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DRAFT REPORT

GEOLOGIC AND GEOTECHNICAL EVALUATION OF THE SANTA ROSA AQUEDUCT CROSSING OF THE RODGERS CREEK FAULT, SANTA ROSA, CALIFORNIA

Prepared for:

MMI Engineering, Inc.

and SONOMA COUNTY WATER AGENCY

SEPTEMBER 2011

CONTENTS

DRAFT

Page

1.0 EXECUTIVE SUMMARY 3

2.0 INTRODUCTION 5

2.1 Project Description 5
2.2 Scope of Work 5

3.0 REGIONAL GEOLOGY 6

3.1 Rodgers Creek Fault 6
3.1.1 Geologic Slip Rate 7
3.1.2 Earthquake Recurrence 7
3.1.3 Evidence of Aseismic Slip (Fault Creep) 7

4.0 SANTA ROSA AQUEDUCT FAULT CROSSING DESCRIPTION 8

4.1 Site Geology 8

5.0 REVIEW OF EXISTING PUBLISHED AND UNPUBLISHED LITERATURE 8

5.1 Previous Mapping Studies of the rodgers Creek fault 9
5.2 Previous Trenching Investigations 9

6.0 AQUEDUCT FAULT CROSSING EVALUATION 10

6.1 Aerial Photographic Interpretation 10
6.2 Interpretation of LiDAR Data 11
6.3 Field Reconnaissance 11
6.4 Seismic data Interpretation 12
6.5 Subsurface Exploration 13
6.5.1 CPT Transect 14
6.5.2 Geotechnical Boring 15
6.6 Site Subsurface Geotechnical Conditions 15
6.6.1 Laboratory Test Results 15

7.0 SURFACE FAULT RUPTURE HAZARD 16

7.1 Fault Crossing Geometry 17
7.1.1 Fault Structure at Depth 17
7.1.2 Fault Strands at Sonoma Avenue 17
7.1.3 Pipeline Fault Crossing Orientation 17
7.2 Deterministic Design Earthquake Magnitude 18
7.3 Adjustments for Fault Creep 19
7.4 Expected Amount of Surface Fault Displacement 19
7.5 Distribution of Active Surface Fault Displacement 21
7.5.1 Fault Crossings A and B 21
7.5.2 Fault Crossings C and D 21
7.5.3 Fault Crossing E 22

8.0 CONCLUSIONS AND DISCUSSION 22

9.0 RECOMMENDATIONS 24

10.0 REFERENCES 25

TABLES

Table

Fault Crossing Parameters for Santa Rosa Aqueduct Crossing of the Rodgers Creek Fault 1

Soil Parameters for Santa Rosa Aqueduct Crossing of the Rodgers Creek Fault 2

Summary of findings for fault-rupture hazards along the Santa Rosa Aqueduct across the Rodgers Creek Fault, Santa Rosa 3

FIGURES

Figure

Regional Geologic Map Showing Isostatic Gravity Contours 1

Fault Map Showing USGS Seismic Line 2

2-D Seismic Line along Sonoma Avenue across Rodgers Creek Fault 3

Detail of Interpreted 2-D Seismic Line in Project Area 4

Conceptual Diagram of Right-Lateral Strike-Slip Fault Flower Structure 5

LiDAR Base Map Showing Seismic Line and Subsurface Exploration Locations 6

CPT and Geotechnical Boring Transect 7

Displacement Profile for Main Fault Zone 8

Displacement Profile for Secondary Fault Zone E 9

APPENDICES

Appendix

Cone Penetration Test (CPT) Result ..... A

Geotechnical Boring Log ..... B

Laboratory Test Results C

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1.0 EXECUTIVE SUMMARY

This report summarizes the results of our evaluation of the Santa Rosa Aqueduct crossing of the Rodgers Creek fault in Santa Rosa, California, performed for the Sonoma County Water Agency (SCWA). As part of our assessment, we reviewed published and unpublished scientific and consulting reports, processed and interpreted LiDAR elevation data and 2D seismic reflection data. We also conducted limited subsurface exploration consisting of 12 CPT and one geotechnical boring completed to average depths of 70 feet.

The study was conducted to evaluate fault rupture hazards for the Santa Rosa Aqueduct associated with a large earthquake on the Rodgers Creek Fault. The principal objectives of the study were to: (1) delineate the location and width of the active strand(s) of the Rodgers Creek Fault where it crosses the aqueduct, (2) provide information on the likely amount and distribution of fault-rupture displacement, and (3) estimate the geotechnical properties of the geologic deposits at the pipeline fault crossing (summarized in Table 1). This information is required for engineering-based evaluation of fault-rupture hazard to the aqueduct across the Rodgers Creek Fault.

The Santa Rosa Aqueduct crosses the Rodgers Creek Fault between Talbot Drive and Midway Avenue in Santa Rosa, California. The center of the fault zone (i.e., the main trace) is constrained within about 300 feet (90 m), in the vicinity of Talbot and Macklyn Avenues, based on interpretation of reflection seismic data combined with the CPT transect conducted for this study. Within the zone two possible fault traces ('C' and 'D') are interpreted that bound the shear zone. An additional fault, trace 'E', is inferred on the basis of the seismic data, offset subsurface stratigraphy identified on the CPT transect, and a broad upwarp in Sonoma Avenue across the surface projection of the fault centered between Rosedale and Alderbrook Avenues. Based on the CPT profile, the zone of possible faulting centered on fault E is 200 feet (60 m) wide.

At the Santa Rosa Aqueduct crossing of the Rodgers Creek fault, the existing buried pipeline has an orientation (trend) of N72°W (72° clockwise from north). The fault zone, and individual fault strands A through E have a general orientation (strike) of N17°W (17° ± 3° counterclockwise from north). The acute intersection between the two is therefore 89° ± 3° During right-lateral fault movement, this geometry will result primarily in lateral shear causing tension along the pipeline at the fault crossing.

Based on review of the scientific literature, we consider a deterministic magnitude of Mw 7.0 as the design earthquake on the Rodgers Creek Fault. Empirical relations developed by Wells and Coppersmith (1994) suggest an average subsurface displacement of 3.1 ± 1.8 ft for a Mw 7.0 earthquake. Based on the published geologic rate of 9 ± 1 mm/yr (WGEP, 2008) and inferred average fault creep rate of 4.9 ± 0.6 mm/yr (Funning and others, 2007), horizontal displacement of 3.4 ± 0.6 feet and 4 to 12 inches of vertical displacement is possible.

TABLE 1: Parameters for Design of the Santa Rosa Aqueduct Crossing of the Rodgers Creek fault.

Fault Trace	Range of estimated earthquake magnitude on Rodgers Creek fault	Estimate of coseismic right-lateral slip	Estimate of vertical component of slip	Width of zone of primary offset Distributed Strain	Crossing angle of pipe to strike of fault	Native materials surrounding pipe (based on laboratory test data)
A and B	Mw 7.0 with a range of about ± 0.2 **Design Earthquake: Mw 7.0**	Not applicable, active faulting does not reach ground surface based on available trenching data	Not applicable.	Not applicable.	89° ± 3° (tension	See Table 2, Appendix C CLAYEY SAND (SC) to fat CLAY (CH): Dry density of 84 psf; Initial water content 11 to 35%; Apparent cohesion 0.4 ksf; Apparent friction angle 22°
C and D		3.1 ± 1.8 ft	4 to 12 inches	300 feet wide fault zone (Figure 8) 80% on two primary traces: **1.0 to 3.9 ft** 20% distributed **0.3 to 1.0 ft**.		
E		Unknown, conservatively same as main fault	Unknown, conservatively same as main fault	200 feet wide fault zone (Figure 9) 70% on one primary trace: **0.9 to 3.4 ft** 30% distributed **0.4 to 1.5 ft**.		

Geologic descriptions and laboratory analyses for representative soil samples obtained from geotechnical boring B-1 (Appendices B and C) characterize the geotechnical properties of earth materials along, and at the depth of, the aqueduct across the Rodgers Creek Fault. There likely is no contrast in material properties at the depth of the pipeline across the fault based on the results of the CPT transect. Based on results of geotechnical drilling and CPT, we estimate materials at the depth of the pipe (10 feet; Table 1) consist of clayey sand to clay (SC-CH) with an average dry density of 85 pcf, initial water content of 5-10%, apparent cohesion of 0.4 ksf, and an apparent friction angle of 22 degrees.

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INTRODUCTION

This report presents the results of a desktop study, supported by field observations, of fault rupture hazards to SCWA's Santa Rosa Aqueduct crossing of the Rodgers Creek Fault along Sonoma Avenue in Santa Rosa, California. The study included 1) review of available published and unpublished scientific literature, geotechnical reports, and maps; combined with, 2) interpretation of available LiDAR and seismic reflection data; and, 3) collection and interpretation of subsurface geotechnical data including CPT and borings to locate the Rodgers Creek fault relative to the aqueduct at the Sonoma Avenue fault crossing, determine the width of faulting and number of fault strands, characterize the amount and distribution of expected fault displacement, and document existing soil conditions.

1.1 PROJECT DESCRIPTION

Based on the information provided, we understand that the Santa Rosa Aqueduct is buried beneath the roadway of Sonoma Avenue. Constructed in 1959, the Santa Rosa Aqueduct crosses the Rodger Creek fault near the intersection of Talbot Drive. The aqueduct is predominantly a 36-inch cement mortar lined and coated steel pipeline with bell and spigot connections (MMI, 2005). The purpose of this study is to provide fault rupture data and geotechnical input for analytical modeling of the integrity of the existing pipeline and mitigation design.

1.2 SCOPE OF WORK

Identifying the location(s) of the active fault trace(s) of the Rodgers Creek Fault across the Santa Rosa Aqueduct is important for defining the probable distribution of deformation during a large earthquake on the fault. The purpose of our geotechnical field explorations and laboratory testing program was to collect information of the subsurface conditions along the new alignment to evaluate geotechnical and geologic conditions and hazards. The scope of services performed included the following tasks:

- Compilation and review of previous geotechnical and geologic maps and studies;
- Review of 1942-vintage stereo aerial photographs (USDA COF-7-25, -26, and -27; approximately 1:20,000 scale);
- Discussions with Dr. Robert McLaughlin and Dr. Robert Williams of the US Geological Survey Reconnaissance of the project site to view current site conditions;
- Obtaining, processing, and interpreting 2-D seismic data collected by the USGS along Sonoma Avenue;
- Conduct a field exploration and laboratory-testing program consisting of both Cone Penetration Tests (CPTs) and a mud rotary boring.
- Development of geotechnical data on subsurface soil conditions at the fault crossing;

- Determination of the location(s) and width(s) of active fault trace(s) at the aqueduct crossing;
- Derivation of the angle of intersection between the aqueduct and active fault trace(s);
- Estimation of the amount of ongoing aseismic slip (fault creep) and the amount of expected coseismic surface fault displacement;
- Summary of results and conclusions to MMI Engineering to facilitate pipeline rupture modeling, and;
- Preparation of this combined geotechnical and surface fault rupture evaluation report that includes the results of field exploration and laboratory testing.

This report presents a brief overview of the regional geologic setting, state of knowledge of the Rodgers Creek fault and previous studies, and results of geotechnical investigations for the purpose of characterizing subsurface conditions at the depth of the proposed aqueduct replacement; followed by presentation of our technical results, conclusions, and recommendations for mitigating potential fault-rupture hazards.

2.0 REGIONAL GEOLOGY

The San Francisco Bay area lies along an active system of faults forming the boundary between the North American and Pacific plates including the San Andreas, Hayward-Rodgers Creek, and Calaveras faults, as well as many lesser structures. The Rodgers Creek fault is a major component of the larger San Andreas fault system, connecting the Hayward fault on the south to the Maacama fault on the north.

2.1 RODGERS CREEK FAULT

The Rodgers Creek Fault is one of the primary active faults in the San Francisco Bay area, and is considered capable of generating an earthquake large enough to result in surface rupture that may damage structures overlying the fault trace. The U.S. Geological Survey estimates that there is a 15.2% probability of a M7.0 rupture of the Rodger's Creek fault in the next 30 years.

