Subject:	**Soil Abrasivity Testing Summary (Final Draft)**
Project feature:	Geotechnical
Prepared for:	California Department of Water Resources (DWR) / Delta Conveyance Office (DCO)
Prepared by:	Delta Conveyance Design and Construction Authority (DCA)
Copies to:	File
Date/Version:	December 23, 2021
Reference no.:	EDM_GE_CE_TMO_Soil-Abrasivity-Testing-Summary_000944_V03_FD_20211223

1. Summary

Between 2011 and 2018, Tonon USA (Tonon) performed a series of soil abrasion tests (SATs) on soil samples obtained by the DWR, to quantify the abrasivity of soils within the planned tunnel horizon. These tests were performed on samples from elevations of between -100 and -170 feet (North American Vertical Datum 1988 [NAVD88]) from project borings drilled between 2009 and 2018, as shown in Attachment 1. The results of the tests are contained in Appendix E of the *2013 Geotechnical Data Report* (DWR, 2013), Appendix E9 of the *2018 Bouldin Island Geotechnical Data Report* (DWR, 2018), and are summarized in Attachment 2. The summary of results in Attachment 2 includes a detailed review of the actual soil sample intervals used in the prior SAT testing. Where the requested soil sample intervals were available, as summarized in Table 1 of Attachment 2, they were taken as test intervals. Where these were not available, the reported intervals were used. The results of these tests indicate the soil abrasivity within the planned tunnel horizon ranges from medium to high (Jakobsen et al., 2013). The SAT classification is shown in Table 1.

Table 1. SAT Classification

Category	SAT
Low	≤ 7.0
Medium	7.1 – 21.9
High	≥ 22.0

Source: Jakobsen et al. (2013)
Notes:
Yellow shading indicates a medium SAT classification
Orange shading indicates a high SAT classification
≤ = less than or equal to
≥ = greater than or equal to

Given the importance of soil abrasivity in project tunnel drive planning, the DCA completed additional testing to confirm the Tonon test results and to evaluate the volcanic ash (Tephra – VP) and other soils within the tunnel horizon using the remaining samples stored in DWR's and AECOM's Sacramento warehouses. Attachment 3 provides a detailed summary of the 2020 DCA testing program, including the depth, soil type, and testing purpose of each sample. The selected samples were shipped to two different laboratories: (1) the Norwegian Technical Institute (NTNU), which was were responsible for developing the SAT testing procedure (Nilsen et al., 2006, 2007); and (2) the Colorado School of Mines (CSM) in Golden, Colorado.

Table 2 presents the results of the 2020 DCA testing program and includes the SAT values from prior testing, where available. Attachment 1 presents a map giving the locations of all borings for which SAT results are now available. The NTNU and CSM results suggest the abrasivity of the soils within the planned tunnel horizon is low to medium. It is noted that the tests conducted by Tonon USA follow the procedure outlined by Nilsen (2006), using a maximum allowable grain size of 1 millimeter (mm), while the 2020 DCA tests follow Nilsen (2007) and allow for a grain size of up to 4 mm. Jakobsen et al. (2013) demonstrated that there is a negligible difference between the two methods and that the SAT results are approximately equivalent, within the accuracy of the test. No further distinction between the 1 mm and 4 mm tests will be made.

Table 2. Summary of Delta Conveyance SAT Results

Boring ID	Depth Range (ft bgs)		USCS[a,b]	DCA Testing Purpose			SAT Results		
	From	To		Confirmatory[c]	Tephra[d]	New[e]	NTNU[f]	CSM[f]	Tonon[b]
DCA-DH-050	150.4	157.2	SP-SM	X			24.5	30.0	37.0
DCA-DH-054	99.5	105.3	SM	X			17.5	20.0	34.0
DCIF-DH-013	116.5	119.0	SM	X			9.5	16.0	23.0
DCIF-DH-015	109.5	116.0	SM	X			10.5	14.0	28.0
DCRA-DH-007	101.5	117.7	SM	X			10.0	13.0	28.5
DCRA-DH-012	142.0	147.5	s(ML)	X			5.5	13.0	48.0
DCA-DH-014	130.0	132.0	VP		X	X	7.5		
DCA-DH-024	142.0	143.5	VP		X	X	1.5		
DCBF-DH-018	157.0	157.5	SM			X		28.0	
DCBF-DH-018	162.5	163.0	SP-SM			X		30.5	
DCBF-DH-021	108.0	109.5	(CL)s			X	4.5		
DCE-DH-003	145.3	148.5	SP			X		14.0	
DCE-DH-003	165.3	167.0	MH			X		3.5	
DCE-DH-004	142.5	146.0	CL			X		2.0	
DCE-DH-005	162.8	163.6	SM			X		0.0	
DCE-DH-005	166.5	168.5	SM			X		13.5	
DCN4-DH-034	138.0	141.3	VP		X	X	1.0		
DCR-DH-010	149.0	149.5	ML			X	4.0		
DCR-DH-010	159.0	159.5	SC			X	10.5		
DCRA-DH-004	142.0	144.0	(CL)s			X		0.5	
DCRA-DH-004	162.5	164.5	s(ML)			X		2.0	
DCRA-DH-005	186.9	187.7	VP		X	X	1.0		

Table 2. Summary of Delta Conveyance SAT Results

Boring ID	Depth Range (ft bgs)		USCS[a,b]	DCA Testing Purpose			SAT Results		
	From	To		Confirmatory[c]	Tephra[d]	New[e]	NTNU[f]	CSM[f]	Tonon[b]
DCRA-DH-006	163.0	164.5	SP-SM			X	15.5		
WFT-DH-002	228.0	232.0	VP		X	X	1.0		
DCA-DH-008a	115.5	116.8	SP						27.5
DCA-DH-014	70.0	72.6	SM						16.0
DCA-DH-017	77.0	83.5	SP						18.5
DCA-DH-024	72.0	81.5	SM						25.0
DCA-DH-024	144.0	147.0	SP						7.0
DCA-DH-030	80.0	84.0	SP-SM						20.0
DCA-DH-030	130.0	136.5	(ML)s						7.5
DCA-DH-031	124.5	127.0	S(CL)						8.5
DCA-DH-037	75.0	81.5	SP						23.0
DCA-DH-059	147.0	148.5	SM						26.5
DCBF-DH-002	120.0	121.5	SP						45.0
DCBF-DH-002	125.0	126.3	SM						45.0
DCIF-DH-013	156.2	156.7	(SM)g						28.0
DCIF-DH-015	164.5	165.0	(SP)g						32.0
DCRA-DH-002	76.5	77.5	SP						51.5
DCRA-DH-002	81.5	83.0	(GM)s						39.5
DCRA-DH-003	141.5	142.0	SM						23.0
DCRA-DH-004	151.5	153.0	SP						31.0
DCRA-DH-006	140.0	140.5	SP-SM						37.0
DCRA-DH-006	148.0	151.0	SM						39.5
DCRA-DH-009	151.5	124.9	SM						20.5
DCRA-DH-010	172.5	179.0	SM						24.5
DCRA-DH-011	118.0	120.0	SP-SM						30.0
DCRA-DH-011	124.5	125.0	SM						59.5
DCRA-DH-012	77.5	84.0	SM						41.0
DCRA-DH-013	128.0	138.0	SP						22.0

