In developing this GDM, Amec Foster Wheeler (PB team member) relied on subsurface information obtained during Adv. PE phase and by its predecessor company AMEC, by MACTEC in the AA, ACE, and PE phase studies and its other predecessor companies, Law/Crandall and LeRoy Crandall and Associates, as well as subsurface information obtained by other firms. Subsurface conditions are, by their nature, uncertain and may vary from those encountered at the locations where visual inspections, borings, surveys, or other explorations were made.

7.0 BIBLIOGRAPHY

Abrahamson, N.A., and Silva, W.J., 2008, Summary of the Abrahamson & Silva NGA Ground Motion Relations, Earthquake Spectra, Volume. 24, No. 1, pp. 67-97.

Boore, D.M., and Atkinson, G.M., 2008, Ground-Motion Prediction Equations for the Average Horizontal Component of PGA, PGV, and 5%-Damped PSA at Spectral Periods Between 0.01 s and 10.0 s, Earthquake Spectra, Volume 24, No.1, p. 99-138.

Campbell, K.W., and Bozorgnia, Y., 2008, Ground Motion Model for the Geometric Mean Horizontal Component of PGA, PGV, PGD and 5% Damped Linear Elastic Response Spectra for Periods Ranging from 0.01s to 10.0 s, Earthquake Spectra, Volume 24, No.1, pp. 139-171.

Chiou, B.S.J., and Youngs, R.R., 2008, An NGA Model for the Average Horizontal Component of Peak Ground Motion and Response Spectra, Earthquake Spectra, Volume 24, No.1, pp. 173-215.

Duncan, J. M., and Bursey, A., 2007, Soil and Rock Modulus Correlations for Geotechnical Engineering, Center for Geotechnical Practice and Research, Virginia Tech.

Federal Emergency Management Agency, 2009, NEHRP Seismic Provisions for New Buildings and Structures, FEMA P-750.

Federal Emergency Management Agency, 2000, Prestandard and Commentary ~~For~~**for** the Seismic Rehabilitation of Buildings, FEMA 356.

Federal Highway Administration, 2009, Technical Manual for Design and Construction of Road Tunnels – Civil Elements, Publication No. FHWA-NHI-10-034.

Metro, 2010, "Final Geotechnical and Environmental Report for Advanced Conceptual Engineering, Proposed Westside Subway Extension, Los Angeles, California," November 15, 2010, Project Number 4953-09-0472.

Metro, 2011, "Preliminary Geotechnical and Environmental Report, Westside Subway Extension, Los Angeles, California, Volumes 1 through 3," report dated December 21, 2011.

Metro, 2011, "Century City Area Fault Investigation Report, Westside Subway Extension, Los Angeles, California, Volumes 1 and 2," report dated October 14, 2011.

Metro, 2014, "Metro Rail Design Criteria, Section 5: Structural/Geotechnical," dated October 24, 2014.

Metro, 2015, "Geotechnical Data Report, Tunnel Reaches 4 and 5, Westside Subway Extension, Los Angeles, California," report dated September 2015.

Metro, 2016, "Environmental Data Report (Amendment 8), Tunnel Reaches 4 and 5, Westside Subway Extension, Los Angeles, California," report dated February 2016.

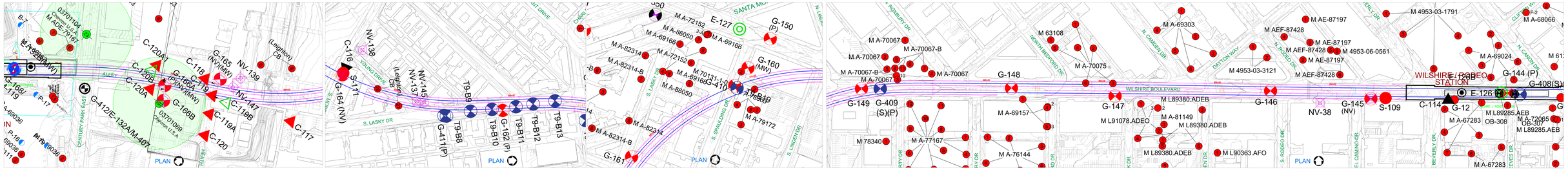
Metro, 2016, "Geotechnical Data Report (Amendment 8), Tunnel Reaches 4 and 5, Westside Subway Extension, Los Angeles, California," report dated February 2016.

Thewes, M., and Burger. B., 2004, Clogging of TBM drives in Clay, Tunnels and Tunneling International, June 2004, pp. 28-31.

U. S. Geological Survey, 2011, "2008 Interactive Deaggregation," Website: https://geohazards.usgs.gov/deaggint/2008/index.php

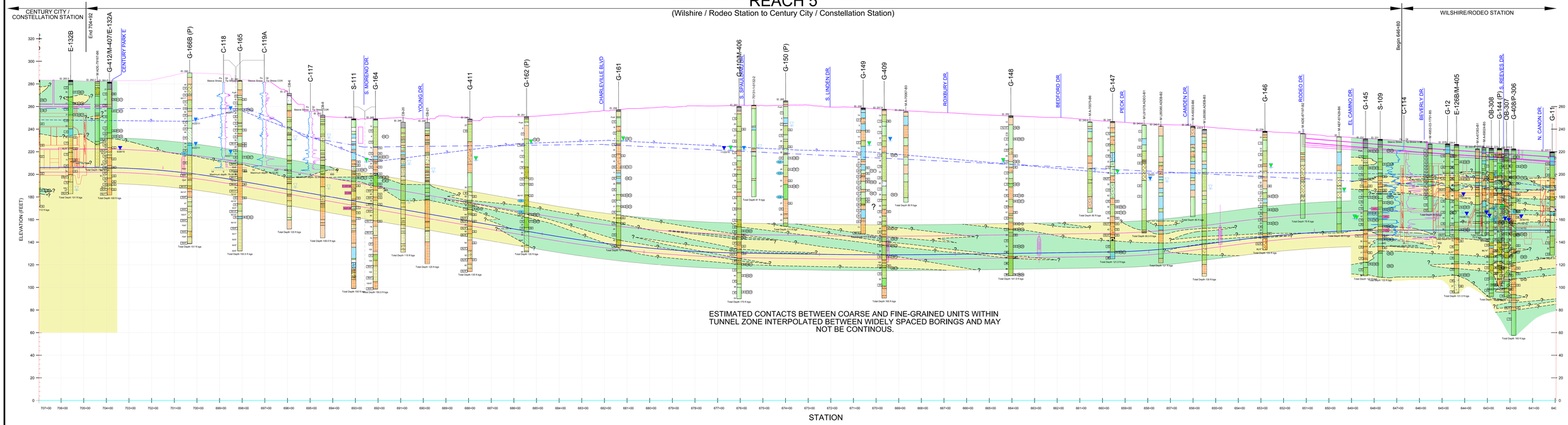
PLATES

Plate 1-1: Soil Profile along Tunnel Reach 4
Plate 1-2: Soil Profile along Tunnel Reach 5
Plates 2-1 through 2-3: Particle Size Distribution of Soils Anticipated in Tunnel Excavation (Reach 4)
Plate 2-4: TBM Clogging Potential of Soils (Reach 4)
Plates 3-1 through 3-4: Particle Size Distribution of Soils Anticipated in Tunnel Excavation (Reach 5)
Plate 3-5: TBM Clogging Potential of Soils (Reach 5)
Plate 4: Seismic Design Parameters (Reaches 4 and 5)



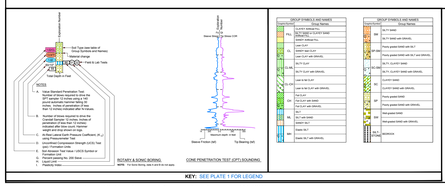
REACH 5

(Wilshire / Rodeo Station to Century City / Constellation Station)



ESTIMATED CONTACTS BETWEEN COARSE AND FINE-GRAINED UNITS WITHIN TUNNEL ZONE INTERPOLATED BETWEEN WIDELY SPACED BORINGS AND MAY NOT BE CONTINOUS.