The Rodgers Creek Fault was first recognized and mapped as a young geologic feature by Weaver (1949). The fault has since been mapped as a discontinuous zone of sub-parallel strands from San Pablo Bay to Geyerville, and subdivided into the Rodgers Creek, Healdsberg, and Maacama faults. The 1974 Alquist-Priolo Special Studies Zone map CDMG, 1974) located fault traces primarily based on mapping by Brown (1970). No well-defined geomorphic features were observed across the Santa Rosa Plain and, therefore, a single concealed fault trace was inferred to connect the Healdsburg fault to the north with the Rodgers Creek fault to the south (Figure 1). However, the locations of the fault strands within young alluvium underlying Santa Rosa has not been fully resolved.

Historically, the Rodgers Creek fault has been seismically quiescent. No evidence appears in the historical record of a large earthquake on the Rodgers Creek Fault, implying that the most recent earthquake (MRE) occurred before 1824, when historical records were kept at a Franciscan mission built in Sonoma, and possibly before 1776, when a mission and presidio were first established in San Francisco (Hecker and others, 2005). The only moderate to large earthquakes located near the fault were the October 1, 1969 M 5.6 and 5.7 earthquakes near Santa Rosa, and the Mare Island event of 1898 (Wong and Bott, 1995). Based on historical accounts for the region, the 1898 earthquake is interpreted as an event with magnitude between 6.2 and 6.7 that occurred along the southernmost section of the Rodgers Creek fault (Toppozada and others, 1992).

2.1.1 Geologic Slip Rate

Paleoseismic trenching investigations on the Rodgers Creek fault provide information on the late Holocene slip rate, event chronology, and likely slip per event for the fault in the vicinity of the Santa Rosa Aqueduct fault crossings. These studies report a geologic slip rate of 6.4 - 10.4 mm/yr for the southern portion of the fault (Schwartz and others, 1992; Hecker and others, 2005). WGCEP (2008) adopt a value of 9 ± 1 mm/yr for the long-term slip rate on the Rodgers Creek fault.

2.1.2 Earthquake Recurrence

Results of fault trenching on the Rodgers Creek fault document the occurrence of three surface-rupturing earthquakes between about A.D. 1000 and 1776 (Schwartz et. al, 1992). Research studies indicate a recurrence interval of between 131 to 370 years (preferred value of 230 years), calculated from geologic data and regional earthquake models. Radiocarbon dating from faulted alluvial sequence at the site indicates that the most recent earthquake (MRE) occurred no earlier than A.D. 1690 and most likely occurred after A.D. 1715 (Hecker and others, 2005). The elapsed time since the MRE on the Rodgers Creek fault therefore is more than 187 years and less than 321 years.

2.1.3 Evidence of Aseismic Slip (Fault Creep)

The Rodgers Creek Fault links two known active creeping faults – the Hayward fault to the southeast, and the Maacama fault to the northwest (Galehouse and Lienkaemper, 2003; Funning and others, 2007). Aseismic slip (fault creep) is occurring primarily along the northern Rodgers Creek fault. Because aseismic creep occurs along the northern Rodgers Creek Fault, elastic strain accumulates along the near-surface sections of the fault at a slower rate than at seismogenic depths, where the fault can be locked. Satellite-based measurements of surface creep (Funning and others, 2007) show that the northern Rodgers Creek fault has an average creep rate of about 3 to 6 mm/yr, with creep rates highest at the northern end of the fault.

Paleoseismic investigations on the non-creeping southern portion of the fault indicate that the fault slipped horizontally up to ~6 feet (2 m) in the last major (Mw 7) event (Budding et al., 1991; Hecker et al., 2005). As discussed below, in Section 7.3 – Adjustments for Fault Creep, the presence of ongoing fault creep of approximately 3.2 ± 0.3 mm/yr on the northern

portion of the fault in the vicinity of the Santa Rosa Aqueduct fault crossing, based on InSAR data (Funning and others, 2007) results in lower predicted fault offset in future earthquakes.

3.0 SANTA ROSA AQUEDUCT FAULT CROSSING DESCRIPTION

The Santa Rosa aqueduct crosses the Rodgers Creek Fault in the vicinity of the AP fault trace located at the intersection of Sonoma Avenue with Talbot Drive in Santa Rosa, California (Figures 1 and 2). At this location, the pipeline currently is located within the westbound lanes of Sonoma Avenue. The location of the fault crossing has been heavily modified by road and residential construction.

3.1 SITE GEOLOGY

The aqueduct crossing of the Rodgers Creek fault is located on the Santa Rosa Plain. The pipeline is buried within Holocene (less than 11,000 years old) alluvial fan deposits. Alluvium in the vicinity of the aqueduct fault crossing is thicker than 70 feet based on borings and overlies the Glen Ellen Formation (Cardwell, 1958; this study). Quaternary alluvial deposits create highly continuous reflection sequences in the available seismic reflection data while the underlying Mesozoic-to-Cenozoic basement surface of the Franciscan Complex, imaged east of the Rodgers Creek fault, generates distinctive high amplitude reflections (Williams and others, in preparation). The bedrock surface is offset downwards to the west, forming a basin up to 1 km deep. This basin shallows to the west as the profile crosses the southeastern side of Trenton Ridge (Williams and others, 2008a and 2008b).

The roadway and alluvium along Sonoma Avenue is underlain by a thick package of Quaternary deposits of the Plio-Pleistocene Glen Ellen Formation. The shallow alluvial deposits at the depth of the aqueduct consist of relatively continuous layers of clay, silt and sand with occasional clean sands and gravels based on nearby trench exposures (Cooper Clark Associates, 1978; Herzog Associates, 1989; BACE Geotechnical, 1992) and borings and CPT performed for this study. Locally Santa Rosa Aqueduct is emplaced within trench backfill beneath road base fill along Sonoma Avenue that is of unknown composition and density.

4.0 REVIEW OF EXISTING PUBLISHED AND UNPUBLISHED LITERATURE

The Rodgers Creek fault was first recognized and mapped as a young geologic feature by Weaver (1949). The fault has since been mapped as a discontinuous zone of sub-parallel strands from San Pablo Bay to Geyerville, and subdivided into the Rodgers Creek, Healdsberg, and Maacama faults. Numerous investigators have mapped the Rodgers Creek fault in the vicinity of the Santa Rosa aqueduct crossing at Sonoma Avenue, including Blake and others (1971), Fox and others (1973), Sims and others (1973), CDMG (1974), Huffman and Armstrong (1980), Bryant (1982), Wagner and Bortugno (1982), Jennings (1988), and McLaughlin and others (2008). Nearly all these workers interpret the main active Rodgers Creek fault zone intersecting Sonoma Avenue as a single distinct fault trace. (e.g. Figure 1).

The 1974 Alquist-Priolo Special Studies Zone map (CDMG, 1974) located fault traces primarily based on mapping by Brown (1970). No well-defined geomorphic features were observed across the Santa Rosa Plain and, therefore, a single concealed fault trace was inferred to connect the Healdsburg fault to the north with the Rodgers Creek fault to the south. Fault evaluation reports submitted to the CGS for nearby projects provide information on location and width of deformation associated with the main creeping trace of the fault and possible secondary traces.

4.1 PREVIOUS MAPPING STUDIES OF THE RODGERS CREEK FAULT

The concealed trace of the Rodgers Creek fault was mapped along Doyle Park Drive, west of the current inferred pipeline fault crossing, by Fox and others (1973) and on the original Alquist-Priolo Special Studies Zone Map (CDMG, 1974, Hart, 1982). Based on a detailed gravity anomaly survey (Chapman, 1982) that delineated a buried fault east of Memorial Hospital, the Rodgers Creek fault was relocated one block east to Talbot Avenue. The Special Studies Zone Map was modified to reflect the new location of the inferred fault along Talbot Street (CDMG, 1983). A zone of about 660 feet on either side of the inferred fault trace has been zoned as requiring additional study prior to construction of structures for human occupancy.

Regional geologic mapping (e.g. Figures 1 and 2) suggests that the Rodgers Creek fault forms a step-over where it crosses the Santa Rosa Plain. However, the locations of the fault strands within young alluvium underlying Santa Rosa have not been fully resolved. Fault surfaces are being derived from geologic mapping, subsurface projection of fault dips from the surface geology and earthquake hypocenters (McCabe and others, 2002). The preliminary 3D map of the Santa Rosa Plain area highlights two large basins are divided by a structural high associated with the W-NW-trending, NE-dipping Trenton thrust fault.

Although the Rodgers Creek fault was believed to cross Sonoma Ave in the vicinity of Talbot Ave in Santa Rosa, its exact location was concealed by urban development and stream activity that have obscured its surficial features and made its trace difficult to recognize. Prior to this study the Rodgers Creek fault was only grossly located in the urban area by gravity measurements (Langenheim and others, 2006; McPhee and others, 2007), shallow trenching near Doyle Park school, and geologic map projections of two traces of the fault from south of Doyle Park (Mclaughlin and others, 2008).

4.2 PREVIOUS TRENCHING INVESTIGATIONS

Fault evaluation reports submitted to the CGS for nearby projects were reviewed to obtain site-specific information on the location of the presence active faulting in the vicinity of the Santa Rosa Aqueduct crossing of the Rodgers Creek fault. The reports reviewed for this project include relevant studies by Cooper Clark Associates (1978), Herzog Associates (1989), and BACE Geotechnical (1992). These studies are summarized below. A complete citation for each of these reports is included in the reference section

Previous trenching studies in the vicinity of the Santa Rosa aqueduct crossing of the inferred buried trace of the Rodgers Creek fault provide some information on the likely location of the fault. A long (513 ft) continuous trench, approximately 11 feet deep, located across the southern portion of the Doyle Park school facility south of Sonoma Avenue documented the absence of faulting that constrains the likely location of the concealed trace of the Rodgers Creek fault within the CGS hazard zone (BACE Geotechnical, 1992). The trenching exposures suggest that the fault is located east of Talbot Avenue, likely between Talbot and Macklyn Avenues, although no trenching results are available that expose the fault in this area or document absence of faulting.

Cooper Clark Associates (1978) excavated a trench approximately 300 north-northwest of the Doyle Park School property. Their trench exposed apparent offset of discontinuous sediments that they interpreted as a possible fault. However, the observed discontinuity did not extend to depth and did not offset deeper sediment layers.

Results of a subsequent fault study by Herzog Associates (1989) for the parcel north of the Cooper Clark study site documented evidence in trenches for no active faulting along the trend of the features mapped by Cooper Clark. Herzog Associates (1989) concluded that the features mapped by Cooper Clark likely are not indicative of recent fault offset but rather may be the result of localized erosion of alluvial deposits. The primary evidence that Herzog Associates (1989) cite against fault offset is the absence of offset of deeper, older deposits below the apparent offset of upper sediments in the trench by Cooper Clark. It therefore is unlikely that the Cooper Clark trenches exposed a strand of the Rodgers Creek and we conclude that the main buried strand of the Rodgers Creek fault likely is located east of Talbot Avenue.

5.0 AQUEDUCT FAULT CROSSING EVALUATION

1942-vintage stereo-paired, black-and-white aerial photographs were reviewed at a scale of 1:20,000 to: (1) evaluate the pre-development land use in the vicinity of the aqueduct fault crossing, and (2) interpret photo-lineaments suggestive of fault-related deformation. In the vicinity of Santa Rosa Aqueduct, the Rodgers Creek Fault exhibits subtle geomorphic evidence of displacement such as offset drainages, aligned topographic sags, and tonal lineaments. Results of field reconnaissance conducted on June and July of 2011 confirmed the presence of possible fault creep deformation where previously mapped and provided site-specific observations on the inferred Santa Rosa Aqueduct crossing of the Rodgers Creek fault. Observations from our interpretation of the historic aerial photography and LiDAR terrain data, interpretation of available seismic reflection data along Sonoma Avenue, field reconnaissance, and subsurface investigations are provided below.

5.1 AERIAL PHOTOGRAPHIC INTERPRETATION

It is valuable to analyze early historical photography that predates most development in order to view the natural unmodified landscape, which may contain tonal contrasts, scarps, lineaments, drainage pattern anomalies, and other geomorphic features indicative of faulting.

These interpretations are used in conjunction with our subsurface investigation to support our findings in the report.

Based on our review of available 1942 black and white, 1:20,000-scale aerial photography, we identified a possible fault-related, northwest-striking lineament between Rosedale and Alderbrook Avenues, east of Talbot Avenue. This lineament appears to coincide with a pre-existing topographic swale identified on LiDAR data, consistent with possible warping or diffuse surface rupture in young sediments across the Santa Rosa Plain. Right-lateral offsets of Spring, Matanzas, and Santa Rosa Creeks, also identified on the LiDAR terrain data, were noted on the aerial photographs.