Table 2. Summary of Delta Conveyance SAT Results

Boring ID	Depth Range (ft bgs)		USCS[a,b]	DCA Testing Purpose			SAT Results		
	From	To		Confirmatory[c]	Tephra[d]	New[e]	NTNU[f]	CSM[f]	Tonon[b]
DCRA-DH-014	138.5	139.0	SM						53.0
DCRA-DH-014	148.5	153.5	SP-SM						41.0
DCRA-DH-017	76.5	81.5	SM						46.5
DCRA-DH-022	121.0	127.5	(CL)s, SM						43.0
WFT-DH-001	108.0	109.5	SM						13.0
WFT-DH-001	123.0	124.5	SM						13.5
WFT-DH-002	81.5	83.0	SP-SM						16.0
WFT-DH-002	106.0	107.5	SM						22.0
WFT-DH-003	90.5	92.5	SP						15.5
WFT-DH-003	127.3	128.5	SM						15.0

[a] Unified Soil Classification System

[b] Appendix A-D (DWR, 2013), Appendix E (DWR, 2018)

[c] Confirmatory samples are used to compare results against previously tested samples

[d] Samples containing tephra (volcanic ash) were previously untested. (Maier, K.L., et al., 2015)

[e] Samples from new borings will be tested to investigate data gaps within the tunnel horizon along the central and eastern corridors as defined in the NOP and near the southern forebay

[f] Mean AVS as presented in NTNU Testing Report (2020) and CSM Testing Report (2020)

Notes:

For an explanation of cell shading, refer to Table 1

ft bgs = feet below ground surface

ID = identification

CL = clay, V P= tephra, MH = silt, SM = silty sand, SP = poorly-graded sand, SP-SM = poorly-graded sand with silt, GM = gravel with silt

Figure 1 presents a “box and whiskers” plot of prior SAT test results by Tonon, with 2020 DCA test results from NTNU and CSM superimposed as individual points.

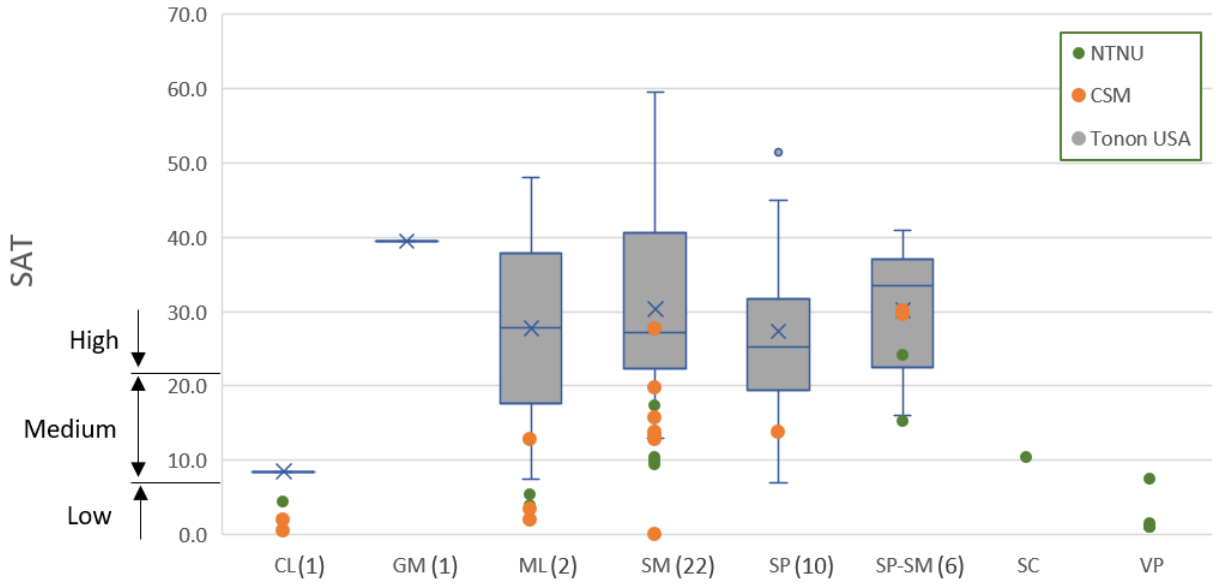
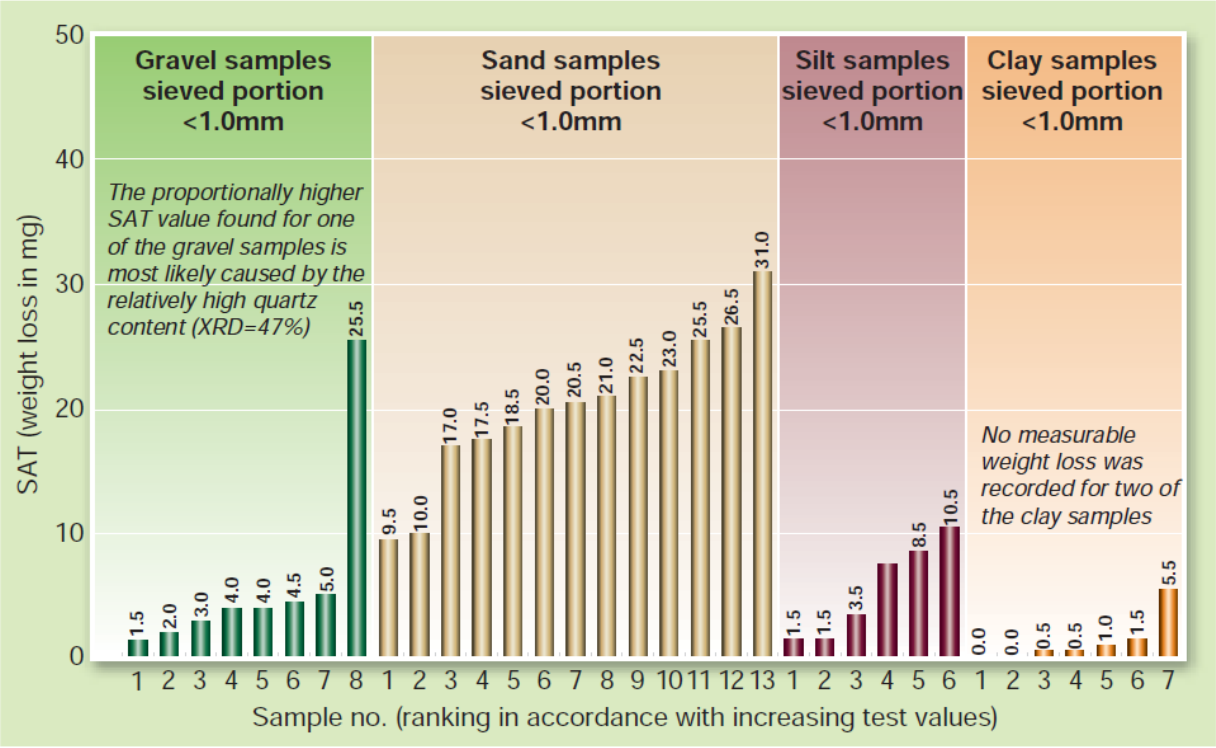