Legend & Explanation



Symbol Labels:

- (MW) Groundwater monitoring (observation) well
- (NV) Boring with noise and vibration test
- (P) Boring with pressuremeter testing
- (S-Wave) Boring / CPT with shear wave velocity measurements
- (S/2011) Groundwater depth measured in an observation well and date of measurement (*1)
- Shallowest overnight groundwater depth measured in a boring
- Shallowest groundwater depth measured during drilling of a boring
- * Asterisk (*) denotes depth at which water sample was collected for environmental testing
- Groundwater seepage
- Tunnel Cross Passage (Profile View)
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Notes:

(*1) For wells with more than one well screen, two water levels shown indicating water levels measured in respectively screened zones.

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Geologic Units:

- af ARTIFICIAL FILL, projection of fill along profile is poorly confined due to lack of local boring data.
- Qal YOUNGER ALLUVIUM
- Qalo OLDER ALLUVIUM
- Qlw LAKEWOOD FORMATION
- Qsp SAN PEDRO FORMATION
- Geologic contact line, dashed where approximate, queried where poorly constrained
- Fine / Coarse grained contact line, dashed where approximate, queried where poorly constrained
- Coarse - grained Soils - Sands, fine to coarse grained, variable clay, silt, and gravel; horizontal correlation inferred
- Fine - grained Soils - Clays and Silts, variable sand and gravel; horizontal correlation inferred

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PROFILE: H=100', V=20' VERTICAL EXAGGERATION = 5:1

PROFILE: H=100', V=20' VERTICAL EXAGGERATION = 5:1

REV	DATE	BY	APP	DESCRIPTION

DESIGNED BY	PE/RM
DRAWN BY	KO/KC
CHECKED BY	DLP
IN CHARGE	MBH / PM
DATE	1/21/2016

Metro — LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY

PB — PROJECT MANAGER

WESTSIDE PURPLE LINE EXTENSION
ADVANCED PRELIMINARY ENGINEERING
SOIL PROFILE, FIELD AND LABORATORY TEST DATA
TUNNEL REACH 5
STATION 640+80 to 704+92

CONTRACT NO
DRAWING NO PLATE 1-2 REV
SCALE AS NOTED
SHEET NO

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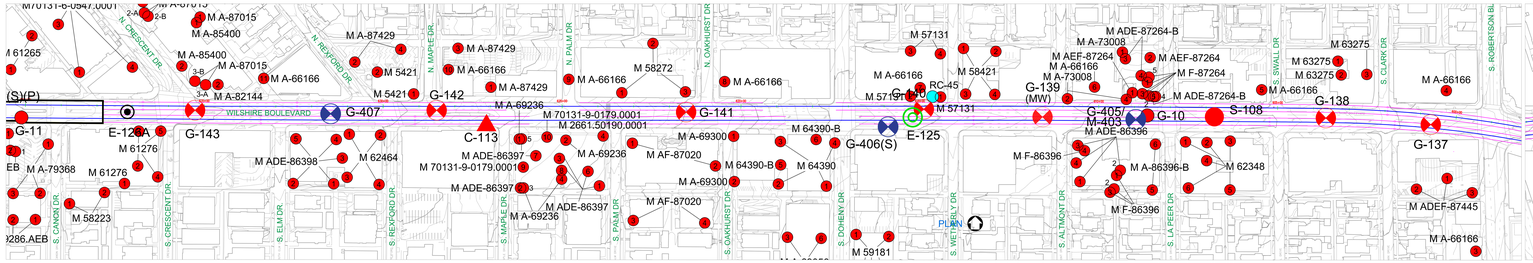
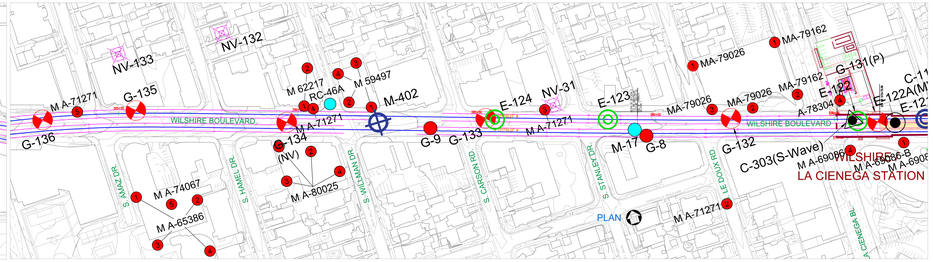
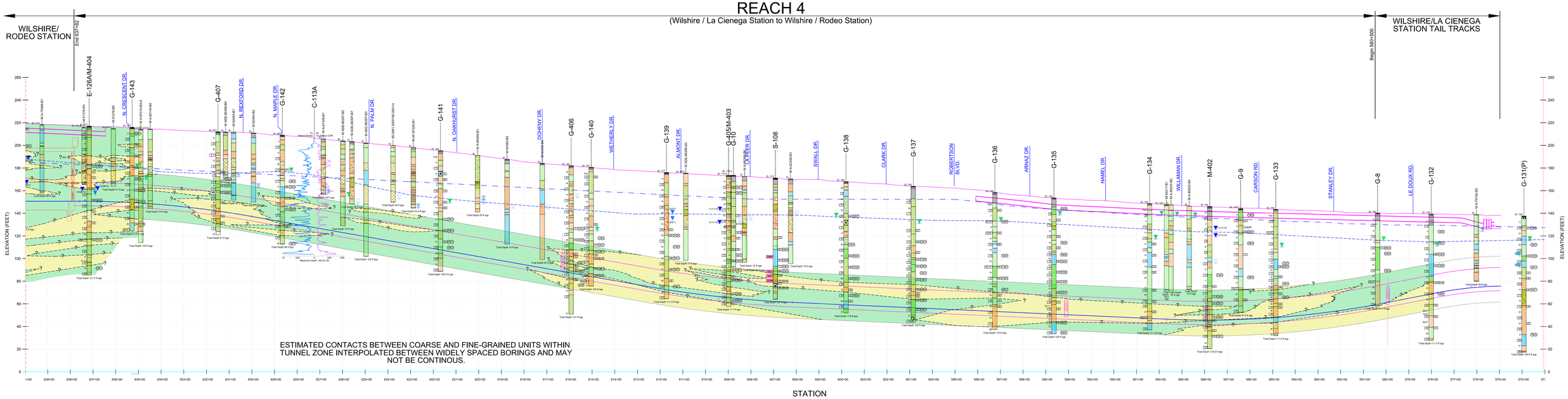




REACH 4

(Wilshire / La Cienega Station to Wilshire / Rodeo Station)



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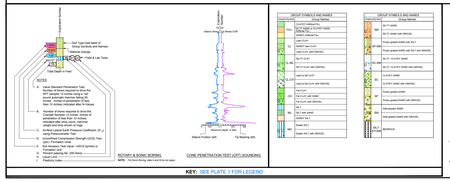
Legend & Explanation



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LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY

Metro

PB

PROJECT MANAGER

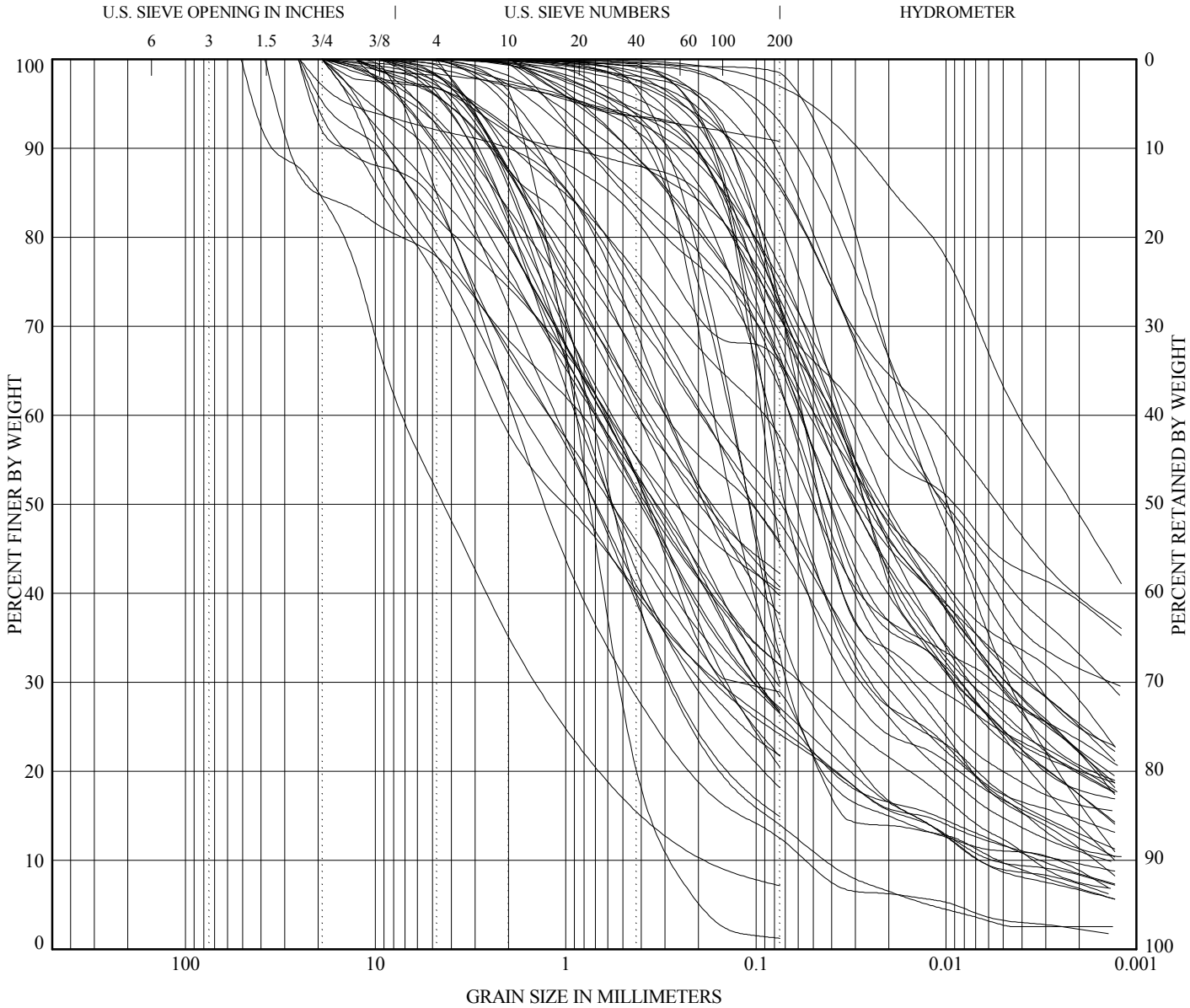
WESTSIDE PURPLE LINE EXTENSION
ADVANCED PRELIMINARY ENGINEERING
SOIL PROFILE, FIELD AND LABORATORY TEST DATA
TUNNEL REACH 4
STATION 580+50 to 637+82

CONTRACT NO.

DRAWING NO. PLATE 1-1 REV.

SCALE AS NOTED

SHEET NO.



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Boring No. /Depth (ft)

E-126A/M-404; 40.5	G-140; 95.5	S-108; 86
E-126A/M-404; 45.5	G-141; 60.5	S-108; 91
E-126A/M-404; 55.5	G-141; 70.5	S-108; 93
E-126A/M-404; 65.5	G-141; 80.5	S-108; 97
E-126A/M-404; 75.5	G-142; 55.5	
G-133; 74.5	G-142; 65.5	
G-133; 83.5	G-142; 80.5	
G-134; 76.5	G-143; 55.5	
G-134; 95.5	G-143; 65.5	
G-135; 83.5	G-143; 70.5	
G-135; 92	G-405/M-403; 83.5	
G-135; 98	G-405/M-403; 89.5	
G-135; 110	G-405/M-403; 92.5	
G-136; 90.5	G-405/M-403; 110.5	
G-136; 95.5	G-405/M-403; 113.5	
G-136; 100.5	G-406; 78	
G-137; 82.5	G-406; 88	
G-137; 91	G-406; 93	
G-137; 94.5	G-406; 100.5	
G-137; 100.5	G-407; 47.5	
G-137; 109	G-407; 53.5	
G-138; 85.5	G-407; 62.5	
G-138; 95.5	G-407; 74.5	
G-138; 100.5	G-407; 80.5	
G-138; 105.5	M-402; 79.5	
G-139; 85.5	M-402; 85.5	
G-139; 95.5	M-402; 97.5	
G-140; 77.5	M-402; 100.5	
G-140; 80.5	M-402; 109.5	
G-140; 89.5	S-108; 82	

TUNNEL REACH 4

Prepared/Date: SK 01/08/2016 **Checked/Date:** FW 01/08/2016

MTA Westside Subway Exension
Los Angeles, California

amec foster wheeler

PARTICLE SIZE DISTRIBUTION
Project No.: 4953-11-1423
Plate: 2-1

MACTEC LA GRAIN SIZE 500 CURVES S:\ONGOING\FRANK WANG\2015-105 WSE PURPLE LINE SECTION 2_LATEST_BH2 WORKING FILES (20151205)\DRAFT GINT LOGS\LIBRARY AMEC JUNE2012.GLB
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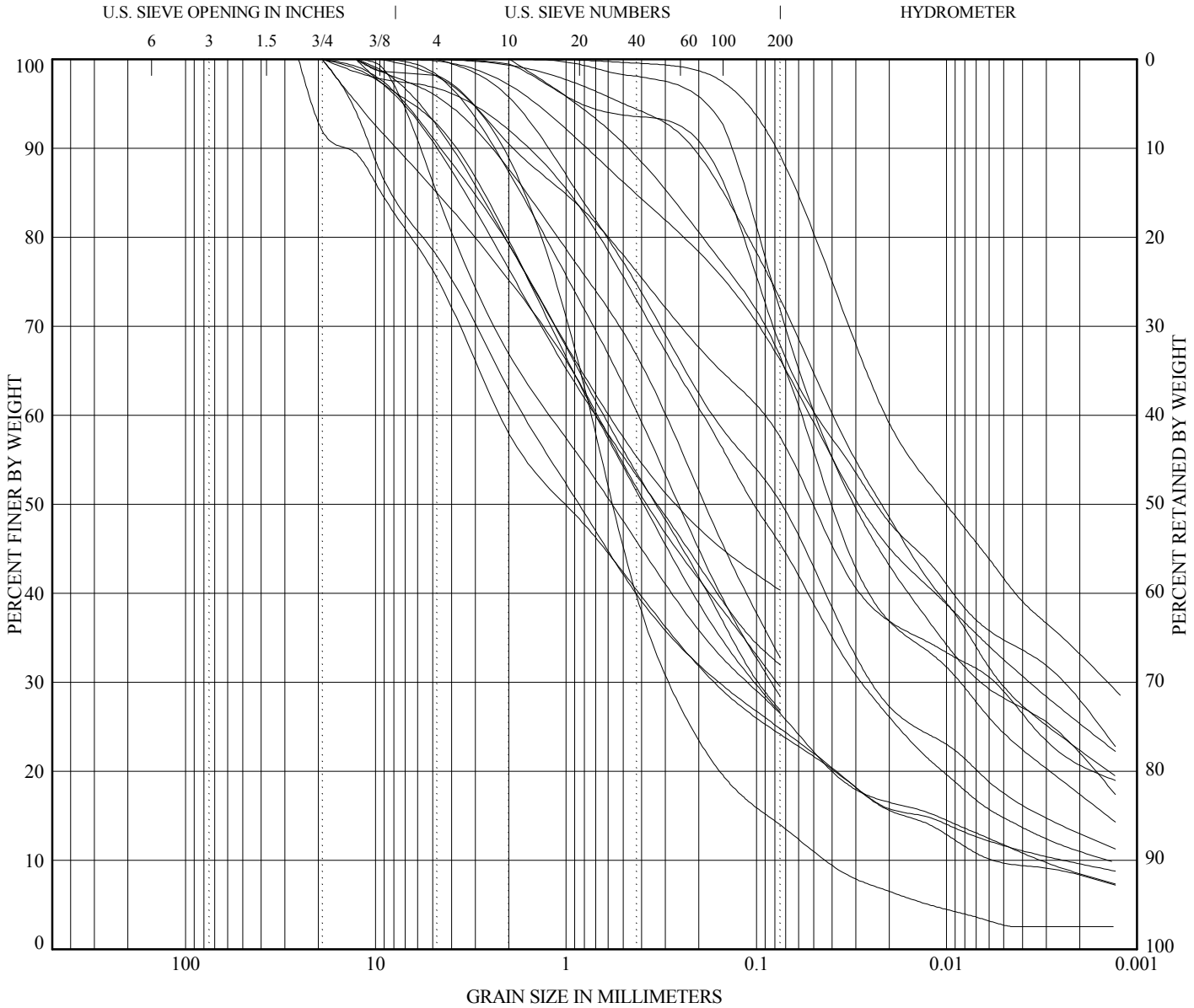

COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Boring No. /Depth (ft)

E-126A/M-404; 40.5
E-126A/M-404; 45.5
E-126A/M-404; 55.5
E-126A/M-404; 65.5
E-126A/M-404; 75.5
G-134; 76.5
G-134; 95.5
G-135; 83.5
G-136; 90.5
G-137; 82.5
G-137; 91
G-137; 94.5
G-138; 85.5
G-138; 95.5
G-143; 55.5
G-143; 65.5
G-143; 70.5
G-405/M-403; 83.5
S-108; 82
S-108; 86

TUNNEL REACH 4 - OLDER ALLUVIUM (Qalo)

Prepared/Date: SK 01/08/2016 **Checked/Date:** FW 01/08/2016

MTA Westside Subway Exension
Los Angeles, California

amec foster wheeler

PARTICLE SIZE DISTRIBUTION
Project No.: 4953-11-1423
Plate: 2-2

MACTEC LA GRAIN SIZE 500 CURVES S:\ONGOING\FRANK WANG\2015-105 WSE PURPLE LINE SECTION 2_LATEST_BH2 WORKING FILES (20151205)\DRAFT GINT LOGS\LIBRARY AMEC JUNE2012.GLB
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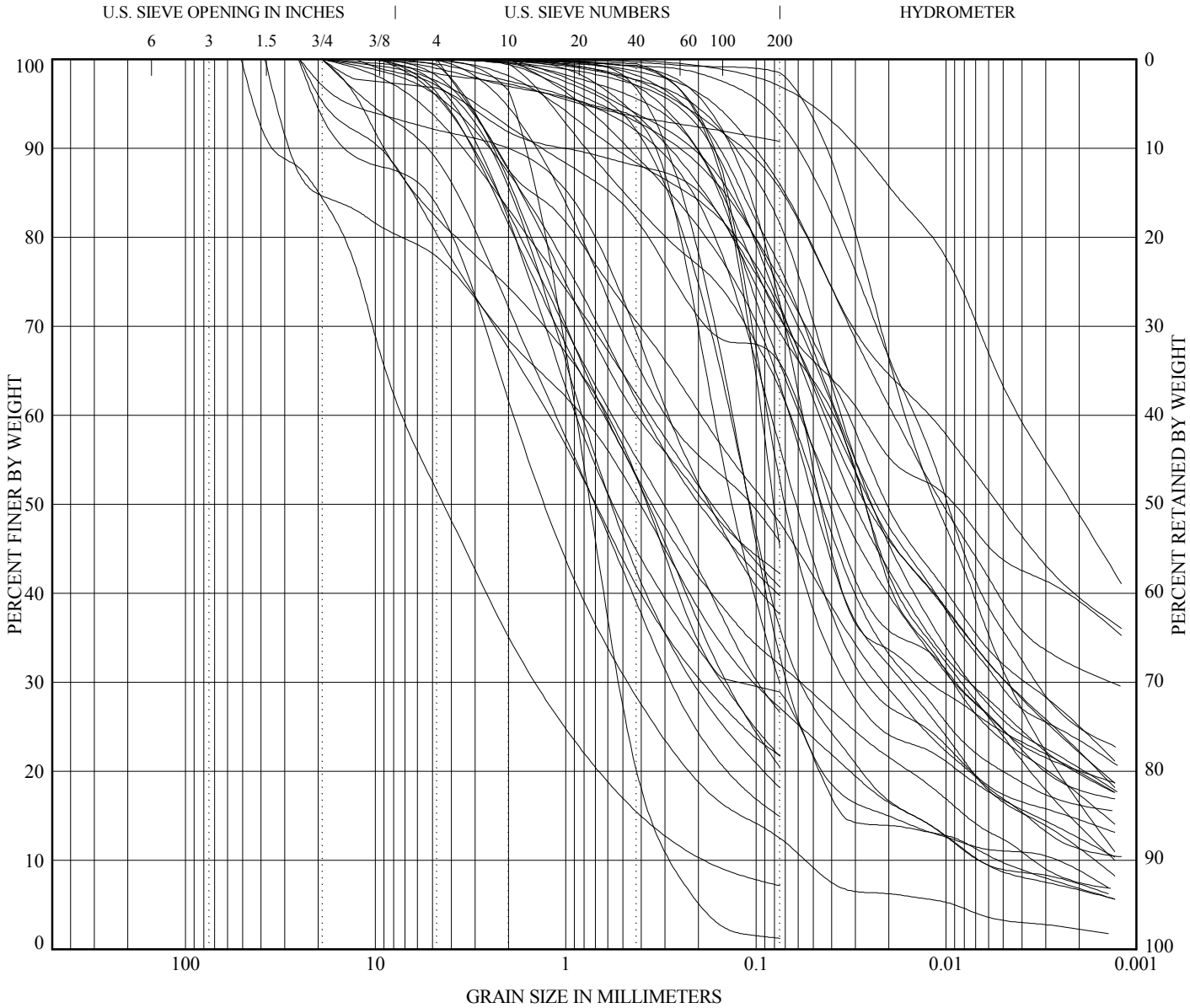

COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Boring No. /Depth (ft)

G-133; 74.5
G-133; 83.5
G-135; 92
G-135; 98
G-135; 110
G-136; 95.5
G-136; 100.5
G-137; 100.5
G-137; 109
G-138; 100.5
G-138; 105.5
G-139; 85.5
G-139; 95.5
G-140; 77.5
G-140; 80.5
G-140; 89.5
G-140; 95.5
G-141; 60.5
G-141; 70.5
G-141; 80.5
G-142; 55.5
G-142; 65.5
G-142; 80.5
G-405/M-403; 89.5
G-405/M-403; 92.5
G-405/M-403; 110.5
G-405/M-403; 113.5
G-406; 78
G-406; 88
G-406; 93
G-406; 100.5
G-407; 47.5
G-407; 53.5
G-407; 62.5
G-407; 74.5
G-407; 80.5
M-402; 79.5
M-402; 85.5
M-402; 97.5
M-402; 100.5
M-402; 109.5
S-108; 91
S-108; 93
S-108; 97

TUNNEL REACH 4- SAN PEDRO FORMATION (Qsp)