5.2 INTERPRETATION OF LIDAR DATA

Assessment of faulting included processing and interpretation of detailed (1-m resolution) LiDAR (LIght Detection and Ranging) elevation data available on-line. This high-resolution airborne laser swath mapping data was acquired along the Rodgers Creek fault faults as part of the EarthScope Facility project funded by the National Science Foundation (NSF). The LiDAR data covering the Rogers Creek fault was collected on April 10, 2007, as part of the Northern California Fault System LiDAR Survey by the National Center for Airborne Laser Mapping (NCALM). The data were downloaded from the NCALM site (http://calm.geo.berkeley.edu/ncalm/ddc.html) in WGS84 projection.

LiDAR data collection uses the same principle as RADAR except that the LiDAR technique uses a laser instead of radio waves for the measurement of elevation from an airplane flyover. In its raw form, LiDAR is stored as a series of x, y, and z points with x and y providing longitude and latitude; and z the ground elevation. Digital data were processed to obtain bare earth elevations for construction of an updated, highly detailed topographic base map for the vicinity of the fault crossing. Derivative products from the raw LiDAR data include a digital elevation model (DEM) of the bare earth ground surface, contours of ground elevation, and a shaded relief map of the ground surface (Figure 6).

The LiDAR data were post-processed by Fugro to produce a detailed topographic base map (1:1,200-scale) with 1-foot contours for the entire project area. The detailed topographic data allow for accurate delineation of surface features potentially caused by deformation associated with the Rodgers Creek fault. In addition, the elevation of Sonoma Avenue, derived from LiDAR, was used to construct the CPT profile (Figure 7).

Evidence of possible deformation in the vicinity of the Santa Rosa Aqueduct fault crossing identified on LiDAR-derived shaded relief maps include two pronounced right-lateral offsets of Spring and Matanzas Creeks coincident with the mapped locations of fault traces C, D, and E south of Sonoma Avenue (Figure 6).

5.3 FIELD RECONNAISSANCE

Field reconnaissance of the site and surrounding area was performed on June and July, 2011, by Christopher Hitchcock, Certified Engineering Geologist, and Adam Wade, Senior Staff

Geologist, to evaluate onsite evidence of aseismic creep, offsite fault-related creep deformation of cultural features within nearby subdivisions, and obtain information on surface deposits and site geotechnical conditions. The vicinity of the Santa Rosa Aqueduct along Sonoma Avenue is fully developed, with the exception of Doyle Park to the south. No exposures of native materials were observed near the fault crossing.

Geologic field reconnaissance at the site focused on: (1) interpretation of fault traces and photolineaments based on the examination of aerial photography; (2) photolineaments and features identified on LiDAR-derived topography during this study; (3) examination of sidewalks and other cultural features for evidence of fault creep; and (4) delineation of Quaternary deposits to evaluate the recency of activity of potentially active faults. Field mapping focused primarily on the identification of geomorphic features possibly related to faulting and creep.

Significant site alterations related to residential development across much of the site has either removed or obscured evidence of possible tectonic-related geomorphology and Quaternary deposits at the site; therefore, much of the geologic field reconnaissance was conducted offsite. The geologic reconnaissance focused primarily on the mapping of geomorphic features south of Sonoma Avenue in the area of Doyle Park, including offsets of Spring and Matanzas Creeks.

Evidence of possible fault creep related deformation in sidewalks was noted along Sonoma Avenue, including right-laterally offset curbs. However, this apparent deformation may be related to other causes, such as roadway fill settlement and no consistent pattern was noted in pavement, curbs, or sidewalks that clearly define zones of deformation coincident with inferred fault locations. One exception is a subtle dip coincident with a north-south striking photolineament and upwarp in the roadway of Sonoma Avenue that coincides with the inferred Fault E crossing, discussed in more detail below (Figures 6 and 7).

5.4 SEISMIC DATA INTERPRETATION

High-resolution seismic data acquired along Sonoma Avenue across the Rodgers Creek fault by the USGS provide valuable information for the interpretation of the location, width, and geometry of faulting associated with the Rodgers Creek fault across the Santa Rosa Aqueduct. The 2-D seismic data were obtained using a Thumper vibrator consisting of a 10,000-kg Ford F-650 truck-mounted vibrator that is capable of being driven on paved roads with a 2,727 kg peak output force as a seismic source (Williams and others, 2008a and 2008b). The thumper was swept from 15 to 120 Hz in 14s with a common mid-point spacing of 5 m and the nominal fold was 36 traces. At each vibration point (VP) the USGS stacked 4, 14-s-long, 15-120 Hz sweeps and generated a 2-s correlated record with a 2.0 ms sample interval. The VP station interval was 10 m and single 8-Hz geophones were placed at 5 m intervals. The recording array was generally 144 channels and stack fold averaged about 35 with a predominantly off-end-push shooting configuration.

The seismic data were obtained from Dr. Robert Williams of the USGS in SEGY format (x.y,z) and loaded onto workstations for interpretation using SMT Kingdom Suite seismic interpretation software. A project GIS also was developed to compile and display the raster an

SMT Kingdom Suite project for the rendering and interpreting seismic data. The data were interpreted to map fault offsets based diffraction patterns, folded or tilted stratigraphic horizons based on the continuity of reflectors. The interpretation of the high-resolution seismic reflection data, tied to shot-points, was integrated with the results of the CPT transect and geotechnical boring also collected along Sonoma Avenue.

The Sonoma Avenue seismic profile provides excellent imaging of the Rodgers Creek fault zone along the Santa Rosa Aqueduct north of Doyle Elementary School (Figures 3 and 4). The Rodgers Creek fault below Sonoma Avenue was imaged up to about 40 m depth. Preliminary interpretation of the data by the USGS (Williams and others, in preparation) indicates that the Rodgers Creek fault present in the subsurface below Sonoma Avenue is not simply a narrow single fault trace, as previously mapped (e.g. Figure 1), but rather consists of a broad zone of multiple related fault traces. This interpretation is consistent with our interpretation of the seismic data combined with results of the CPT and borehole transect described in more detail below.

Williams and others (in preparation) interpret the zone of distributed faulting as accommodating an eastern stepover shift or bend in the fault across Santa Rosa to align with the Healdsburg fault segment located northeast of the city. They identify at least two main traces that straddle a 400-m wide upwarped area below Doyle Elementary School very near the geologic map projections. The maximum height of the upwarping of older sediments at depth is about 30 to 40 m (Williams and others, in preparation).

Fault traces are rarely straight, they curve, branch, or can step en echelon. This results in a variety of strike-slip related surface deformation including a pattern of multiple faults that originate from a single, steeply dipping strike-slip fault at depth. Harding and Lowell (1979) refer to this upward-branching geometry from a single strand in basement as a “flower” structure. In cross-section, the displacements are dominantly reverse or normal depending on whether the overall fault geometry is transpressional (i.e. with a small component of shortening) or transtensional (with a small component of extension). Fault zones with dominantly reverse faulting are known as positive flowers, those with dominantly normal offsets are known as negative flowers (Figure 5).

5.5 SUBSURFACE EXPLORATION

The objective of a fault rupture hazard investigation is to determine the location, geometry, and width of possible surface fault deformation. Typically the standard is to demonstrate the presence of unfaulted, continuous Pleistocene stratigraphy beneath a site relative to a known Holocene-active fault. Where subsurface deposits are faulted or deformed, the location and width of active faulting can be constrained for mitigation planning.

There are several different methods to investigate the subsurface conditions. The most common and direct approach is trenching, which produces a continuous exposure and allows the geologist to map the walls of the trench. Other approaches include transects of closely spaced borings or CPT’s designed to follow layers in the subsurface. In areas of limited access, dense urbanization, or thick, young Holocene alluvium, trenching is not the best approach for

assessing the fault rupture hazard. All three conditions are present along Sonoma Avenue. We therefore utilized a combination of closely-spaced, continuously Cone Penetration Tests (CPT) with borings to evaluate the continuity of subsurface stratigraphy across the Rodgers Creek fault.

Field data collection was conducted between July 5th and 8th, 2011, with CPTs and a geotechnical boring advanced along the proposed alignment. Subsurface exploration consisted of twelve (12) Cone Penetration Tests (CPTs) and one geotechnical boring. Gregg Drilling Inc., of Martinez, California, performed all of the explorations using truck-mounted platforms. Depths of the explorations ranged from approximately 40 feet to 70 feet and were back filled in accordance with local city and county guidelines. The approximate locations of the explorations were determined by using a hand-held GPS, and/or measured from known locations on the site plan, and should be considered accurate only to the degree implied by the methods used.

Logs and details describing the subsurface explorations for the geotechnical boring and CPTs are included in Appendix A and Appendix B respectively. The borehole locations are shown on the Site Plan and Geologic Section (Figures 6 and 7). The subsurface conditions encountered in the boring are summarized below in Section 6.6.

5.5.1 CPT Transect

To evaluate the presence of faulting associated with the Rodgers Creek Fault, a transect of twelve (12) Cone Penetrometer Tests (CPTs) was performed to follow horizontal alluvial layers in the subsurface. Each CPT sounding is produced by pushing a truck-mounted probe into the soil. As the tip is advanced, the cone bearing and sleeve friction are measured and interpreted to distinguish different soil layers based on their grain size and cohesion. By documenting and tracing these horizontal layers beneath Sonoma Boulevard across the projection of the fault, it is possible to infer where these layers are disrupted or cut by the fault.

The objective of the subsurface CPT is to trace unfaulted, continuous Pleistocene stratigraphy along the aqueduct and determine where subsurface horizons may be faulted or deformed relative to the projection of the Rodgers Creek fault. If the horizons are old enough and sufficiently continuous, as we believe them to be, we are able to delineate where the fault is relative to the aqueduct.

A detailed cross section was constructed along the exploration transect that combines data from the CPT soundings and the geotechnical borings. The purpose of cross section C-C' (Plate 1), constructed at a scale of 1 inch equals 10 feet, was to map out subsurface strata and evaluate the presence or absence of faulting. The elevations of the ground surface at each CPT sounding and boring (Table 1) were accurately plotted, in addition to the elevations of the trench, which was also surveyed with the CPT locations.

The colored units on Plate 1 (Figure 7) depict the diagnostic units of sand (yellow) and silts/clays (blue) that were interpreted from the Fugro CPT data using the method of Campanella and Roberson (1981). These data are provided in Appendix A. The friction ratio, which is plotted for each CPT in Plate 1, typically has lower values in sands than in the finer

grained materials. Contacts are extrapolated (dashed lines) between CPTs and boring B-1. Many of the contacts interpreted in CPT soundings were observed in boring B-1. However, some of the picks from the borehole did not match the elevations of the CPT contacts. This is primarily due to the difference in classification methodologies. The CPT textural classification was consistently finer grained than the geologists' visual classification.

The 12 CPT soundings were most useful in defining a well-bedded section of continuous, unfaulted sands and interbedded silts and clays across the transect below a depth of about 40 feet. The CPT soundings were able to identify sand beds higher in section, but generally the materials in the upper 40 feet were more coarsely bedded and less diagnostic.

5.5.2 Geotechnical Boring

Exploratory Boring B-1, located in the east-bound lane of Sonoma Avenue near the intersection of Talbot Drive, was drilled by Fugro on July 8, 2011. The purpose of the boring was to: 1) validate ('ground truth') stratigraphy inferred from nearby CPT by proving visual identification of subsurface depositions, and 2) obtain samples for laboratory testing of buried soil properties at the depth of the aqueduct.

The exploratory boring was conducted using a truck-mounted Versa Drill V100M drilling rig. The approximate locations of the exploratory boring are shown on the Site Plan. The log of this boring is provided in Appendix B. Boring B-1 was advanced to a depth of 70 feet using mud rotary drilling techniques. Driven samples were collected with an automatic hammer, at roughly 5-foot intervals, using a Standard Penetration Test (SPT) split-barrel drive sampler (outside diameter of 2.0 inches, inside diameter of 1.375 inches).

5.6 SITE SUBSURFACE GEOTECHNICAL CONDITIONS

Soils encountered within explorations on the older alluvial fan varied between gravel and sand layers, interlayered with semi continuous layers of clay and silt. Generalized stratigraphic descriptions and relationships are based on samples collected at 5-foot intervals. In general, the deeper layers were more coarse-grained and usually contained fine to coarse gravels and sands. Detailed descriptions of the soils encountered in the explorations are presented on the boring and CPT logs (Appendices A and B).