Figure 1. Summary of Current Project SAT Test Results

Boxes denote ± one standard deviation, "whiskers" denote data minimum and maximum, lines denote mean values, and "x"s denote average values; horizontal axis is USCS soil type and axis value in parenthesis is number of Tonon USA tests per soil type. Note the Tonon data outlier datapoint shown for SP soil type.

Figure 2 presents a plot of reported SAT values from the Seattle, Washington area by soil type (Nilsen, 2006).



Source: (Nilsen et al., 2006)

Figure 2. SAT Test Results for the Seattle Area Soil Samples (Particles less than 1.0 millimeter)

Table 3 presents the confirmatory testing results presented in Table 1, alongside of geological unit identified by the DCA and quartz content results from X-ray diffraction tests performed on samples of the soil strata by Tonon USA.

Table 3. Summary of SAT Confirmatory Test Results

Boring ID	Depth Range (ft bgs)		USCS[a,b]	SAT Results			Geological Unit	Quartz Content (%)
	From	To		NTNU[c]	CSM[c]	Tonon[b]		
DCA-DH-050	150.4	156.0	SP-SM	24.5	30.0	37.0	Qr	37.0
DCA-DH-054	99.5	105.3	SM	17.5	20.0	34.0	Qm	30.5
DCIF-DH-013	116.5	119.0	SM	9.5	16.0	23.0	Qr	50.3
DCIF-DH-015	110.7	116.0	SM	10.5	14.0	28.0	Qtl	49.9
DCRA-DH-007	101.5	117.7	SM	10.0	13.0	28.5	Qr	46.1
DCRA-DH-012	142.0	147.5	s(ML)	5.5	13.0	48.0	Qr	Not Available

[a] Unified Soil Classification System

[b] Appendix A-D (DWR, 2013), Appendix E (DWR, 2018).

[c] Mean AVS as presented in NTNU Testing Report (2020) and CSM Testing Report (2020)

Notes:

For an explanation of cell shading refer to Table 1

NA = not available

Qm = Modesto

Qr = Riverbank

Qtl = Turlock Lake

Figure 3 presents a plot of the difference in reported SAT values versus the quartz content for the sand samples of the confirmatory dataset (note, the quartz content for the silt samples were not available).

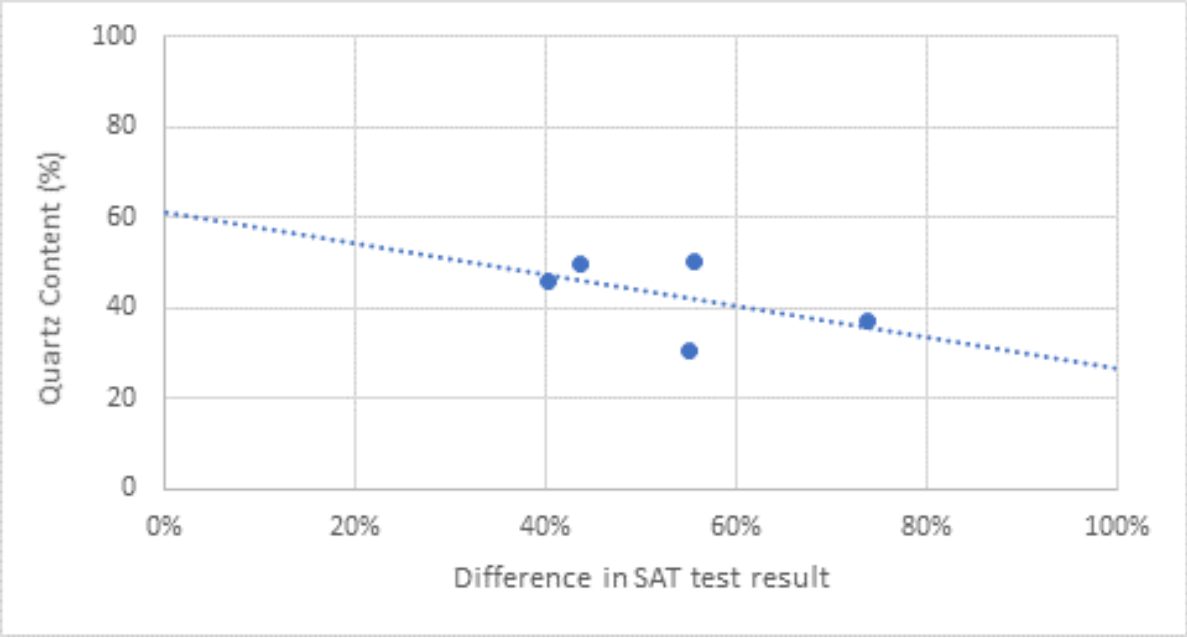


Figure 3. Difference between Confirmatory SAT Values and Quartz Content

Ratio of 2020 confirmatory results (average of NTNU and CSM value) to Tonon USA results

Observations

The following observations were noted:

If one averages the SAT values reported by NTNU and CSM for a given "confirmatory" soil sample and compares the average to the Tonon result for the same sample, the 2020 DCA results are between 19- and 74-percent of the Tonon USA result, with an average of approximately 50-percent. That difference is even higher if one compares the Tonon USA results directly to the NTNU results.

The contrast in the difference between the 2020 DCA results and the prior results is most evident for the materials classified as silt (ML), especially when compared to the silt material results presented for the Seattle area on Figure 2.

There does not appear to be a correlation between the variability of the test results to the geological unit. The six confirmatory samples were collected from the Pleistocene alluvial soils of the Riverbank, Modesto, and Turlock Lake formations.

There may be a correlation between the quartz content of the soils and the differences in SAT results (Figure 3). It may be observed that sands with greater quartz contents reported lower differences between the confirmatory results and those from Tonon. This would agree with the observation that the greatest discrepancy in results is with the silt samples, which would be expected to generally have low quartz content.