Prepared/Date: SK 01/08/2016 Checked/Date: FW 01/08/2016

MTA Westside Subway Exension
Los Angeles, California

amec foster wheeler

PARTICLE SIZE DISTRIBUTION
Project No.: 4953-11-1423
Plate: 2-3

MACTEC LA GRAIN SIZE 500 CURVES S:\ONGOING\FRANK WANG\2015-105 WSE PURPLE LINE SECTION 2_LATEST_BH2 WORKING FILES (20151205)\DRAFT GINT LOGS\LIBRARY AMEC JUNE2012.GLB
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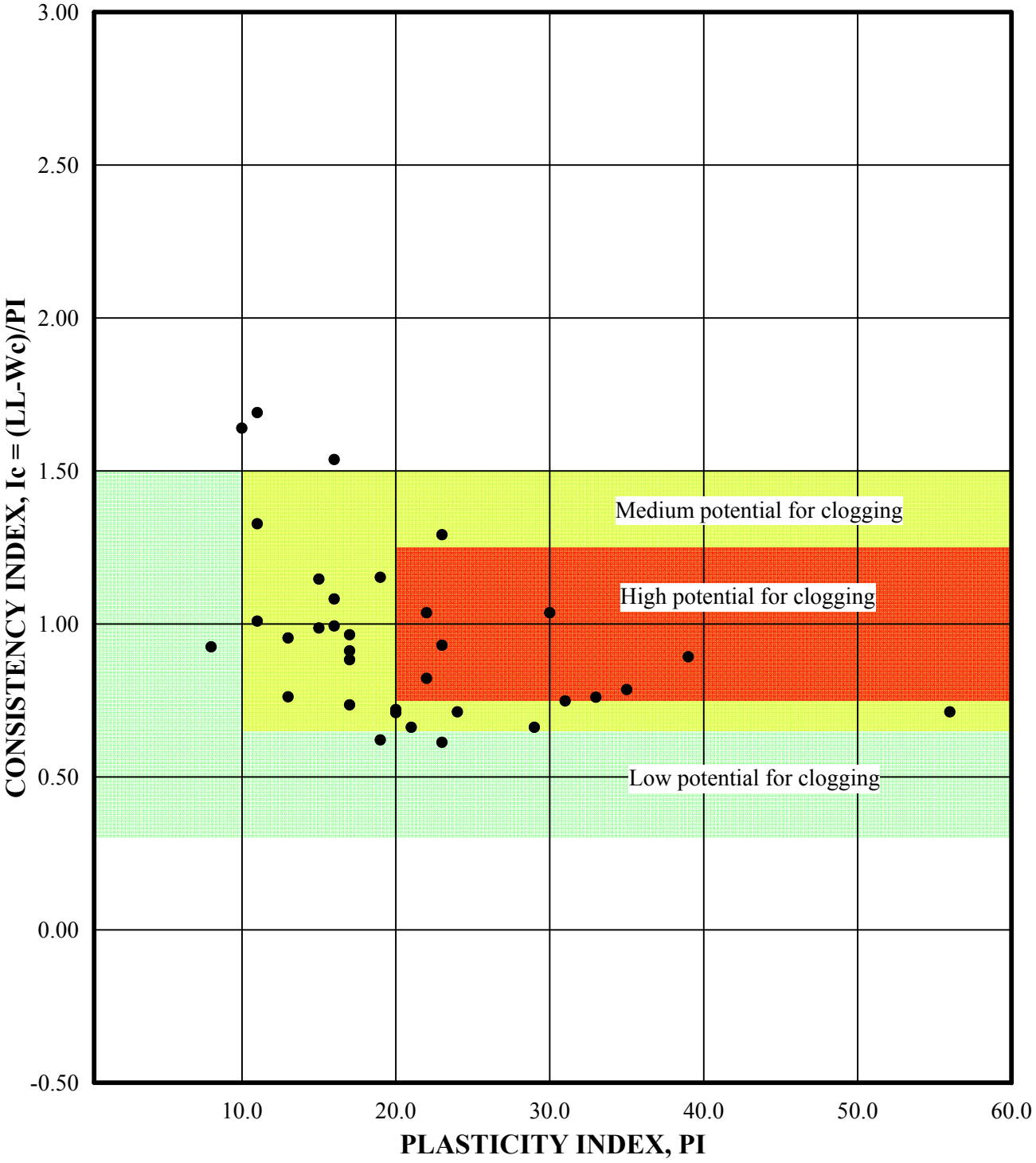
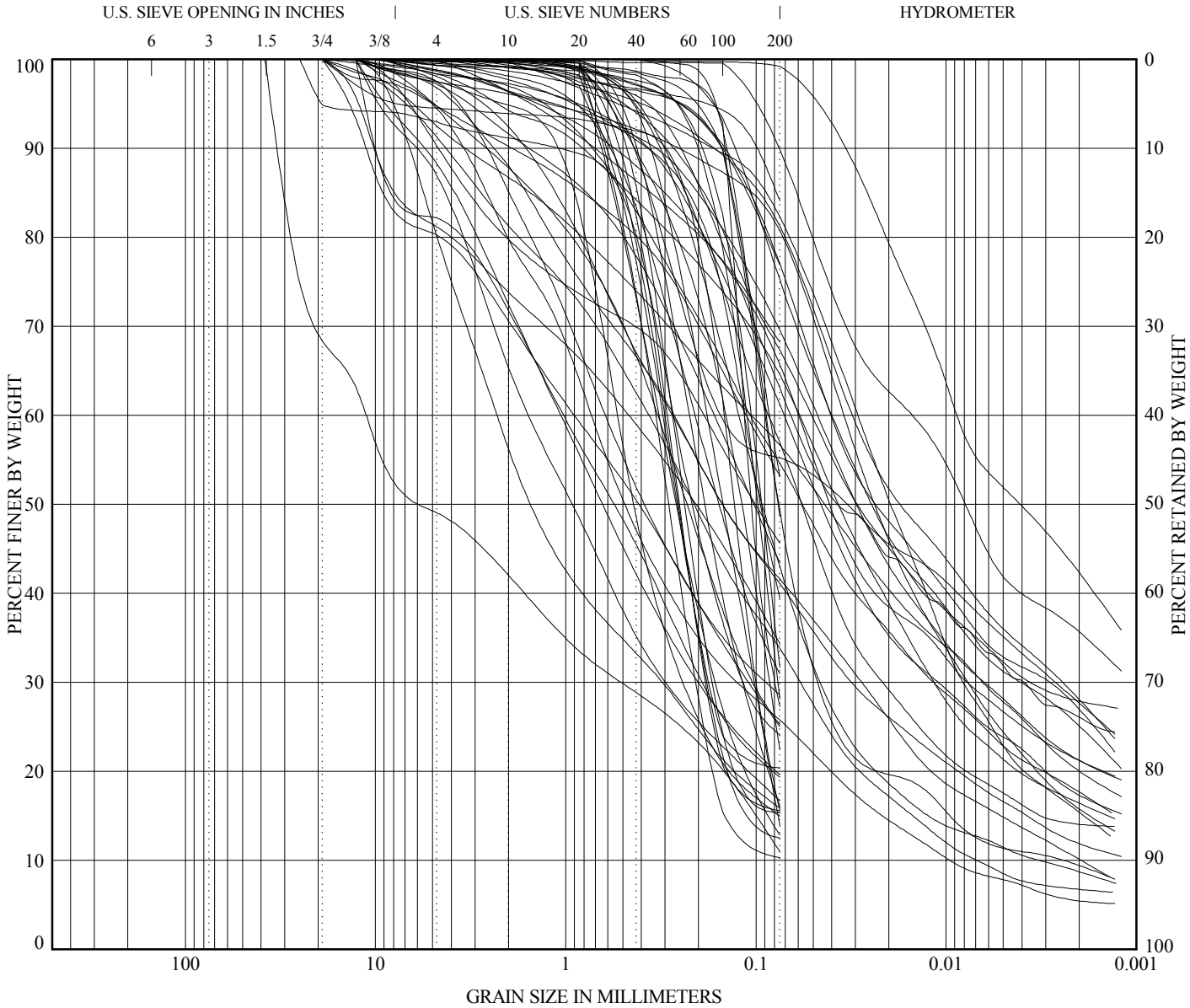
TUNNEL REACH 4



Reference: *Clogging of TBM drives in clay*, M. Thewes and W. Burger, 2005

Prepared/Date: SK 1/8/16
Checked/Date: FW 1/8/16

MTA Westside Subway Extension Los Angeles, California	amec foster wheeler	TBM Clogging Potential of soils (Reach 4) Project No.: 4953-11-1422 Plate 2-4



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Boring No. /Depth (ft)

G-145; 65.5
G-145; 71.5
G-145; 80.5
G-146; 69.5
G-146; 81.5
G-146; 90.5
G-147; 90.5
G-147; 95.5
G-147; 100.5
G-147; 115.5
G-148; 95.5
G-148; 100.5
G-148; 105.5
G-148; 115.5
G-148; 125.5
G-161; 95.5
G-161; 100.5
G-162; 87.5
G-162; 93.5
G-164; 57.5
G-164; 60.5
G-164; 69.5
G-164; 75.5
G-164; 90.5
G-165; 67.5
G-165; 79.5
G-165; 91.5
G-165; 103.5
G-166A/B; 68.5
G-166A/B; 85
G-166A/B; 100.5
G-166A/B; 105.5
G-409; 105.5
G-409; 117.5
G-409; 120.5
G-409; 130.5
G-410/M-406; 110.5
G-410/M-406; 113.5
G-410/M-406; 116.5
G-410/M-406; 123.5
G-410/M-406; 130.5
G-410/M-406; 139.5
G-411; 68.5
G-411; 76.5
G-411; 84.5
G-411; 99.5
G-412/M-407; 68
G-412/M-407; 75.5
S-109; 56
S-109; 62
S-109; 77
S-109; 86
S-109; 88.5
S-111; 59
S-111; 70
S-111; 78.5
S-111; 83
S-111; 88