Our interpretations of the site subsurface geologic conditions are presented in Cross section A-A' as shown in Figure 3.

5.6.1 Laboratory Test Results

Geotechnical laboratory testing was conducted on selected soil samples collected from boring B-1 by Fugro. The geotechnical laboratory test program included classification tests such as gradation, fines content, and Atterberg limits as well as direct shear testing for select samples at various depths. The results of the laboratory tests are presented in Appendix C - Laboratory Test Results.

Laboratory analyses were performed on seven representative soil samples to characterize the geotechnical properties of earth materials along and beneath the Santa Rosa Aqueduct across the Rodgers Creek Fault (Table 2; Appendix C). The samples were collected from borehole B-1 at varying depths below the ground surface, including a three-point, consolidated undrained direct shear test performed on a representative sample at the depth of the proposed aqueduct replacement to provide a cohesive strength value and phi angle for the material likely traversed by the pipeline.

There likely is no contrast in material properties at the depth of the aqueduct across the fault based on lateral correlation of the available CPT data. Mechanical sieve tests were performed on four samples to evaluate grain size distribution of the deposits (Appendix C). The sieve analyses indicate that the alluvial deposits consist of a mixture of clayey sand, clay, and gravel. This analysis is consistent with our description of the deposits based on visual inspection of samples from geotechnical boring B-1 (Appendix B). For the sample at the proposed aqueduct depth of roughly 10 feet, the three-point test produced a failure envelope with an interpreted phi angle of 22 degrees and a cohesive strength of 0.4 ksf. Dry density of the sample was 84 pcf (Table 2; Appendix A).

Table 2.

Summary of Representative Soil Properties at Pipeline Depth, obtained from Boring B-1.

Depth (in feet)	Description	Fines Content (%)	Moisture Content (%)	Unit Wet Weight (pcf)	Unit Dry Weight (pcf)	Atterberg Limits (LL/PI*)	Friction Angle, ϕ	Cohesive Strength (ksf)
6	Dark yellowish brown CLAYEY SAND (SC)	22	35	-	-	-	-	-
11.1	Dark brown fat CLAY (CH)	-	-	114	84	58/42	22°	0.4
20	Very dark grayish brown Well-graded GRAVEL with CLAY and SAND (GW-GC)	9	11	-	-	-	-	-

* The liquid limit (LL) is the water content at which a soil changes from plastic to liquid. The PI is the difference between the liquid limit and the plastic limit (PI = LL-PL).

6.0 SURFACE FAULT RUPTURE HAZARD

Based on review of existing geologic maps and reports, integration of the most recent research on the Rodgers Creek fault, and our interpretation of LiDAR and seismic reflection data in the vicinity of the Santa Rosa Aqueduct crossing of the fault, we have identified the likely locations of fault strands within the fault zone relative to the aqueduct. While we cannot

preclude the possibility of new fault breaks developing during future earthquakes, historical occurrences of surface fault rupture have generally followed pre-existing fault traces. Below we provide information on the orientation and width of deformation associated with active strand(s) of the Rodgers Creek Fault where they cross the Santa Rosa Aqueduct, the likely amount and distribution of fault-rupture displacement, and we estimate the geotechnical properties of the geologic deposits at the pipeline fault crossing.

6.1 FAULT CROSSING GEOMETRY

The location, number, orientation, distribution, and style of deformation associated with surface traces of the Rodgers Creek Fault at Sonoma Avenue directly controls the surface fault offset hazard to the Santa Rosa Aqueduct. Unfortunately the fault zone is both broader than previously thought, based on interpretation of the available seismic reflection data, and insufficient fault trench data is available to evaluate each fault feature at the ground surface. In addition, obtaining such data for individual fault traces logistically is not feasible. Therefore, we discuss the overall fault geometry associated with the Rodgers Creek Fault based on interpretation of the available data, including subsurface data collected for this study, and each individual fault strand based on fault-specific information derived from existing and new datasets.

6.1.1 Fault Structure at Depth

Based on the presence of lateral displacement from ongoing fault creep and regional relations, the majority of movement along the fault consists of right lateral displacement, with a minor but largely unknown component of southwest-down vertical displacement. In cross-section, the apparent displacements of subsurface seismic reflections are dominantly reverse (Figures 3 and 4) and near-surface stratigraphic layers identified in the CPT transect (Figure 7) are consistent with an overall transpressional fault geometry. As noted above, strike-slip fault zones with dominantly reverse faulting are known as positive flower structures (Figure 5; Sylvester, 1988).

6.1.2 Fault Strands at Sonoma Avenue

A total of five distinct fault strands are identified merging into a single vertical strand at depth (Figures 2 and 3). These fault strands are labeled, from west to east, faults A through E (Figure 6). A second, shallow USGS seismic profile, located in Doyle Park about 500 m south of Sonoma Ave, also imaged an upwarped, or folded area (Williams and others, in preparation). The Doyle Park profile imaged five distinct fault traces, located primarily in the eastern half of the park, and east of the Alquist-Priolo trace, that offset reflectors in the 115 ft (35 m) to 230 ft (70 m) depth range (Williams and others, in preparation).

6.1.3 Pipeline Fault Crossing Orientation

At the Santa Rosa Aqueduct crossing of the Rodgers Creek fault, the existing buried pipeline has an orientation (trend) of N72°W (72° clockwise from north). The fault zone, and individual fault strands A through E have a general orientation (strike) of N17°W (17° ± 3°

counterclockwise from north). The acute intersection between the two is therefore 89° ± 3° During right-lateral fault movement, this geometry will result primarily in lateral shear causing tension along the pipeline at the fault crossing.

If the fault at depth is within a constraining bend (positive flower), the crossing angle could be even more favorable as the fault may strike more northwesterly at an angle > 90° with fault, placing the pipe in tension. Orientation to the northeast should place the fault in a transtensional regime (e.g. Figure 5), the opposite of the transpressional pattern of faulting observed. Evidence for the orientation of the fault primarily consists of connecting known outcrops and trench exposures of the fault on the southern and northern ends of the Santa Rosa Plain. The fault may actually trend more abruptly to the northwest in the vicinity of Sonoma Avenue although no direct evidence of this bend is apparent with the possible exception of projection between apparent right-lateral offsets of Spring and Santa Rosa Creeks.

6.2 DETERMINISTIC DESIGN EARTHQUAKE MAGNITUDE

Current research suggests that the Rodgers Creek Fault is capable of generating an earthquake as large as Mw 7.0. These estimates are based primarily on the length of the fault and the expected subsurface rupture area, regional fault models, paleoseismic investigations (e.g. Schwartz and others, 1992; Hecker and others, 2005) as well as relations between these parameters and the magnitudes of worldwide historical ruptures (Wells and Coppersmith, 1994). The WGCEP (2003; 2008) rupture model for the Rodgers Creek Fault considers rupture on the fault, a floating rupture of M_w 6.9 that could occur anywhere along the fault zone without regard to defined segmentation boundaries, and a combined Hayward-Rodgers Creek Fault zone rupture.

The Rodgers Creek Fault is considered to be a possible extension of the Hayward Fault, although the connection between the two faults under San Pablo Bay is poorly understood. A dilatational step-over between the right-lateral Hayward and Rodgers Creek faults exists beneath San Pablo Bay (Parsons and others, 2003). A key question is whether an earthquake on one of the faults could rupture through the step-over, enhancing its maximum possible magnitude. The estimate for a combined Hayward-Rodgers Creek rupture source is about M_w 7.2, with a range of M_w 7.1 to 7.3 (WGCEP, 2003; 2008). Although earthquakes on multiple faults do occur, they are much rarer than earthquakes on a single fault. The Hayward and Rodgers Creek faults converge to within 4 km of one another in the vicinity of San Pablo Bay, but recent interpretation of data from beneath the Bay indicates a low likelihood of strike-slip transfer faults connecting the Hayward and Rodgers Creek faults (Parsons and others, 2003).

The combined Hayward-Rodgers Creek rupture scenario has an estimated occurrence rate that is an order of magnitude less than the occurrence rates for the Rodgers Creek fault rupture only (WGCEP, 2008). We therefore adopt an Mw 7.0 as the design earthquake magnitude on the Rodgers Creek Fault.

6.3 ADJUSTMENTS FOR FAULT CREEP

The Rodgers Creek fault is one of just a few faults known throughout the world that are characterized by surface fault creep. In response to tectonic stresses, a creeping fault will move aseismically, either continuously or episodically, with an average rate that often is a significant fraction of its long-term slip rate (Funning and others, 2007). Creep on a fault therefore has the potential to reduce the magnitude of a future earthquake and thus the amount of surface rupture compared to the case where the fault is fully locked (e.g., Working Group on California Earthquake Probabilities, 2003; Schmidt and others, 2005). The rate of aseismic creep and the rate of "deep" slip (as approximated by the average long-term slip rate) on the fault therefore are critical information needed for estimating expected amounts of displacement during a large-magnitude earthquake.

Because aseismic creep is believed to occur along the northern Rodgers Creek Fault, elastic strain accumulates along the near-surface sections of the fault at a slower rate than at seismogenic depths, where the fault can be locked. Therefore, it is likely that displacement along the fault at seismogenic depths during the design earthquake will decrease upward as it reaches areas within which less strain has accumulated, and that the actual average surface displacements will be less than those at depth.

Recent observations based on satellite-derived InSAR data over a 10-year interval results in estimated creep rates up to 6 mm/year, which are comparable with estimates of 4.3 mm/yr obtained from nearby alignment arrays (Funning and others, 2007). The estimate remains somewhat controversial, however, since the evidence on the ground is limited. Although the creep rate for the southern end of the creeping section of the fault obtained from satellite observations by Funning and others (2007) is approximately 3.2 ± 0.3 mm/yr, measured creep values of 1.8 to 4.3 mm/yr at the survey array at Solano Drive, located south of Doyle Park and approximately ¾ of a kilometer south of Sonoma Avenue, suggest the creep rate at Sonoma Avenue could be greater than 4.3 mm/yr. The average fault creep rate on the Rodgers Creek fault of 4.9 ± 0.6 mm/yr for Funning and others (2007) is adopted, consistent with interpolation of results from Funning and others (2007) and modeling by Schmidt and others (2005).

6.4 EXPECTED AMOUNT OF SURFACE FAULT DISPLACEMENT

The full range of possible earthquakes on the Rodgers Creek fault (Mw 6.7 to 7.2), including rupture of the fault with the Hayward fault to the south, would be associated with an average fault offset from 1.5 ft up to as much as 7.2 ft, based solely on empirical relationships (Wells and Coppersmith, 2004). Of this offset, more sophisticated modeling by the USGS (http://earthquake.usgs.gov/regional/nca/simulations/hayward/M7.2.php) shows that the average slip or offset across the Hayward fault from the combined fault rupture is approximately 4 ft (1.2 m). For the northern Rodgers Creek fault, it is approximately 3 ft (0.9 m).

Assuming a more reasonable design earthquake of M7.0, a similar average maximum offset of approximately 3 ft is most likely for the northern portion of the fault in the vicinity of the aqueduct crossing (Toppozada, 1994). We use empirical relations to estimate the expected

amount of fault displacement, based on the design earthquake magnitude (Mw 7.0), fault length, and rupture area. Empirical relations developed by Wells and Coppersmith (1994) suggest an average subsurface displacement of 3.1 ± 1.8 ft for a Mw 7.0 earthquake. This estimate includes two standard deviations and is based on a worldwide database from earthquakes on all fault types.