A review of the SAT results suggests the cleaner sands (poorly graded sand with silt [SP-SM]) are reporting SAT values from CSM and NTNU in the "Medium" to "High" category, although the SAT results are typically 50 percent those reported by Tonon USA.

Samples of volcanic tephra identified as discrete layers within the tunnel horizon, as well as fine-grained silts and clays, appear to have low abrasivity.

2. Recommendations

Given the large differences between the SAT results from Tonon and those from CSM and NTNU, DCA recommends discounting the Tonon results in silts and factoring the results from sands when planning drive lengths.

DCA further recommends using NTNU, the test developer, for future SAT testing; or considering other North American laboratories in conjunction with confirmatory duplicate testing by NTNU to validate the results.

3. References

Colorado School of Mines (CSM). 2020. Soil Abrasion Testing, EMI Report #471. Earth Mechanics Institute.

Department of Water Resources (DWR). 2013. 2009 – 2012 Geotechnical Data Report, Pipeline/Tunnel Option. Delta Habitat Conservation and Conveyance Program.

Department of Water Resources (DWR). 2018. Geotechnical Data Report, Access Road and Site Improvements. Bouldin Island, California WaterFix.

Jakobsen, D., A. Bruland, and F. Dahl. 2013. Review and assessment of the NTNU/SINTEF Soil Abrasion Test (SAT™) for determination of abrasiveness of soil and soft ground. TUST 37. pp. 107 -114.

Maier, K.L., et al. 2015. "Quaternary tephrochronology and deposition in the subsurface Sacramento-San Joaquin Delta." Quaternary Research.-http://dx.doi.org/10.1016/j.yqres.2014.12.007 Accessed June 15, 2020.

Nilsen, B., Dahl, F., Holzhäuser, J., and Raleigh, P. 2006. SAT: NTNU's new soil abrasion test. Tunnels and Tunnelling International. No. 38. pp. 43-45.

Nilsen, B., Dahl, F., Holzhäuser, J. and Raleigh, P. 2007. New test methodology for estimating the abrasiveness of soils for TBM tunneling, RETC Proceedings, 104 – 116.

Norwegian University of Science and Technology (NTNU). 2020. Soil Abrasion Test Report No. 102022149-023. SINTEF.

4. Document History and Quality Assurance

Reviewers listed have completed an internal quality review check and approval process for deliverable documents that is consistent with procedures and directives identified by the Engineering Design Manager and the DCA.

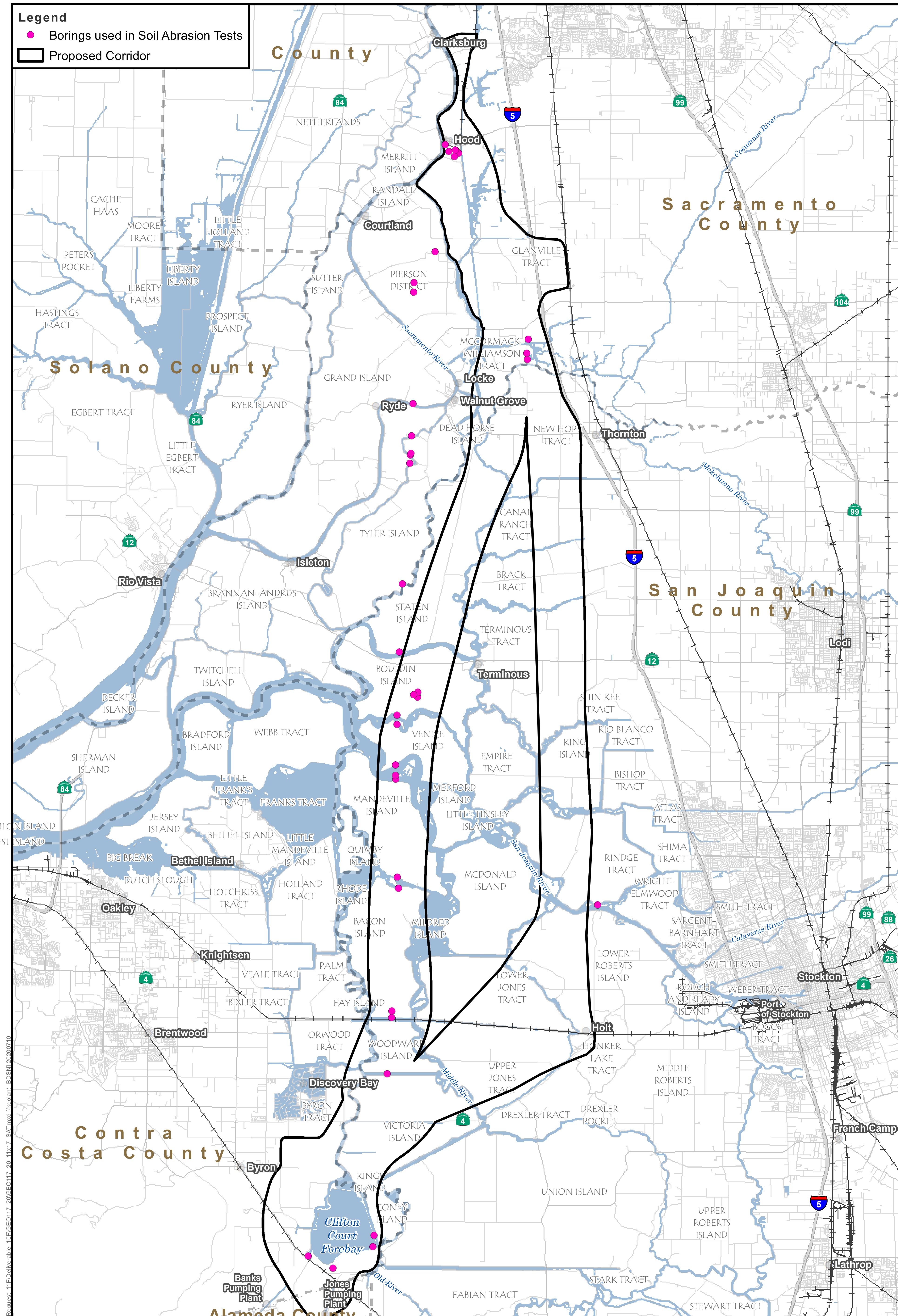
Approval Names and Roles			
Prepared by	**Internal Quality Control review by**	**Consistency review by**	**Approved for submission by**
John Hinton / EDM Geotechnical Engineer	Andrew Finney / EDM Geotechnical and Field Work Lead	Gwen Buchholz / DCA Environmental Consultant	Terry Krause / EDM Project Manager

This interim document is considered preliminary and was prepared under the responsible charge of Andrew Finney, California Professional Engineering License GE2759.

Note to Reader

This is an early foundational technical document. Contents therefore reflect the timeframe associated with submission of the initial and final drafts. Only minor editorial and document date revisions have been made to the current Conformed Final Draft for Administrative Draft Engineering Project Report version.