TUNNEL REACH 5

Prepared/Date: SK 01/08/2016 Checked/Date: FW 01/08/2016

MTA Westside Subway Exension
Los Angeles, California

amec foster wheeler

PARTICLE SIZE DISTRIBUTION
Project No.: 4953-11-1423
Plate: 3-1

MACTEC LA GRAIN SIZE 500 CURVES S:\ONGOING\FRANK WANG\2015-105 WSE PURPLE LINE SECTION 2_LATEST_BH2 WORKING FILES (20151205)\DRAFT GINT LOGS\LIBRARY AMEC JUNE2012.GLB
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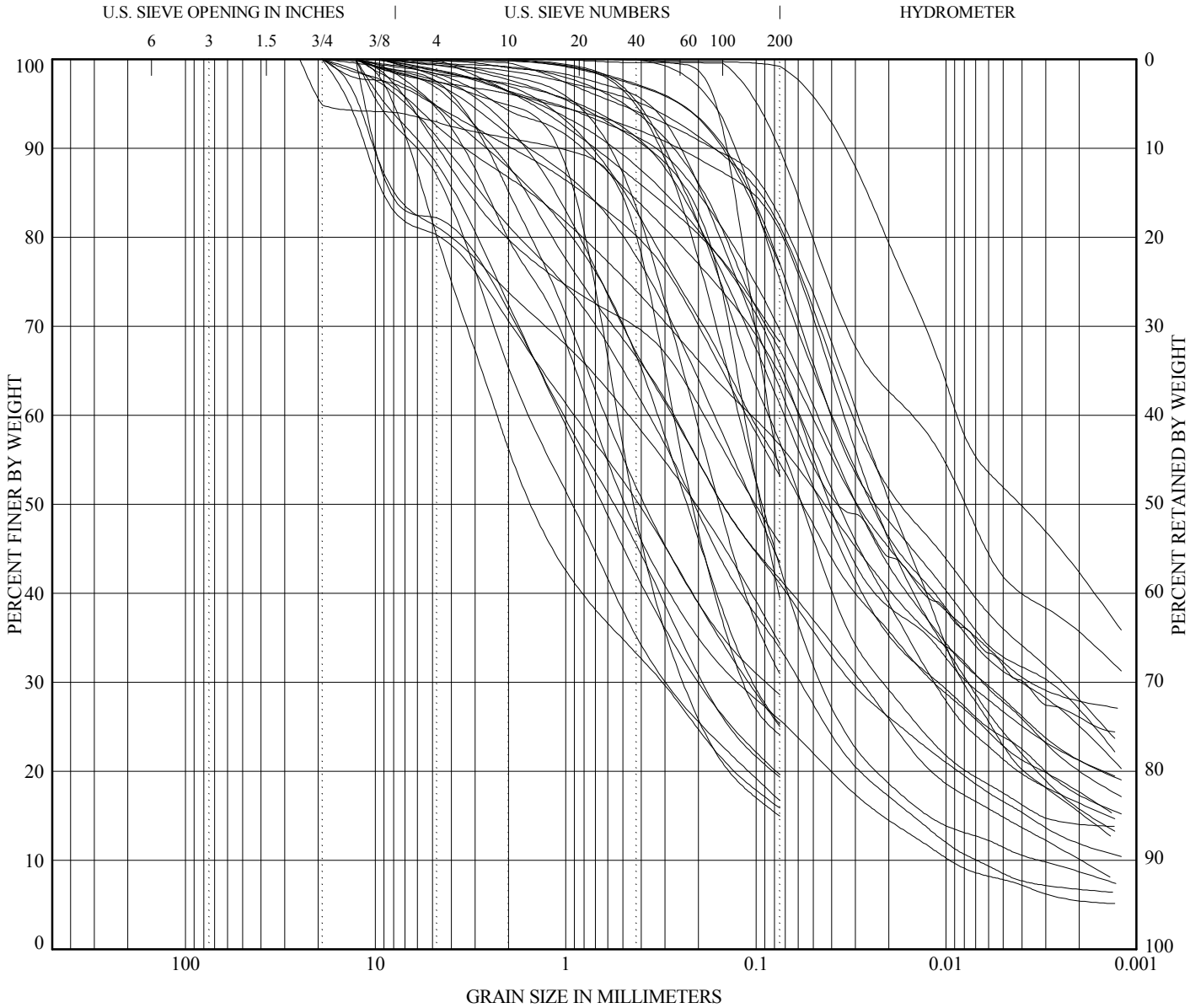


COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Boring No. /Depth (ft)

G-145; 65.5
G-145; 71.5
G-145; 80.5
G-146; 69.5
G-146; 81.5
G-146; 90.5
G-147; 90.5
G-147; 95.5
G-147; 100.5
G-147; 115.5
G-148; 95.5
G-148; 100.5
G-148; 105.5
G-148; 115.5
G-148; 125.5
G-161; 95.5
G-161; 100.5
G-162; 87.5
G-162; 93.5
G-165; 67.5
G-166A/B; 68.5
G-409; 105.5
G-409; 117.5
G-409; 120.5
G-409; 130.5
G-410/M-406; 110.5
G-410/M-406; 113.5
G-410/M-406; 116.5
G-410/M-406; 123.5
G-410/M-406; 130.5
G-410/M-406; 139.5
G-411; 68.5
G-411; 76.5
G-411; 84.5
S-109; 56
S-109; 62
S-109; 77
S-109; 86
S-109; 88.5

TUNNEL REACH 5 - OLDER ALLUVIUM (Qalo)

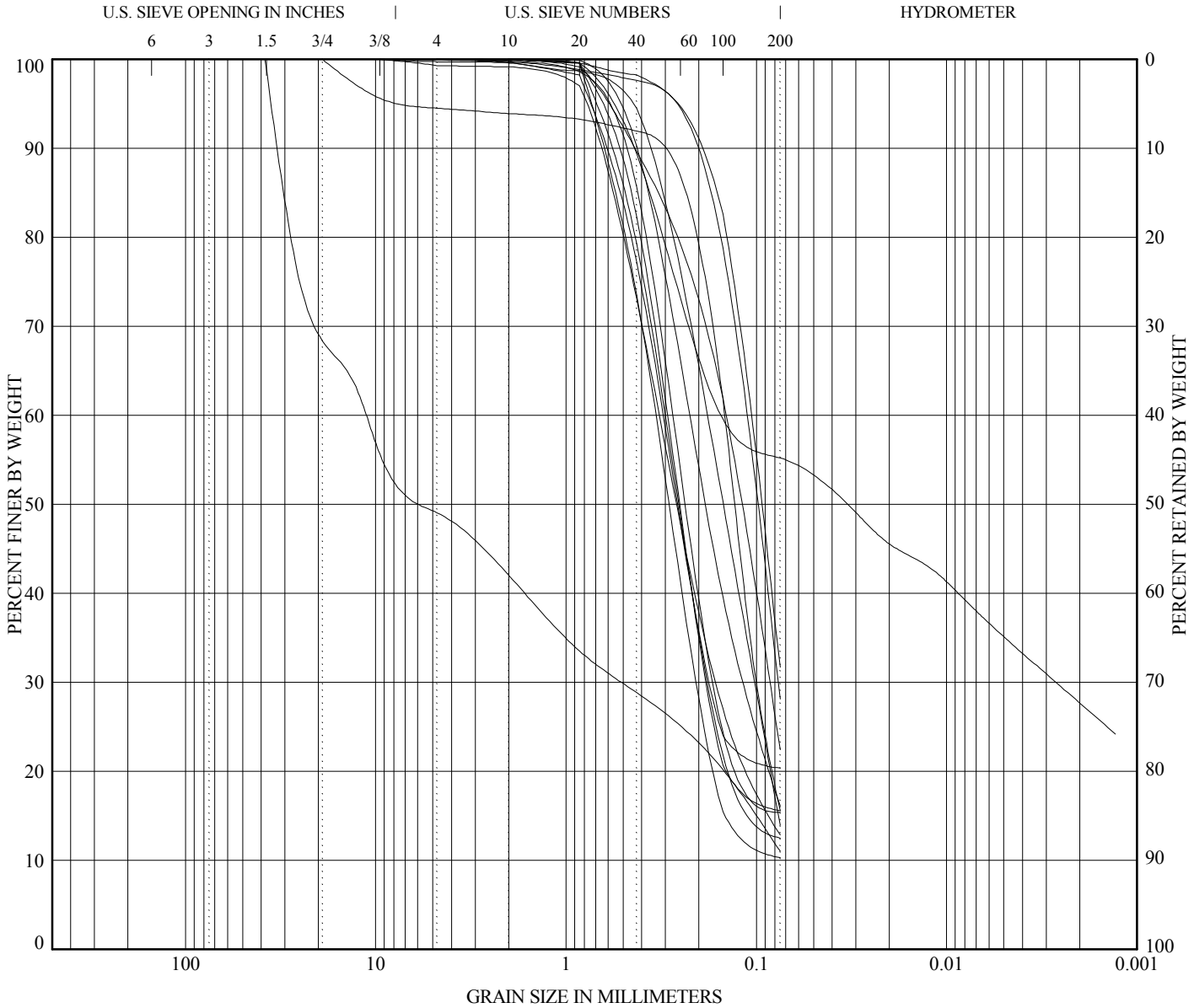
Prepared/Date: SK 01/08/2016 Checked/Date: FW 01/08/2016