Alternatively, to estimate the amount of expected fault displacement at the Santa Rosa Aqueduct crossing of the Rodgers Creek Fault from available geologic and geodetic slip rate information, we compared the rate of fault creep with the rate of long-term geologic slip, and adjusted the expected amount of surface displacement accordingly. Paleoseismic studies show that the long-term geologic slip rate on the northern Calaveras fault is between 6.4 and 10.4 mm/yr (Schwartz and others, 1992; Budding and others, 1999; Hecker and others, 2005). The WGCEP (2008) use a value of 9 ± 1 mm/yr for the slip rate on the Rodgers Creek fault. As stated above, a fault creep rate of 4.9 ± 0.6 mm/yr is adopted consistent with Funning and others (2007), based on modeling by Schmidt and others (2005). The rate of strain accumulation along the fault at the surface is the difference between the geologic slip rate and the fault creep rate. Based on the values given above, we estimate the rate of strain accumulation as:

Geologic Rate - Creep Rate = (9 ± 1 mm/yr) - (4.9 ± 1.7 mm/yr) = 4.1 ± 2.7 mm/yr

Active aseismic creep likely releases some of the strain accumulating over time. Therefore, the best prediction of coseismic surface displacement at the pipeline/fault crossing is estimated from existing slip rate and recurrence data of surface-fault ruptures along the Rodgers Creek fault. It is important to note that estimated recurrence period on the Rodgers Creek Fault is roughly 230 years (Hecker and others, 2005), and thus the fault is overdue for a large earthquake with associated ground rupture within the design life of the aqueduct. The estimated coseismic displacement expected from the design earthquake is represented by the equation:

D (Displacement) = **R** (Rate of strain accumulation) * **T** (Time since most recent event)

Rate: 4.1 ± 2.7 mm/yr

Time: 254 +/- 67 yr (since last earthquake)

Displacement = 4.1 mm/yr * 254 years = 3.4 ± 0.6 feet

The amount of coseismic vertical offset that may occur at the fault crossings from surface rupture is unknown, but there are limited data that enables a rough estimate of vertical displacement. Recent analyses of the relative amounts and sense of slip at the USGS Tule Pond Site in Fremont suggest that the vertical component of total slip is perhaps 30% of the lateral component or roughly 4 to 12 inches of vertical offset, distributed across the fault strands. This estimate is consistent with the commonly assumed ratios of 10:1 to 3:1 (horizontal: vertical) for components of slip along strike- slip faults throughout the world.

6.5 DISTRIBUTION OF ACTIVE SURFACE FAULT DISPLACEMENT

There is considerable uncertainty in the location and width of the Rodgers Creek fault zone in the vicinity of where it crosses the Santa Rosa aqueduct along Sonoma Avenue. The fault is concealed beneath alluvial fan deposits and is shown as a dashed (inferred) single fault strand on regional fault maps (Figure 1). The location of the fault primarily has based on projection of the mapped surface fault exposed north and south of the Santa Rosa Plain, modified in part based on geophysical survey data (Figure 2). Therefore, the location and character of the Rodgers Creek fault has previously been poorly constrained where it crosses Sonoma Avenue and the Santa Rosa aqueduct.

Based on field observations after the 1999 Duzce earthquake in Turkey, Rockwell and others (2002) showed that a significant percentage of the total surface displacement occurred as distributed deformation away from the primary fault rupture. Through detailed surveying of linear features displaced by the surface rupture (e.g., alignments of trees, fence lines, walls, canals), Rockwell and others (2002) showed that as much as 15 to 20% of the total lateral slip occurred as bending or drag in a zone typically 15 to 60 feet wide (5 to 20 m wide) bounding the main fault rupture. The 1999 Duzce earthquake is relevant to our assessment of the Rodgers Creek Fault at the Santa Rosa Aqueduct fault crossing because its magnitude (Mw 7.1) is similar to the Mw 7.0 design earthquake on the Rodgers Creek Fault, and similar surface-rupture length. Similar amounts of near-fault bending were documented along the San Andreas Fault near Fort Ross (Sonoma County) as a result of the 1906 San Francisco earthquake (Lawson, 1908; Bray and Kelson, 2006).

6.5.1 Fault Crossings A and B

Faults A and B (Figure 6) are inferred on the basis of apparently disrupted (tilted) subsurface layers at depth (~50 to 75 feet) beneath Sonoma Avenue in the vicinity of Doyle School. In addition, changes in the subsurface elevation of subsurface sand and silt layers on the CPT transect are permissive of near-surface faulting. However, previous trenching studies across the surface projection of faults A and B in the vicinity of the Santa Rosa aqueduct crossing provide direct evidence against surface fault rupture on these faults.

The long (513 ft) continuous trench, approximately 11 feet deep, located across the southern portion of the Doyle Park school facility south of Sonoma Avenue crossed both fault A and B and documented the absence of faulted (offset or tilted) surface deposits across the surface projection of either Fault A or B (BACE Geotechnical, 1992).

6.5.2 Fault Crossings C and D

Faults C and D (Figure 6) are inferred on the basis of apparently disrupted (tilted) subsurface layers at depth (~50 to 75 feet) beneath Sonoma Avenue in the vicinity of Talbot Avenue. The faults bound a 300-foot-wide (90 m) zone roughly coincident with the general location of the AP fault trace (1992, 2008), in the vicinity of Talbot and Macklyn Avenues. If surface rupture occurs on this inferred feature, we estimate that 80% of the dextral offset will occur within 40-ft-wide primary rupture zones, centered on faults C and D (Figure 8), with 50%

of the displacement occurring on Fault D, based on the more pronounced offset of subsurface stratigraphic layers. In the absence of any fault trenching data or observed surface deformation (fault creep), we estimate that the remaining 20% of dextral offset could be distributed symmetrically, between the faults and bordering the primary rupture. However, as discussed below, although considered unlikely, we recommend the conservative assumption that all of the surface offset on the Rodgers Creek Fault could be centered on, and constrained within a narrow zone ('knife edge') of 1 to 5 feet width across either fault strand C or D.

6.5.3 Fault Crossing E

Although seismicity, geomorphic, and trenching evidence suggest that the Rodgers Creek fault is primarily a strike-slip fault, upwarping may continue to the ground surface to coincide with a 0.5-m high arching of the Sonoma Ave pavement centered near Hoen Avenue Fault E, is inferred on the basis of projection to the surface of disrupted reflectors in the seismic data (Figures 3 and 4), offset subsurface stratigraphy identified on the CPT transect (Figure 7), and a broad upwarp in Sonoma Avenue across the surface projection of the fault centered between Rosedale and Alderbrook Avenues (also visible on the topographic profile shown on Figure 7). The warping of the ground surface, if related to faulting, is consistent with a component of vertical offset across the dipping fault strand with up-on-the-west displacement, likely equal to or less than 12 inches. The total observed amplitude of the upwarped ground surface is 1.5 feet, which would require multiple earthquakes (repeated displacement) to produce. It should be noted that this broad deformation between Rosedale and Alderbrook Avenues, centered on Hoen Avenue, may not be associated with discrete surface faulting and may be the result of secondary faulting during rupture on the main fault strand at depth, with most of the offset accommodated by faults C and D near Talbot Avenue with associated surface rupture.

Based on the CPT profile, the zone of possible faulting centered on fault E is 200 feet (60 m) wide. At the Fault E crossing of the Santa Rosa Aqueduct, if surface rupture occurs on this inferred feature, we estimate that 70% of the dextral offset will occur within a 60-ft-wide fault zone, centered on the fault (Figure 9). In the absence of any fault trenching data or observed surface deformation (fault creep), we estimate that the remaining 30% of dextral offset could be distributed symmetrically, with 15% occurring in a 70-ft wide zone to the east and 15% occurring in a 70-ft wide zone to the west bordering the primary rupture. However, as discussed below, although considered unlikely, we recommend the conservative assumption that all of the surface offset on the Rodgers Creek Fault could be centered on, and constrained within a narrow zone ('knife edge') of 1 to 5 feet width across fault strand E.

7.0 CONCLUSIONS

The available information from previous trenching studies in the vicinity helps constrain the likely location of the fault primarily by documenting where the fault is not present. Interpretation of newly available seismic reflection data shows that the Rodgers Creek Fault is

more complex than previously mapped, likely consisting of up to five discrete fault strands that merge at depth into a single vertical fault (Figures 3 and 4). These strands form a positive 'flower' structure. The surface projection of the subsurface faults (strands 'A' through 'E') intersect Santa Rosa Aqueduct along Sonoma Avenue between Doyle Park Drive and Bobelaine Drive with the main active fault trace consisting of the central faults, faults 'C' and 'D' (Figures 6 and 7).

Based on review of the available data, the main trace of the Rodgers Creek Fault intersects Santa Rosa Aqueduct coincident with the general location of the AP fault trace (1992, 2008), near Talbot Drive in Santa Rosa, California. The center of the fault zone (i.e., the main trace) is constrained within about 300 feet (90 m), in the vicinity of Talbot and Macklyn Avenues, based on interpretation of reflection seismic data combined with the CPT transect conducted for this study. Within the zone two possible fault traces ('C' and 'D') are interpreted that bound the shear zone. An additional fault, trace 'E', is inferred on the basis of the seismic data, offset subsurface stratigraphy identified on the CPT transect, and a broad upwarp in Sonoma Avenue across the surface projection of the fault centered between Rosedale and Alderbrook Avenues. Based on the CPT profile, the zone of possible faulting centered on fault E is 200 feet (60 m) wide.

At the Santa Rosa Aqueduct crossing of the Rodgers Creek fault, the existing buried pipeline has an orientation (trend) of N72°W (72° clockwise from north). The fault zone, and individual fault strands A through E have a general orientation (strike) of N17°W (17° ± 3° counterclockwise from north). The acute intersection between the two is therefore 89° ± 3° During right-lateral fault movement, this geometry will result primarily in lateral shear causing tension along the pipeline at the fault crossing.

The fault likely consists of a 3 to 40-foot-wide (1- to 15-m wide) zone of diffuse shearing, based on examples of similar distributed faulting above strike-slip restraining bends (positive flower structures) within young alluvial sediments (e.g. Sylvester, 1988). However, the location and width of faulting is inferred based on available seismic and CPT data only and has not verified by trenching at the fault crossings.

At the depth of the aqueduct, deposits consist of clayey sand to clay (SC-CH) with an average dry density of 85 pcf, initial water content of 5-10%, apparent cohesion of 0.4 ksf, and an apparent friction angle of 22 degrees (Tables 1 and 2; Appendix C). No significant variation in soil type is anticipated along the aqueduct at the depth of emplacement.

8.0 RECOMMENDATIONS

Table 3 provides a summary of our findings with recommended actions for modeling. We recommend that the engineering evaluation of the Santa Rosa Aqueduct conservatively consider the possibility that the full displacement could occur within narrower zones than the deformation zones represented in Figures 8 and 9. Specifically, based on examples from major earthquakes, strike-slip displacement can be concentrated within a few feet. In addition, given the uncertainty in the distribution of active faulting across the aqueduct between Rosedale and Alderbrook on Fault E, e.g. whether the fault strand is a major component of the Rodgers Creek Fault zone, we recommend that Fault E be considered capable of the entire fault displacement. Therefore, although considered unlikely, we recommend the conservative assumption that all of the surface rupture on the Rodgers Creek Fault could be centered on, and constrained within a narrow zone ('knife edge') of 1 to 5 feet width across fault strands C, D, or E.