Attachment 1
Map of Borings with Samples Used in Soil Abrasion Tests


Legend
Borings used in Soil Abrasion Tests
Proposed Corridor
County
Sacramento County
Solano County
San Joaquin County
Contra Costa County
Alameda County
Clarksburg
Hood
Courtland
Locke
Walnut Grove
Ryde
Thornton
Isleton
Rio Vista
Terminous
Lodi
Bethel Island
Oakley
Knightsen
Brentwood
Discovery Bay
Byron
Holt
Stockton
Port of Stockton
French Camp
Lathrop
Banks Pumping Plant
Jones Pumping Plant
Clifton Court Forebay
Sacramento River
Cosumnes River
Mokelumne River
San Joaquin River
Calaveras River
Middle River
Old River
NETHERLANDS
MERRITT ISLAND
RANDALL ISLAND
CACHE HAAS
MOORE TRACT
LITTLE HOLLAND TRACT
PETERS POCKET
LIBERTY ISLAND
LIBERTY FARMS
SUTTER ISLAND
PIERSON DISTRICT
GLANVILLE TRACT
HASTINGS TRACT
PROSPECT ISLAND
MCCORMACK-WILLIAMSON TRACT
GRAND ISLAND
EGBERT TRACT
RYER ISLAND
DEAD HORSE ISLAND
NEW HOPE TRACT
LITTLE EGBERT TRACT
CANAL RANCH TRACT
TYLER ISLAND
BRACK TRACT
BRANNAN-ANDRUS ISLAND
STATEN ISLAND
TERMINOUS TRACT
TWITCHELL ISLAND
BOULDIN ISLAND
DECKER ISLAND
SHIN KEE TRACT
RIO BLANCO TRACT
BRADFORD ISLAND
WEBB TRACT
VENICE ISLAND
KING ISLAND
SHERMAN ISLAND
EMPIRE TRACT
BISHOP TRACT
LITTLE FRANK'S TRACT
FRANKS TRACT
MEDFORD ISLAND
MANDEVILLE ISLAND
LITTLE TINSLEY ISLAND
JERSEY ISLAND
ATLAS TRACT
DONLON ISLAND
WEST ISLAND
BETHEL ISLAND
LITTLE MANDEVILLE ISLAND
QUIMBY ISLAND
SHIMA TRACT
BIG BREAK
RINDGE TRACT
DUTCH SLOUGH
MCDONALD ISLAND
HOTCHKISS TRACT
HOLLAND TRACT
RHODE ISLAND
WRIGHT-ELMWOOD TRACT
SMITH TRACT
BACON ISLAND
MILDRED ISLAND
SARGENT-BARNHART TRACT
LOWER ROBERTS ISLAND
PALM TRACT
VEALE TRACT
LOWER JONES TRACT
ROUGH AND READY ISLAND
WEBER TRACT
BIXLER TRACT
FAY ISLAND
BOGGS TRACT
ORWOOD TRACT
WOODWARD ISLAND
HONKER LAKE TRACT
UPPER JONES TRACT
MIDDLE ROBERTS ISLAND
BYRON TRACT
VICTORIA ISLAND
DREXLER TRACT
DREXLER POCKET
KINGS ISLAND
UNION ISLAND
CONEY ISLAND
UPPER ROBERTS ISLAND
STARK TRACT
FABIAN TRACT
STEWART TRACT
84
5
99
104
12
4
88
26

DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

For Illustration Purposes Only

N

0 1.5 3 Miles

Figure 1
Borings used in Soil Abrasion Tests

T:\WGI-38\GIS_33_00\GISRequest_11F\Deliverable_10F\GEO117_20\GEO117_20_11x17_SAT.mxd (kdolan) BDSN| 20200710

Data Source: DCA, DWR

Attachment 2
Prior Soil Abrasion Tests Memorandum

DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

Memorandum

Subject	**Soil Abrasion Test Results**
Project feature	Geotechnical
Prepared for	Files
Prepared by	John Hinton/EDM
Copies to	Andrew Finney/EDM
Date/Version	Draft V1, 01/31/2020
Reference no.	EDM_GE_CE_TMO_Soil Abrasion Test Memo_000457_1_D_20200131

1. Introduction

Between 2011 and 2018, a series of Soil Abrasion Tests (SATs) and Slurry Abrasivity Tests were performed by Tonon USA and White Rock Engineering Services, respectively, to quantify the abrasivity of soils within the planned tunnel horizon. These tests were performed on samples from elevations of between -100 and -170 feet (MSL) from project borings drilled between 2009 - 2018. The results of the tests are contained in Appendix E of the 2013 Geotechnical Data Report (DWR, 2013), Appendix E9 of the 2018 Bouldin Island Geotechnical Data Report (DWR, 2018), and summarized in this memo.

1.1 Soil Abrasion Tests

Table 1 was prepared to summarize the abrasion test results completed to-date and to clarify the specific samples and depth ranges tested. Table 1 shows the samples used for each SAT and the resulting average abrasion value (AVS), as performed by Tonon USA, between 2011 and 2012. It should be noted that all samples were of a single material (soil type), as shown in Table 1, except for DCRA-DH-022. Also of note was the fact that the project boring logs identified the AVS value at the top of the sample range in their Remarks column, as shown in Table 1. Table 2 gives the samples used and the associated AVS and LCPC results by Tonon USA from an abrasivity study performed on samples obtained from exploration at Bouldin Island in 2018.

Table 1. Soil Abrasion Test Samples and Results (DWR, 2013)

Test Date Group	Boring	Actual[1]		Reported as		Material Type[4]	AVS
		Depth Range (feet)	Sample Number	Lab Test Results[2]	Boring Logs[3]		
1/31/2011	DCRA-DH-002	76.5-77.5	P09A, P09B	75-77.5	S09A-075.0-076.5	SP	51.5
		81.5-83	P10A, P10B	81.5-83	P10A-081.5-082.0	(GM)s	39.5
	DCRA-DH-006	140-140.5	P23A	140-141	P23A-140.0-140.5	SP-SM	37
		148-151	S23A, P25A	148-151	S23A-148.0-149.5	SM	39.5
	DCRA-DH-010	172.5-179	S25A, P27A, S26A	172.5-179	S25A-172.5-174.0	SM	24.5
	DCRA-DH-011	118-120	S15A, P15A	118-120	S15A-118.0-119.5	SP-SM	30
		124.5-125	P16A	125-126	P16A-124.5-125.0	SM	59.5
	DCRA-DH-012	77.5-84	S12A, P11A, S13A	77.5-84	S12A-077.5-079.0	SM	41
		144.5-145	P24A	144.5-145.5	P24A-144.5-145.0	s(ML)	48
	DCRA-DH-014	138.5-139	P22A	139-140	P22A-138.5-139.0	SM	53
		148.5-153.5	P24A, S24A	148.5-153.5	P24A-148.5-149.0	SP-SM	41
	DCRA-DH-017	76.5-81.5	P12A, S14A, P13A	76.5-81.5	P2A-076.5-077.0	SM	46.5
	DCRA-DH-022	121-127.5	S19A, S20A, P21A	121-127.5	125**	(CL)s, SM	43
3/28/2012	DCA-DH-037	75-81.5	S12A, P15A, S13A	71-88	71**	SP	23
	DCA-DH-031	124.5-127	Box 3	122.5-131.5	Box 3 124.5-127.0	S(CL)	8.5
	DCA-DH-030	80-84	S13A, P16A	72-89.5	72**	SP-SM	20
		130-136.5	S23A, P26A, S24A	124.5-142	124.5**	(ML)s	7.5
	DCA-DH-024	72-81.5	P14A, S14A, P15A, S15a	67.5-83	68**	SM	25
		144-147	P29A, S28A, P28C1/2	143.5-150	147.5**	SP	7
	DCA-DH-017	77-83.5	P15A, P16A, S13A1/2	74-98.5	P14B-074.0-074.5	SP	18.5
	DCA-DH-014	70-72.6	P14A, P14B	63.8-79.5	P13A-065.5-066.0	SM	16