MTA Westside Subway Exension
Los Angeles, California

amec foster wheeler

PARTICLE SIZE DISTRIBUTION
Project No.: 4953-11-1423
Plate: 3-2

MACTEC LA GRAIN SIZE 500 CURVES S:\ONGOING\FRANK WANG\2015-105 WSE PURPLE LINE SECTION 2_LATEST_BH2 WORKING FILES (20151205)\DRAFT GINT LOGS\LIBRARY AMEC JUNE2012.GLB
S:\ONGOING\FRANK WANG\2015-105 WSE PURPLE LINE SECTION 2_LATEST_BH2 WORKING FILES (20151205)\DRAFT GINT LOGS\4953-11-1423 (2016_01_07)-GRAPHS.GPJ 1/8/16



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Boring No. /Depth (ft)
G-164; 57.5
G-164; 60.5
G-164; 69.5
G-164; 75.5
G-164; 90.5
G-165; 79.5
G-165; 91.5
G-165; 103.5
G-166A/B; 85
G-411; 99.5
S-111; 59
S-111; 70
S-111; 78.5
S-111; 83
S-111; 88

TUNNEL REACH 5 - LAKEWOOD FORMATION (Qlw)

Prepared/Date: SK 01/08/2016 **Checked/Date:** FW 01/08/2016

MTA Westside Subway Exension
Los Angeles, California

amec foster wheeler

PARTICLE SIZE DISTRIBUTION
Project No.: 4953-11-1423
Plate: 3-3

MACTEC LA GRAIN SIZE 500 CURVES S:\ONGOING\FRANK WANG\2015-105 WSE PURPLE LINE SECTION 2_LATEST_BH2 WORKING FILES (20151205)\DRAFT GINT LOGS\LIBRARY AMEC JUNE2012.GLB
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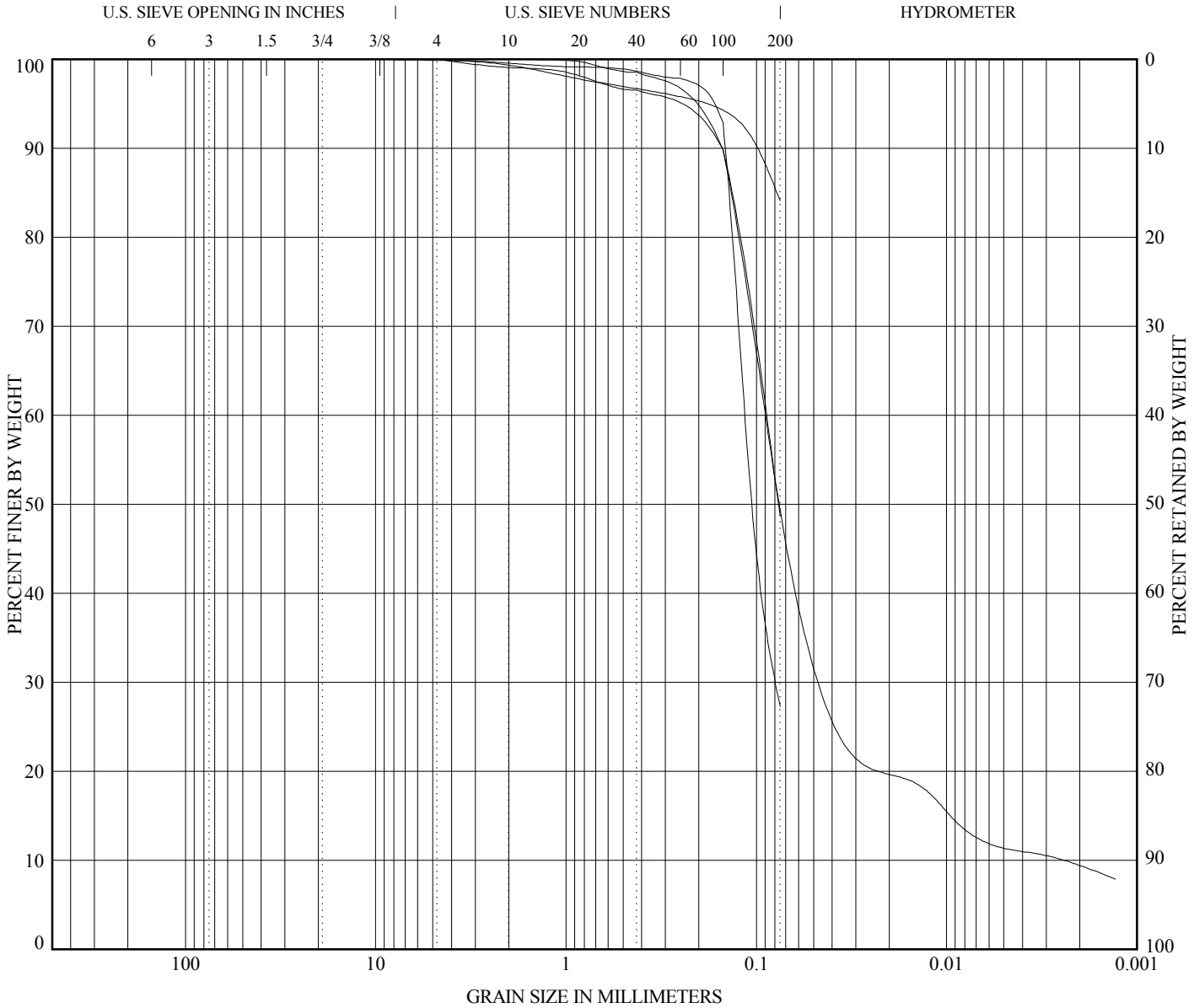

COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Boring No. /Depth (ft)
G-166A/B; 100.5
G-166A/B; 105.5
G-412/M-407; 68
G-412/M-407; 75.5

TUNNEL REACH 5 - SAN PEDRO FORMATION (Qsp)