Table 3. Summary of findings for fault-rupture hazards along the Santa Rosa Aqueduct across the Rodgers Creek Fault, Santa Rosa

Fault Crossing	Approximate Location	Summary of Findings	Recommended Action
A	Between Doyle Park and Talbot	No active fault crossing	None
B	Between Doyle Park and Talbot	No active fault crossing	None
C	Talbot	Active main fault crossing	Model full displacement (Figure 8)
D	Bishop	Active main fault crossing	Model full displacement (Figure 8)
E	Between Rosedale and Alderbrook	Potentially active secondary or main fault crossing	Model full displacement (Figure 9)

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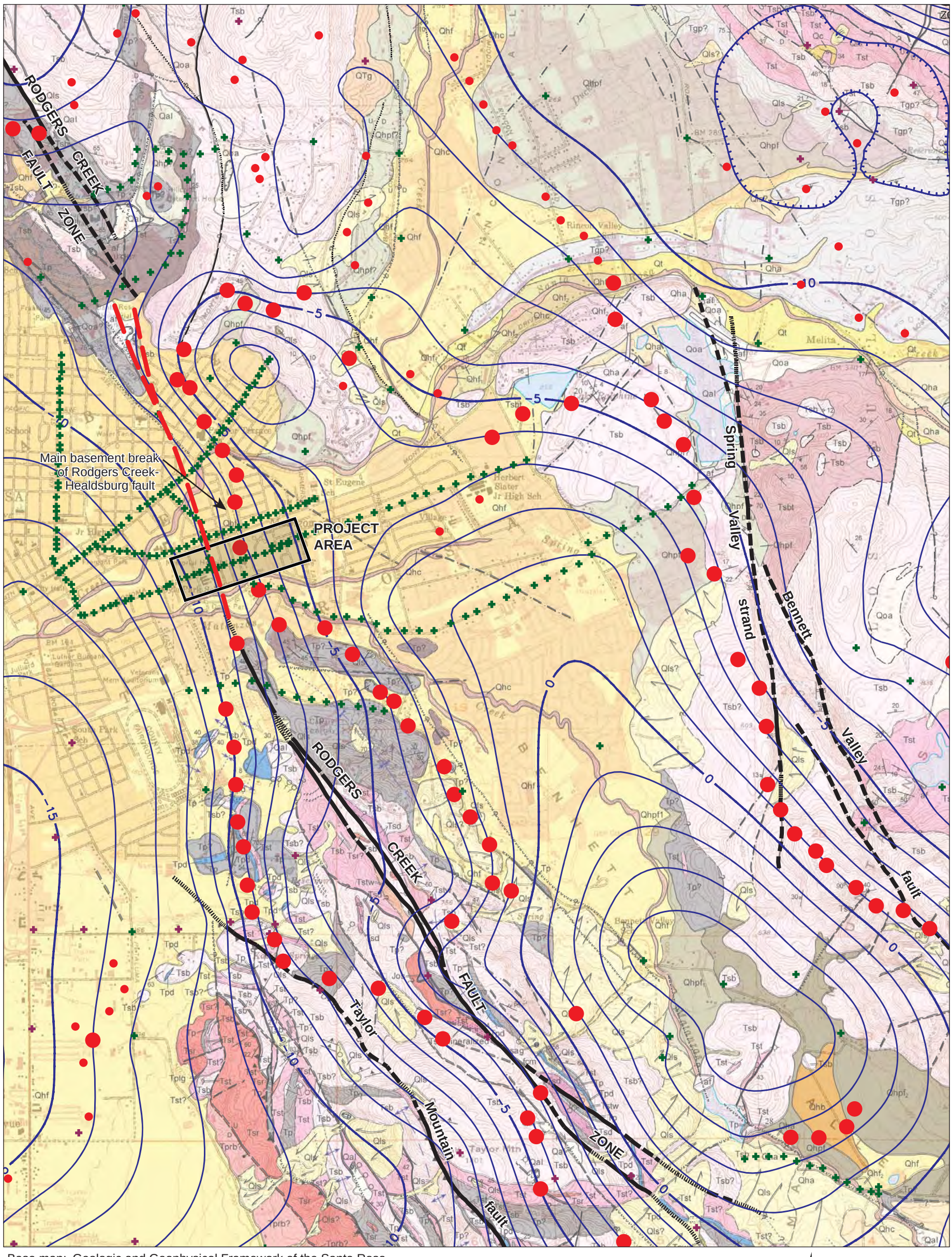
AERIAL PHOTOGRAPHS

Date	Flight Line	Scale
1942	USDA COF-7-25, -26, and -27	1:20,000

FIGURES



Base map: Geologic and Geophysical Framework of the Santa Rosa 7.5' Quadrangle, Sonoma County, California by R.J. McLaughlin et al., 2008

DRAFT

N

0 1 mi

0 1 km

Explanation

A-P fault trace

Gravity Station Locations

California Division of Mines and Geology station

U.S. Geological Survey station

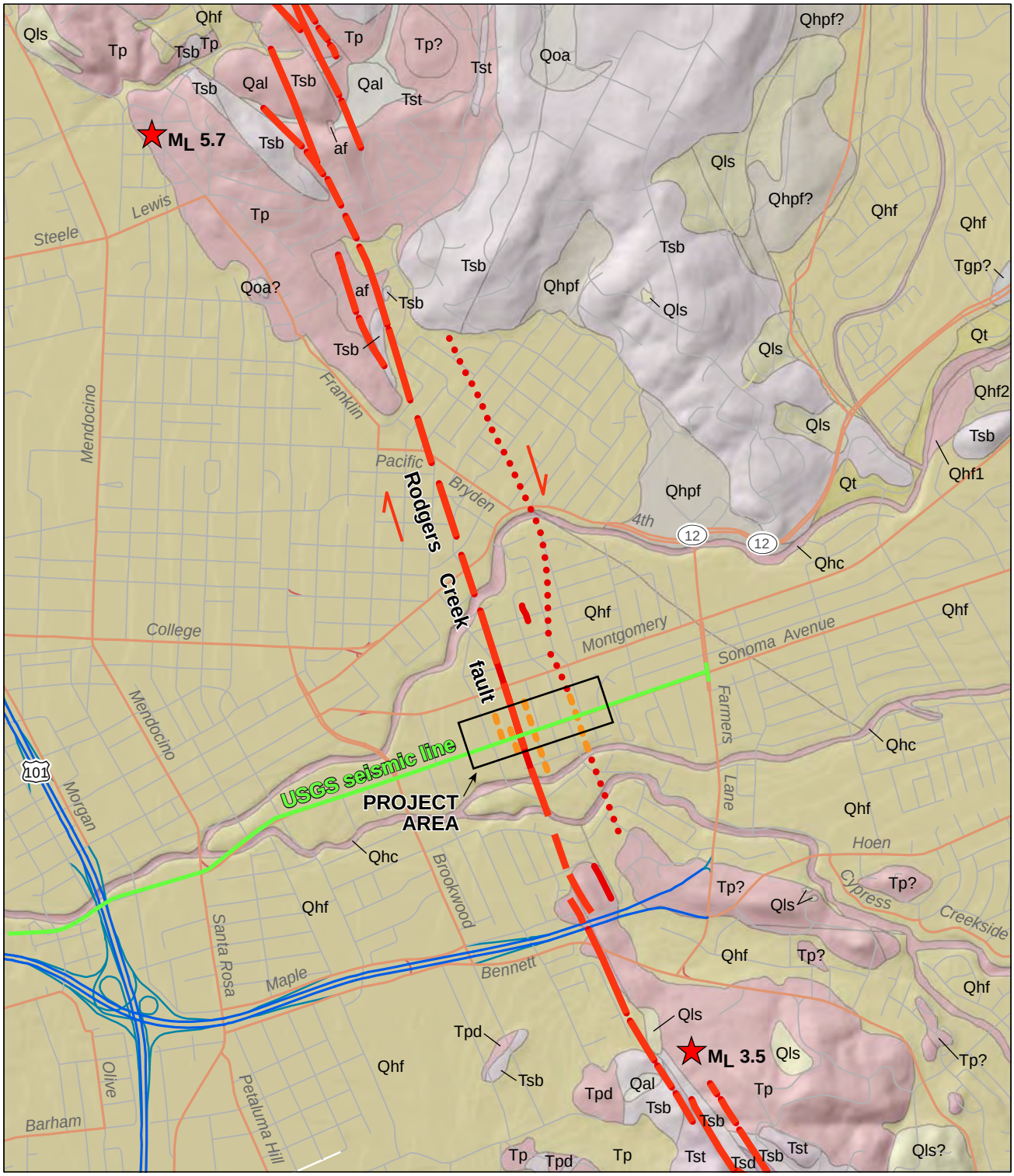
Gravity Anomaly Contours

Contour interval, 1 and 5 mGal. Hachures indicate gravity low. Contours were computer generated based on a 300-m grid. Red circles are density boundaries automatically calculated from grid; larger circles indicate greater than average magnitude of gravity gradient. Smaller circles indicate less than average magnitude of gravity gradient.

Note: Figure modified from Langenheim et al., 2008.

Regional Geologic Map
Showing Isostatic Gravity Contours

FIGURE 1



Explanation

A-P fault trace, arrows indicate direction of movement

Inferrred fault strand, this study

Gravity density boundary from Langenheim et al., 2008

M_L 5.7 Location of earthquake with magnitude indicated (from Wong and Bott, 1995)

N

0 2,000 ft.