Table 1. Soil Abrasion Test Samples and Results (DWR, 2013)

Test Date Group	Boring	Actual[1]		Reported as		Material Type[4]	AVS
		Depth Range (feet)	Sample Number	Lab Test Results[2]	Boring Logs[3]		
11/9/2012	DCRA-DH-003	141.5-142	P21	142	Box 5 142.0-143.5	SM	23
	DCRA-DH-004	Unknown	P24*	152	Box 5 151.5-153.0	SP	31
	DCRA-DH-007	Unknown***	Unknown	117	Box 3 117.7-117.9	SM	28.5
	DCRA-DH-009	Unknown	P16*	122	Box 1 121.5-124.9	SM	20.5
	DCRA-DH-013	Unknown	P18*	129	Box 4 128.0-130.0	SP	22
	DCA-DH-008a	Unknown	P24*	116	Box 2 115.5-116.8	SP	27.5
	DCA-DH-050	Unknown	P33*	156	Box 6 156.0-157.2	SP-SM	37
	DCA-DH-054	Unknown	P22*	100	Box 1 099.5-102.3	SM	34
	DCA-DH-059	147-148.5	P31	147	P31A-147.0-148.5	SM	26.5
	DCBF-DH-002	120-121.5	S21	120	S21A-120.0-121.5	SP	45
		125-126.25	S22	125	S22A-125.0-126.25	SM	45
	DCIF-DH-015	164.5-165	P33	166	Box 10 166.0-166.5	(SP)g	32
		Unknown	P22*	110	Box 4 109.5-110.7	SM	28
	DCIF-DH-013	Unknown	P24*	118	Box 14 116.5-119.0	SM	23
		156.2-156.7	P32	156	Box 20 155-156.2	(SM)g	28

[1] As identified in laboratory test request forms

[2] Appendix E (DWR, 2013)

[3] As shown in Remarks column in logs provided in Appendices A-D (DWR, 2013)

[3] Unified Soil Classification System as defined in the project boring logs provided in Appendices A-D (DWR, 2013)

* No such sample number shown in logs contained in Appendices A-D (DWR, 2013)

** No retained sample noted in logs contained in Appendices A-D (DWR, 2013). Depth given is depth of test “SA” shown in Other Lab Tests column

AVS = average abrasion value

***Reported range is shown as clay (CL), while sample was identified to be sand (SM) and therefore sample was attributed to interval 117.7-177.9.

Table 2. Soil Abrasion Test Samples and Results - Bouldin Island Investigation (DWR, 2018)

Boring	Depth Range (feet)	Project Sample Number	Material Type[1]	AVS	LCPC[2]
WFT-DH-001	108.0-109.5	P21A	SM	13	14
WFT-DH-001	123.0-124.5	P22A	SM	13.5	90
WFT-DH-002	81.5-083.0	P14A	SP-SM	16	56
WFT-DH-002	106.0-107.5	P17A	SM	22	56
WFT-DH-003	90.5-092.5	P17A	SP	15.5	18
WFT-DH-003	127.3-128.5	P25A	SM	15	58

Source: Bouldin Island Geotechnical Data Report

[1] Unified Soil Classification System as defined in the project boring logs provided in Appendix E9 (DWR, 2018)

[2] Laboratoire Central des Ponts et Chaussées abrasion test

AVS = average abrasion value

Table 3 summarizes the range of AVS and LCPC values shown in Tables 1 and 2.

Table 3. Summary of SAT and LCPC results

Test	Minimum	Maximum	Average	Average SAT + 1 std.
SAT	7.0	59.5	29.0	42
LPCC	14.0	90.0	48.7	77

1.2 Slurry Abrasivity Tests

In addition to SATs, a series of slurry abrasivity tests were performed on composite samples from 2010 to 2012 by White Rock Engineering Services. Table 4 summarizes the samples used within each test as well as the associated standard and inhibited Miller Number.

Table 4. Slurry Abrasivity Test Samples and Results

Test Date Group	Boring	Depth Range (feet)	Project Sample Number	Standard Miller Number	Inhibited Miller Number
1/13-1/27	DCRA-DH-001	73-91.5	P07A, S09A	262.1	217.3
		133.5-136.5	P19A, S18A	171.5	132
		147.5-149	P22A	133.1	94.4
	DCRA-DH-002	113.5-114	P16A	405.1	350.6
		115-121.5	S17A, S18A	429.7	385.2
	DCRA-DH-006	83-94.5	S11A, S13A	248.3	163.3
		101.5-102	P15A	148.9	112.7
		155.5-159.5	P26A, S25A	177.4	128.6
	DCRA-DH-008	100-106.5	S15A, S16A	183.9	158.6
	DCRA-DH-010	70-75	P06A, S07A, P07A	188.5	197.5
	DCRA-DH-011	79.5-83	B01A (shaker sample)	162.8	130.5
		125-126	P16A	108.7	87.9
	DCRA-DH-012	84.5-89	P12A, S14A	186.7	155
	DCRA-DH-014	62-68.5	S07A, S08A	183.3	162.2
		72-87	S09A, P11A	243.6	205.5
		138.5-139	P22A	129.2	70.1
	DCRA-DH-017	101-102	P17A	151.2	108.1
	DCRA-DH-022	67.5-69.5	S10A, P10A	162	130.4
		79-83	P12A, S13A	152.2	114
		89-89.5	P14A	292.3	268
		94-104	S16A, S17A, P15A	203.9	134
	DCRA-DH-024	80-86.5	S15A, S16A	276.8	226.6