Prepared/Date: SK 01/08/2016 Checked/Date: FW 01/08/2016

MTA Westside Subway Exension
Los Angeles, California

amec foster wheeler

PARTICLE SIZE DISTRIBUTION
Project No.: 4953-11-1423
Plate: 3-4

MACTEC LA GRAIN SIZE 500 CURVES S:\ONGOING\FRANK WANG\2015-105 WSE PURPLE LINE SECTION 2_LATEST_BH2 WORKING FILES (20151205)\DRAFT GINT LOGS\LIBRARY AMEC JUNE2012.GLB
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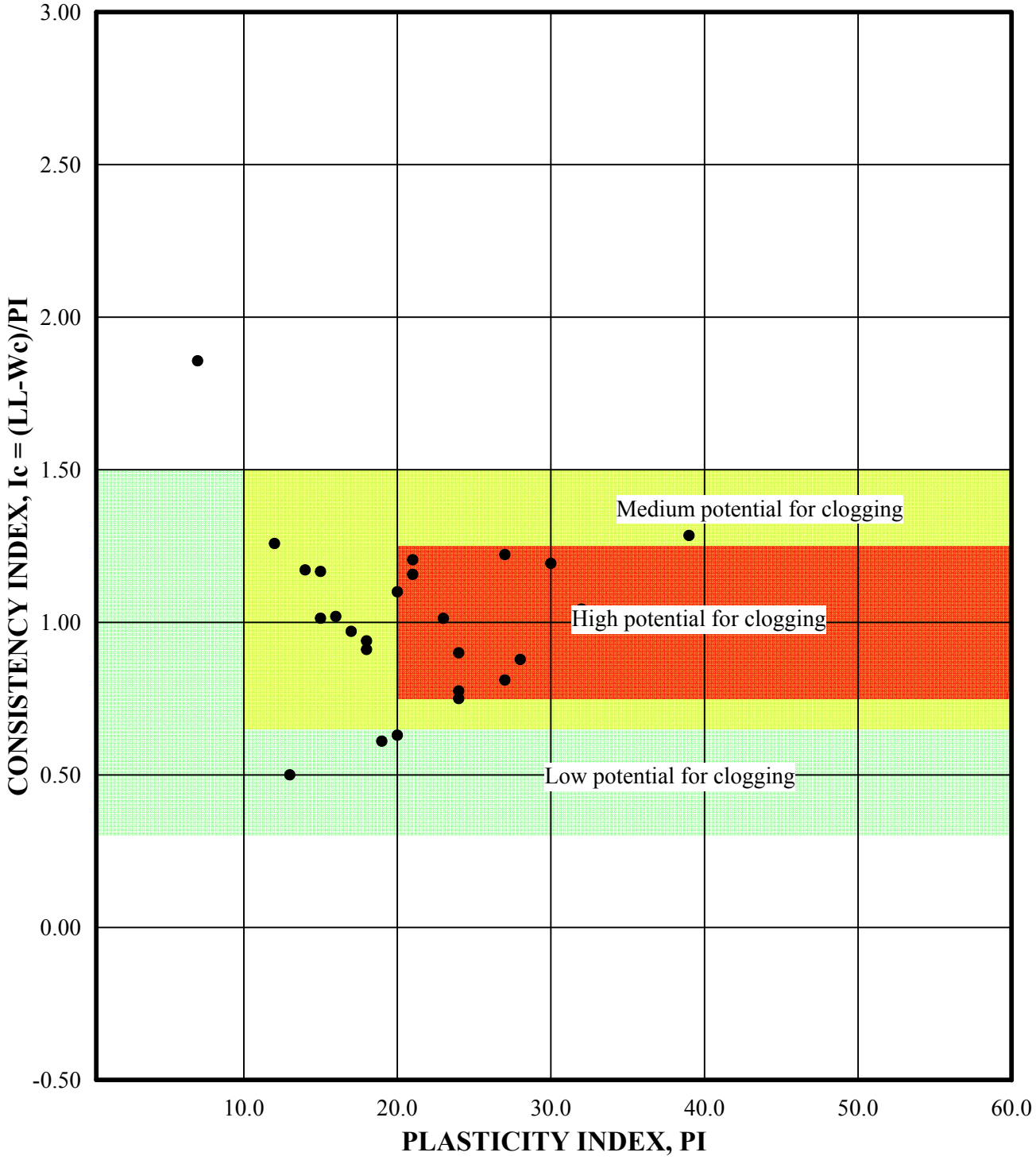
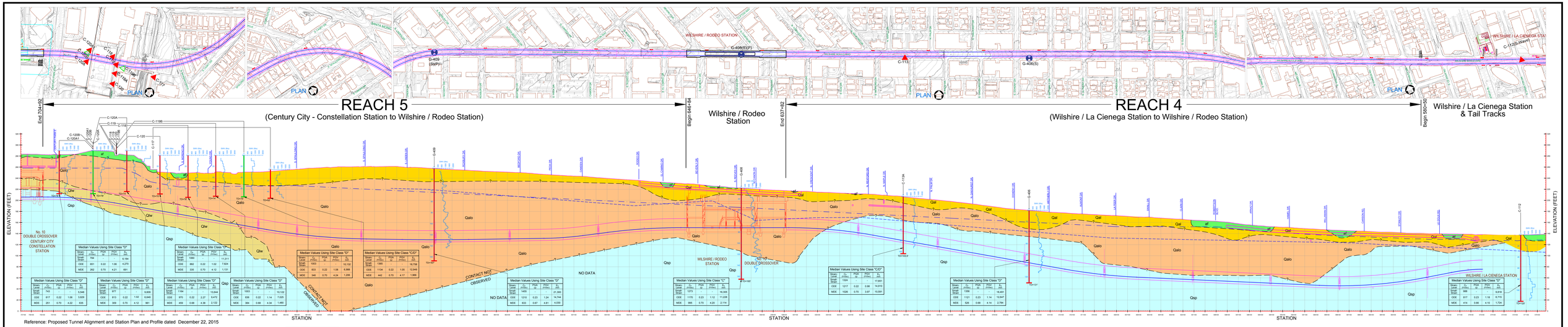
TUNNEL REACH 5



Reference: *Clogging of TBM drives in clay*, M. Thewes and W. Burger, 2005

Prepared/Date: SK 1/8/16
Checked/Date: FW 1/8/16

MTA Westside Subway Extension Los Angeles, California	amec foster wheeler	TBM Clogging Potential of soils (Reach 5) Project No.: 4953-11-1422 Plate 3-5



Reference: Proposed Tunnel Alignment and Station Plan and Profile dated December 22, 2015

Notes:
1. CPTs with seismic measurements are only shown here
2. Average shear-wave velocities estimated within the tunnel zone were used in computing seismic parameters. Tunnel zone is defined as tunnel diameter plus 10 feet above crown and 10 feet below tunnel invert

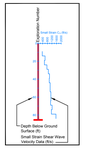
KEY SYMBOLS

Abbreviations:

- E_s Shear wave velocity (Vsec) within Tunnel zone*
- PGA Peak Ground Acceleration at tunnel level
- PGV Peak Ground Velocity at tunnel level
- E_d Elastic Modulus Computed using V_{sec} and a Poisson's ratio of 0.35
- ODE Operating Design Earthquake
- MDE Maximum Design Earthquake
- "D" Site Class based on NEHRP guidelines

*(Tunnel diameter plus 10' above crown and 10' below tunnel invert)

Geologic Formation	Average (C_n, ft/sec)
Older Alluvium	1,148
Lakewood	1,034
San Pedro	1,335



EXPLANATION

Investigations for PE Phase:
- C-113A Geotechnical CPT
- C-119B CPT [Geotechnical + Gas - BAT]

Investigations for Adv. PE Phase drilled in 2015 :
- G-406(S) Rotary-Wash/Hollow Stem Auger Boring

Symbol Labels:
- (S-Wave) Boring / CPT with shear wave velocity measurements

Symbols Legend:
- Site view of station. Alignment based on plans dated December 22, 2015
- Profile view of station (pink) with tunnel outline (black) and track (blue) based on plans dated December 22, 2015
- Site view showing center of tracks (blue), tunnel outlines (magenta dash) with perpendicular lines for of cross passage
- No. 10 double crossover
- Cross passage (profile view)
- Queried where poorly constrained
- Geologic contact line
- Historically recorded highest groundwater level (CDMG, 1998)

Geologic Units:
- af ARTIFICIAL FILL (undocumented)
- Qal YOUNGER ALLUVIUM (Holocene) - predominantly sand, silt and clay
- Qalo OLDER ALLUVIUM - varying layers of Silty Sand, Clayey/Silty Clay, and Silt with occasional gravel
- Qlw LAKEWOOD FORMATION (late Pleistocene) - interbedded Silty sands, Silts, and Clays with clayey Sand Layers
- Qsp SAN PEDRO FORMATION (mid Pleistocene) - predominately greenish gray and bluish gray fine-grained Sands, medium to coarse Sands and some Silt Layers

PROFILE: H=200', V=40' VERTICAL EXAGGERATION = 5:1

HORIZ: 0 50' 100' 200' 400'

VERT: 0 5' 10' 20' 40'

REV	DATE	BY	APP	DESCRIPTION

DESIGNED BY PE/RM
DRAWN BY KC/KO
CHECKED BY HP
IN CHARGE MBH / PM
DATE 1/28/2016

LOS ANGELES COUNTY METROPOLITAN TRANSPORTATION AUTHORITY

Metro

PB AECOM

PROJECT MANAGER: PARSONS BRINCKERHOFF QUADE & DOUGLAS, INC.

WESTSIDE PURPLE LINE EXTENSION
ADVANCED PRELIMINARY ENGINEERING

SEISMIC DESIGN PARAMETERS

TUNNEL REACHES 4 AND 5

STATION 580+50 to 704+92

CONTRACT NO.

DRAWING NO. PLATE 4

REV.

SCALE AS NOTED

SHEET NO.

Usefname: sgsuther jan 25, 2016 @ 9:27am FileNameroot= S:\ACAD\2015-165\956 Purple Line\Phase1-4 & Reach-5\Sections 4 & 5_Plate 4_Seismic parameters.dwg [Plan-1\COR]