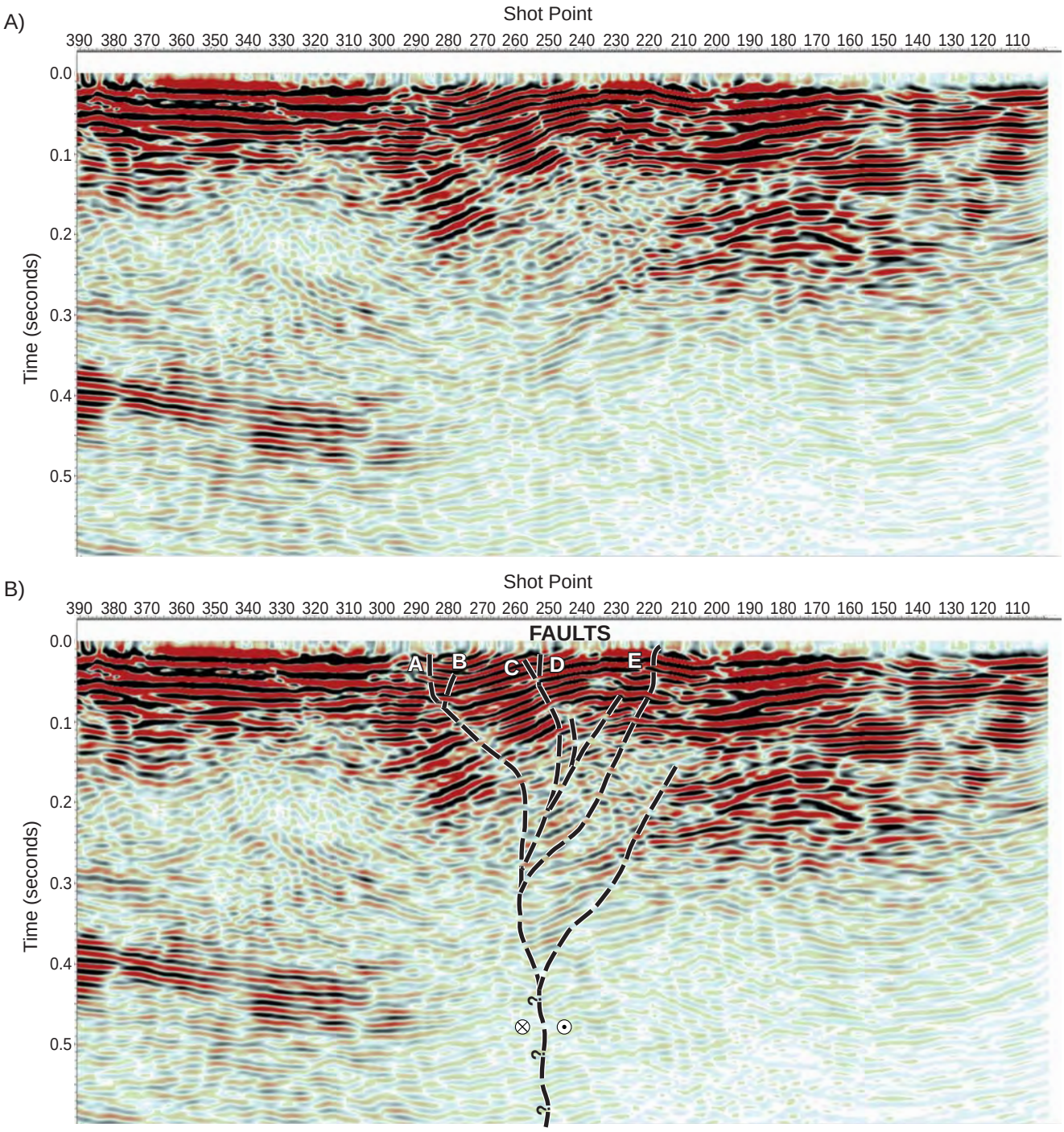
0 500 m

DRAFT

Graphics, Projects, 04.79218600 SCWA Rodgers Creek, modified 08.31.11

Fault Map Showing USGS Seismic Line

FIGURE 2



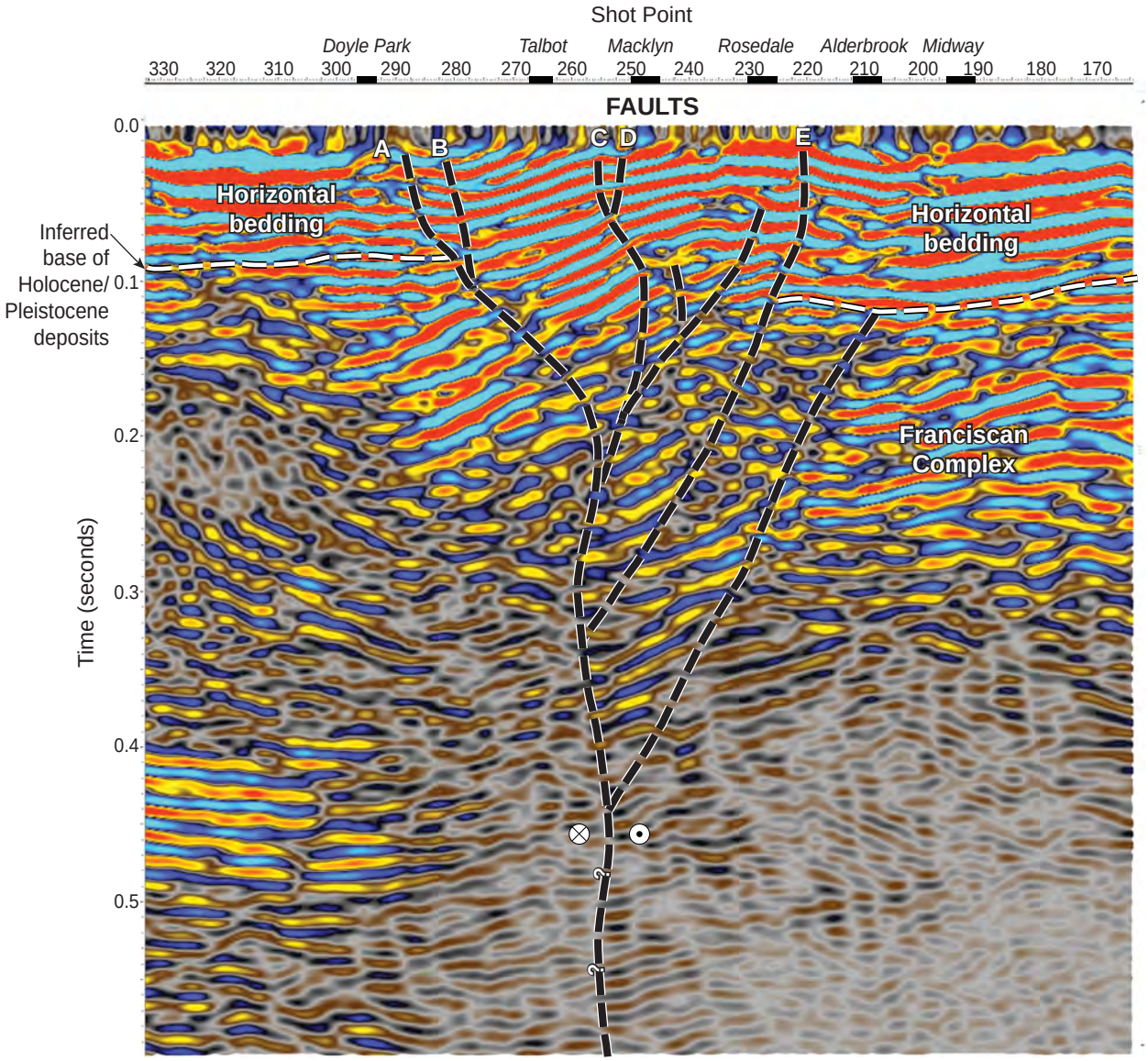
Notes: 1. See Figure 2 for seismic line location.
2. Seismic data courtesy of R. Williams, USGS.

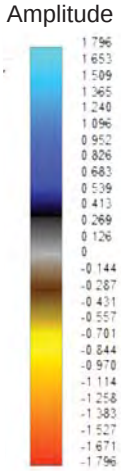
DRAFT

Graphics, Projects, 04.79218600 SCWA Rodgers Creek, modified 08.31.11

Uninterpreted (A) and Interpreted (B) 2-D Seismic Line along Sonoma Avenue across Rodgers Creek Fault

FIGURE 3





Note: Seismic data courtesy of R. Williams, USGS.

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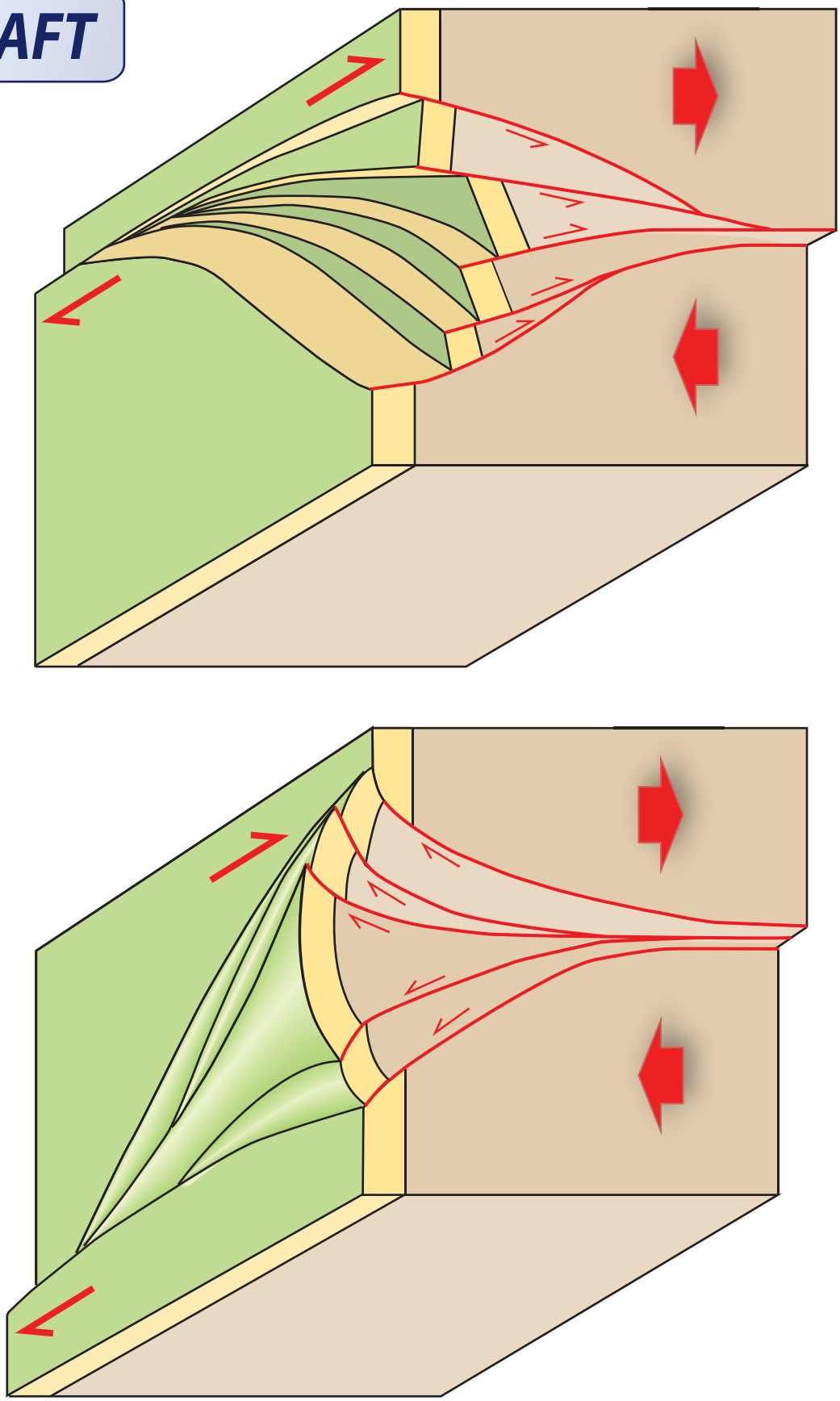
Graphics, Projects, 04.79218600 SCWA Rodgers Creek, modified 08.31.11