Table 4. Slurry Abrasivity Test Samples and Results

Test Date Group	Boring	Depth Range (feet)	Project Sample Number	Standard Miller Number	Inhibited Miller Number
11/4-12/4	DCA-DH-037	71-88	P14A	179	132
	DCA-DH-031	81.2-91.5	Box 1	159	124
		91.5-99.4	P20A	179	139
		122.5-131.5	S21A, S22A	91	46
	DCA-DH-030	72-89.5	P14A, S12A	162	122
		124.5-142	S22A, P25A	62	26
	DCA-DH-024	67.5-83	P13A, P14A	238	194
		143.5-150	P28B, P28C1/2	148	103
	DCA-DH-017	45-50	S06A, S07A	212	186
		74-98.5	P14B, P15A, S13A1/2	N/A*	N/A*
	DCA-DH-014	63.8-79.5	S11B, P13B	171	131
11/4-12/20	DCA-DH-059	125.5-132.0	S20A, P27A, S21A	230	178
	DCBF-DH-001	87.0-96.5	P18A, P19A, S17A	252	177
		126.5-132.5	P26A, S24A, P27A	232	196
	DCBF-DH-003	115.0-121.5	S21A, P26A, S22A	232	171

[1] Year of testing not provided in Appendix E (DWR, 2013)

Source: 2011 Geotechnical Data Report, Appendix E

* Samples were never received by Tonon USA

Table 5 summarizes the range of AVS and LCPC results given in Table 4.

Table 5. Summary of Slurry Abrasivity Test Results

Test	Minimum	Maximum	Average	Average + 1 std.
Standard Miller Number	62.0	429.7	199	273
Inhibited Miller Number	26.0	385.2	157	229

Attachment 3
Additional Soil Abrasion Test Work Plan

DELTA CONVEYANCE DESIGN & CONSTRUCTION AUTHORITY

Memorandum

Subject	**Soil Abrasion Test Work Plan**
Project feature	Geotechnical
Prepared for	Files
Prepared by	John Hinton/EDM
Copies to	Andrew Finney/EDM
Date/Version	Draft, V3, 02/18/2020
Reference no.	DCA_GE_CE_MEM_Soil Abrasion Test Work Plan_000467_1_D_20200213

1. Introduction

Between 2011 and 2018, a series of Soil Abrasion Tests (SATs) were performed by Tonon USA in order to quantify the abrasion potential of soils within the Delta. These tests were performed on samples from elevations of between -100 and -170 feet (MSL) from project borings drilled between 2009 and 2018. The results of the SATs are contained in Appendix E of the 2013 Geotechnical Data Report (DWR, 2013) and the 2018 Bouldin Island Geotechnical Data Report (DWR, 2018). The Tonon USA SAT results classify 71% of the samples as highly abrasive, while the remaining 29% are classified as moderately abrasive.

In order to confirm the 2009-2018 test results, to evaluate the repeatability of the SAT, and to expand the suite of SAT results, the DCA will conduct further abrasion testing on existing samples of soils collected as part of the 2009-2018 exploration programs. The additional testing will be performed at the Colorado School of Mines (CSM) and the Norwegian University of Science and Technology (NTNU), both educational institutions with established testing laboratories. It is noted that the SAT test was originally developed at NTNU (Nilsen et. al, 2006).

1.1 Procedure

Representatives of the DCA identified and catalogued existing soil samples located in the Department of Water Resources and AECOM warehouses in Sacramento. Identified untested soil samples satisfy one or more of the following criteria:

- of similar USCS classification and at similar depths as the original samples tested by Tonon USA
- containing volcanic ash (tephra)
- within a potential tunnel horizon

In addition, samples must meet the following minimum: at least 1kg (2.2lb) of fine material or 2kg (4.4lb) of granular material (>4mm), per NTNU SAT standard (Nilsen et. al, 2006). Attachment 1 presents the 30 soil samples identified for SAT, for which the testing destination is determined as follows:

- 6 confirmatory samples will each be split into two samples (12 samples total) to allow concurrent testing at CSM and NTNU. The minimum size for these samples is twice the above minimums.
- all new samples containing tephra (5 samples total) will be tested at NTNU to allow for direct comparison between different tephra layers
- the remaining new samples (exclusive of samples of tephra) (13 samples total) will be divided into two groups and sent to CSM and NTNU, as defined in Attachment 1.

The unit testing and shipping prices and the final costs are given in Table 1.

Table 1. Soil Abrasion Test Sample Summary

	Number of tests	Cost per test (USD) [1,2]	Administration Fee (USD) [1,2]	Est. Shipping Cost (USD) [3]	Approx. Total Cost (USD)
CSM	15	650	0	50	9,800
NTNU	15	706	200	120	10,915
					20,715

Sources:

[1] Colorado School of Mines, Earth Mechanics Institute; Attachment 2

[2] Norwegian University of Science and Technology; Attachment 3. Includes 25% VAT.

[3] FedEX ground, international: Assuming 4.4 lb/sample, 15 samples per box, 1 box each

2. References

Maier, K.L., et al., (2015). Quaternary tephrochronology and deposition in the subsurface Sacramento–San Joaquin Delta, Quaternary Research (2015), http://dx.doi.org/10.1016/j.yqres.2014.12.007.

Nilsen, Bjørn & Dahl, Filip & Holzhauser, Jurg & Raleigh, Peter. (2006). SAT: NTNU's new soil abrasion test. Tunnels and Tunnelling International. 38. 43-45.

Department of Water Resources (DWR)(2013). 2009 – 2012 Geotechnical Data Report, Pipeline/Tunnel Option. Delta Habitat Conservation and Conveyance Program.

Department of Water Resources (DWR)(2018). Geotechnical Data Report, Access Road and Site Improvements. Bouldin Island, California WaterFix.

Attachment 1

Samples for SAT

Table 1-1. Samples for SAT

Boring ID	Retained Sample [1]	Depth Range		USCS [2]	Testing Purpose			Laboratory	
		To	From		Confirmatory [3]	Tephra [4]	New [5]	CSM	NTNU
DCIF-DH-013	Box 14	116.5	119.0	SM	X			X	X
DCRA-DH-012	Box 4	142.0	147.5	s(ML)	X			X	X
DCA-DH-050	Box 5	150.4	156.0	SP-SM	X			X	X
DCA-DH-054	Box 1	99.5	105.3	SM	X			X	X
DCIF-DH-015	Box 5	110.7	116.0	SM	X			X	X
DCRA-DH-007	Box 1	101.5	117.7	SM	X			X	X
DCA-DH-024	Box 6	142.0	143.5	VP		X	X		X
DCA-DH-014	Box 6	130.0	132.0	VP		X	X		X
DCN4-DH-034	Box 2	138.0	141.3	VP		X	X		X
DCRA-DH-005	Box 13	186.9	187.7	VP		X	X		X
WFT-DH-002	Box 16	228.0	232.0	VP		X	X		X
DCE-DH-003	Box 3	145.3	148.5	SP			X	X	
DCE-DH-003	Box 4	165.3	167.0	MH			X	X	
DCE-DH-004	Box 3	142.5	146.0	CL			X	X	
DCE-DH-005	Box 3	162.8	163.6	SM			X	X	
DCE-DH-005	Box 4	166.5	168.5	SM			X	X	
DCRA-DH-004	Box 4	142.0	144.0	(CL)s			X	X	
DCRA-DH-004	Box 6, 7	162.5	164.5	s(ML)			X	X	
DCBF-DH-018	P32A	157.0	157.5	SM			X	X	
DCBF-DH-018	P33A	162.5	163.0	SP-SM			X	X	
DCBF-DH-021	S19A	108.0	109.5	(CL)s			X		X
DCRA-DH-006	S26A	163.0	164.5	SP-SM			X		X
DCR-DH-010	P27A	149.0	149.5	ML			X		X
DCR-DH-010	P29A	159.0	159.5	SC			X		X

Notes:

[1] Sample will be taken from depth range, exact depth will be determined after weighing 2kg from range.

[2] Unified Soil Classification System, Appendix A-D (DWR, 2013), Appendix E (DWR, 2018).

[3] Confirmatory samples will be used to compare results against previously tested samples.

[4] Samples containing tephra (volcanic ash) will be tested to investigate abrasion potential, as determined by (Maier, K.L., et al., 2015).

[5] Samples from new borings will be tested to investigate the tunnel horizon along the eastern corridor as defined in the NOP and near the southern forebay.

Attachment 2

CSM SAT Pricing

EARTH MECHANICS INSTITUTE

Colorado School of Mines
1312 Maple Street, Golden, CO - 80401. USA.
+1 (303) 273-3123 emi@mines.edu

QUOTE

Customer

Company: Delta Conveyance Design & Construction Authority
Name: John Hinton
Address: 1121 L Street, Suite 1045
City: Sacramento State: CA Zip: 95814
Phone: Cell: 916-352-8455
e-mail: JohnHinton@dcdca.org
CC:

Quote #: Q-107
Date: 2/14/2020
EMI #:
Project #:
Project Name: SAT Testing
Ref:

#	Test Type	Unit Price	Quantity	Line Total
1	SINTEF Testing SAT	$ 650.00	15	$ 9,750.00
			Total (in USD)	**$ 9,750.00**

Quotation Details

***

THANK YOU !

Attachment 3

NTNU SAT Pricing

SINTEF Byggforsk
SINTEF Building and Infrastructure

Postboks 4760 Sluppen
NO-7465 Trondheim
NORWAY

Location:
Sem Sælands vei 1
7034 Trondheim

Direct line: +47 93015284
Telefax: +47 73593380

Enterprise /VAT No: NO 948 007 029 MVA

DELTA Conveyance Design and Construction AUTHORITY
1121 L St, Sacramento
CA 95814
USA

Your ref.	Our ref.	Project No. / File code	Date
John Hinton	Filip Dahl	102022149/SAT	2020-02-14

Quotation for determination of soil abrasivity properties

Thank you very much for your inquiry regarding laboratory testing for determination of soil abrasivity properties by the Soil Abrasiveness Test™ (SAT™). The unit price (one sample) and the required sample amount are given in the following table:

Item	Unit cost (one sample)	Required sample amount
Soil Abrasiveness Test™ (SAT™)[1] in accordance with *"Nilsen, B., Dahl, F., Holzhäuser, J. and Raleigh, P. (2007): "New test methodology for estimating the abrasiveness of soils for TBM tunnelling", RETC Proceedings, pp. 104 - 116.*	**USD 565**	**1 - 2 kg**[1] Representative soil sample.

[1] *The amount should be somewhat increased (3 - 4 kg) if the soil sample consist of a major part of particles > 4.0 mm.*

Prices given in USD are according to the current currency situation and will be valid until 2020-12-31.

An **Administration fee of USD 200** will be added to the total testing cost.

The listed prices for testing include preparation and reporting. The Final Test Report will be provided as an electronically mailed version in PDF format. Hard copies can be provided at an additional cost.

When SINTEF AS executes physical tests of samples, products or analyses of tests performed by others in a Norwegian Laboratory the Norwegian VAT Act states that these services are to be invoiced with VAT. **According to the VAT-Act there will be invoiced 25% VAT**. Please note that foreign businesses might be entitled to refund of input VAT when purchasing goods or services in Norway, provided that certain conditions are fulfilled. Further information about the conditions and how to apply for VAT refund can be found in the attached information letter from our VAT lawyer and the information web-site from Norwegian VAT authorities https://www.skatteetaten.no/en/business-and-organisation/vat-and-duties/vat/refund-of-vat-to-foreign-businesses/.

According to the provided unit prices the total cost for the requested laboratory testing and reporting will be:

15 x SAT™	**USD**	**8 475**
1 x Administration fee	**USD**	**200**
Total	**USD**	**8 675**

The laboratory work performed at SINTEF will be conducted in accordance with the terms specified in the attached "SINTEF - General conditions for smaller projects".

SINTEF shall submit invoices in good order and in English language upon completion of the testing, ev. divided into several invoices if several test rounds will apply.

Payment is according to the specified term expected within 30 days from receipt of the original Invoice.

The specified laboratory work will start as soon as we have received the samples and a written confirmation with reference to this quotation.

The samples should be clearly marked and wrapped individually before shipping (preferably by DHL, FedEx or similar) to the following address:

Rock Laboratory SINTEF/NTNU
S.P. Andersens vei 13A
7031 Trondheim
NORWAY
Att: Filip Dahl (cell phone + 47 93 01 52 84)

Please specify that the shipment contains samples of geological material (clay, silt, sand, gravel) from a tunnel project and that they are intended for laboratory testing. Please note that using the term "soil" should be avoided when shipping samples to Norway due to that it can be mistaken for top-soil/garden mold, which is illegal to import without a dispensation from the Norwegian Food Safety Authority. It should further be stated that the samples are of no commercial value instead of listing the actual value of testing on the Pro-forma invoice, as this will make the clearance through the Norwegian customs more convenient.

The time schedule for the requested laboratory testing will somewhat depend on our current workload on receipt of the samples. Testing of the specified number of samples is however, normally completed within 2 - 3 weeks after the receipt of the samples. Final Test Report is due 1 week after the completion of the laboratory testing.

Preliminary test results are however normally available and reported earlier than the given time schedule.

Please do not hesitate to contact us if you should have any questions regarding the quotation.

Yours sincerely
SINTEF Community
Rock and Soil Mechanics

Filip Dahl
Professional and Market Head
Engineering Geology Lab

Lisbeth I. Alnæs
Research Manager