Detail of Interpreted 2-D Seismic Line in Project Area

FIGURE 4

DRAFT

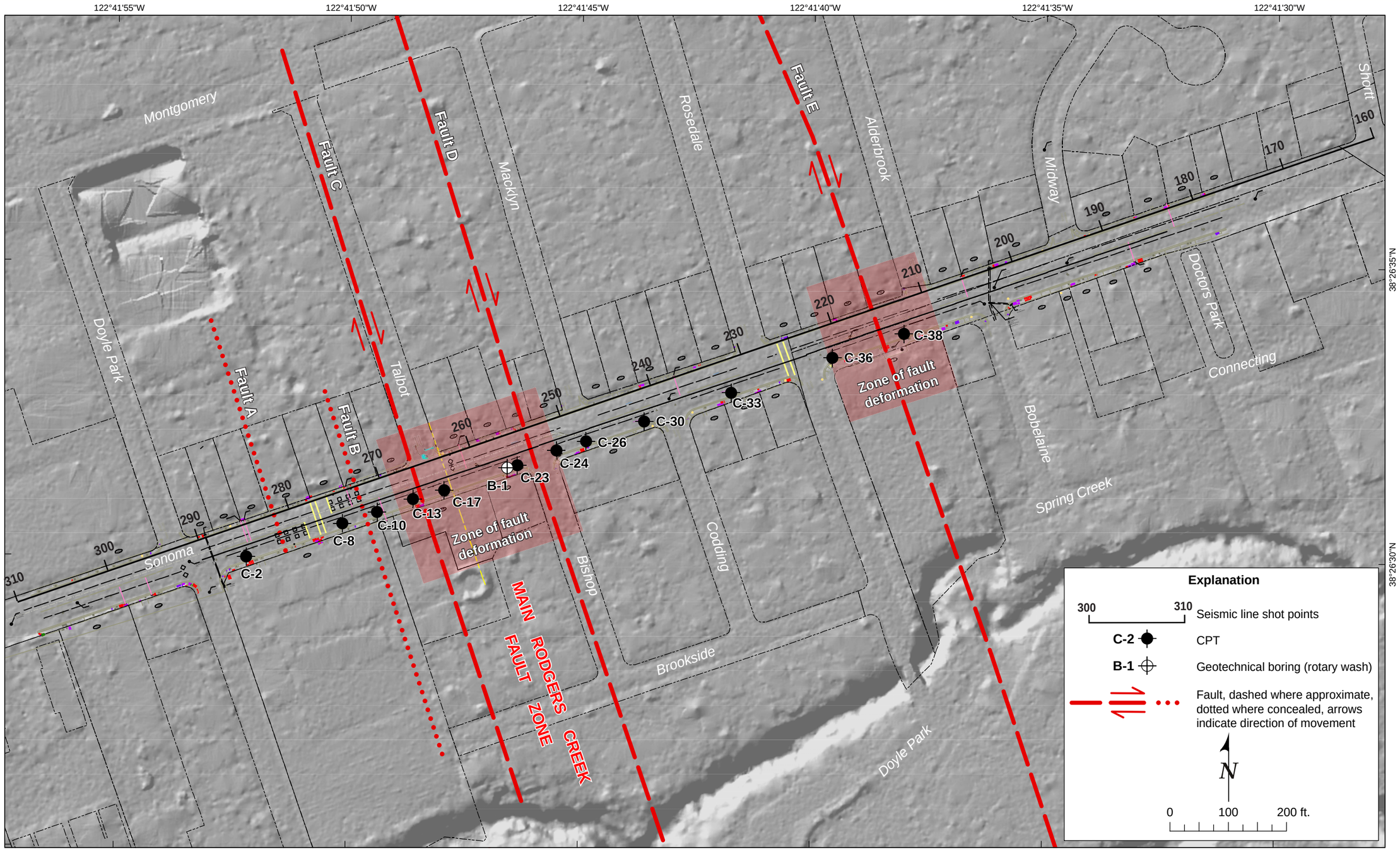


Conceptual Diagram of Right-lateral Strike-slip Fault Flower Structure

Graphics, Projects, 04.79218600 SCWA Rodgers Creek, modified 09.08.11

FIGURE 5

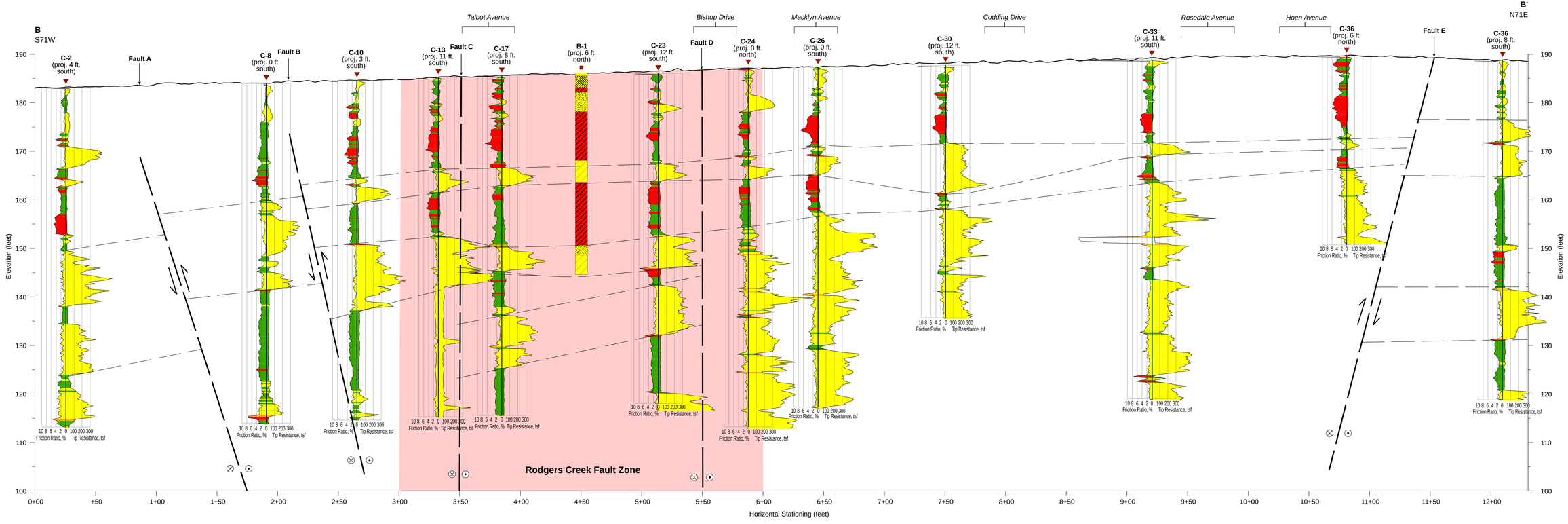
DRAFT



Graphics, Projects, 04.79218600 SCWA Rodgers Creek, modified 08.31.11

LiDAR Base Map Showing Seismic Line and Subsurface Exploration Locations

FIGURE 6



Explanation

Symbols

Fault, arrows indicate direction of movement

Away, towards

Soils (Robertson and Campanella, 1988)

- Fill
- Fill
- CL - lean clay
- SC - clayey sand
- GWGC - well-graded gravel with clay and sand
- SWSC - well-graded sand with clay and gravel

Soil Type Based on CPT Results (Robertson and Campanella, 1988)

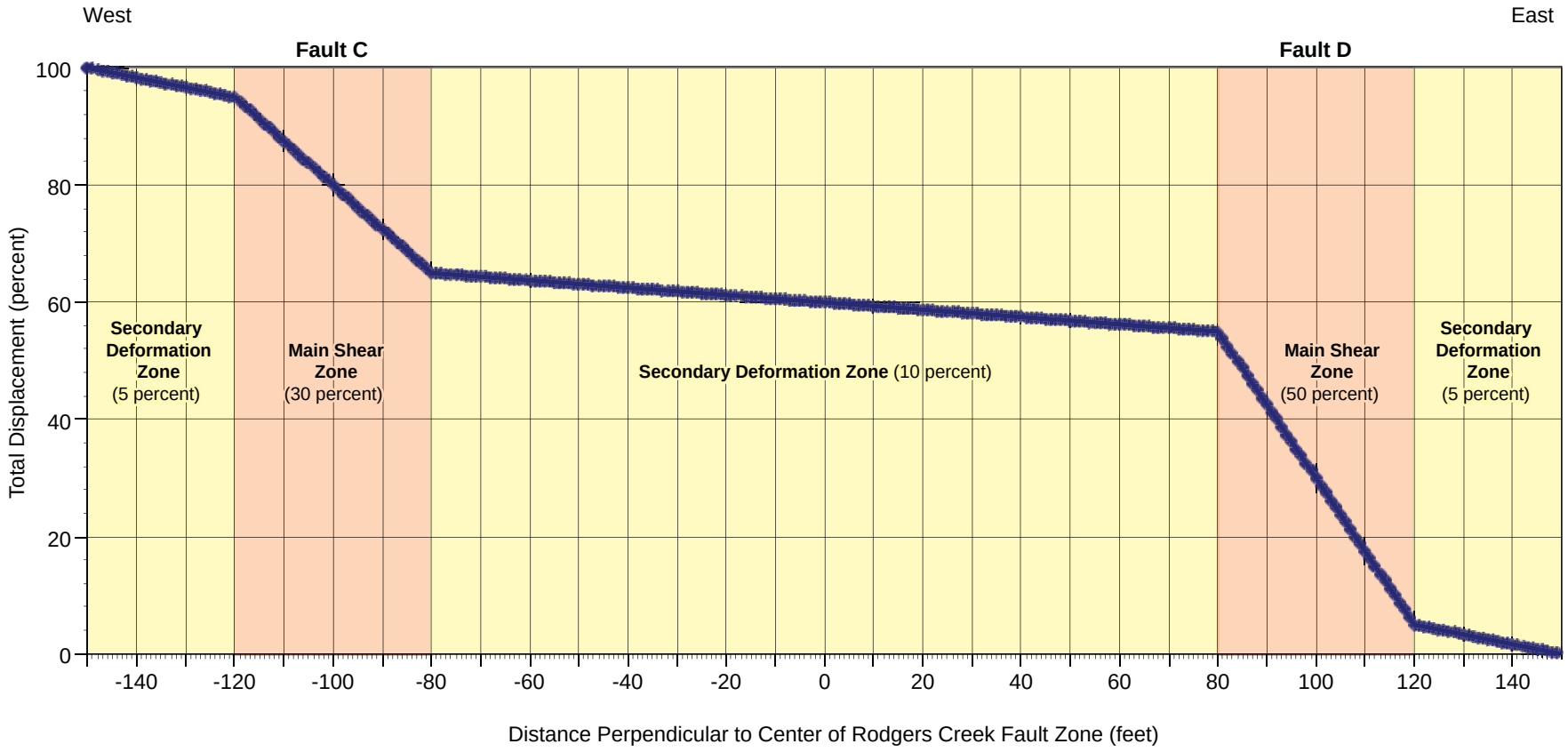
- Silty sand to gravelly sand (SM, SP, GW)
- Very stiff silty clay to clay (CH - CL)
- Clay (CL)
- Sandy silt to clayey silt (ML, MH)
- Organic material (OL - OH)

DRAFT

CPT and Geotechnical Boring Transect along Sonoma Avenue, View to North

FIGURE 7

Graphics, Projects, 04.79218600 SCWA Rodgers Creek, modified 08.31.11

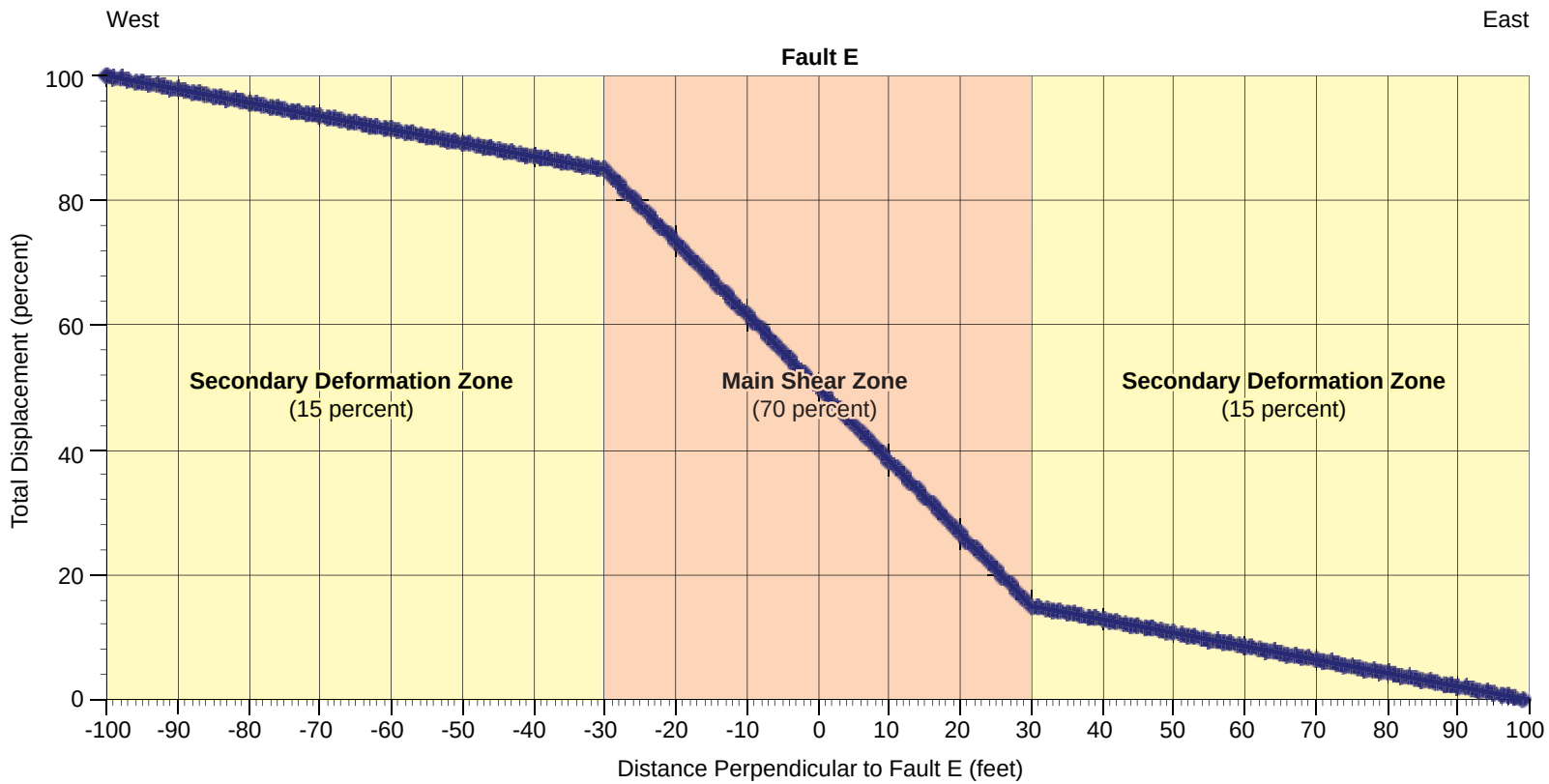


DRAFT

FIGURE 8

Displacement Profile for Main Fault Zone

Fugro Consultants, Inc.
Project No. 04.79218600 SCWA Rodgers Creek



DRAFT

Displacement Profile for Secondary Fault Zone E

FIGURE 9

Fugro Consultants, Inc.
Project No. 04.79218600 SCWA Rodgers Creek

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APPENDIX A

CPT DATA

GREGG DRILLING & TESTING, INC.
GEOTECHNICAL AND ENVIRONMENTAL INVESTIGATION SERVICES

July 11, 2011

Fugro
Attn: Chris Hitchcock

DRAFT

Subject: CPT Site Investigation
SCWA Santa Rosa Aqueduct
Santa Rosa, California
GREGG Project Number: 11-094MA

Dear Mr. Hitchcock:

The following report presents the results of GREGG Drilling & Testing's Cone Penetration Test investigation for the above referenced site. The following testing services were performed:

1	Cone Penetration Tests	(CPTU)	☒
2	Pore Pressure Dissipation Tests	(PPD)	☒
3	Seismic Cone Penetration Tests	(SCPTU)	☐
4	UVOST Laser Induced Fluorescence	(UVOST)	☐
5	Groundwater Sampling	(GWS)	☐
6	Soil Sampling	(SS)	☐
7	Vapor Sampling	(VS)	☐
8	Pressuremeter Testing	(PMT)	☐
9	Vane Shear Testing	(VST)	☐
10	Dilatometer Testing	(DMT)	☐

A list of reference papers providing additional background on the specific tests conducted is provided in the bibliography following the text of the report. If you would like a copy of any of these publications or should you have any questions or comments regarding the contents of this report, please do not hesitate to contact our office at (925) 313-5800.

Sincerely,
GREGG Drilling & Testing, Inc.

Mary Walden
Operations Manager

950 Howe Rd • Martinez, California 94553 • (925) 313-5800 • FAX (925) 313-0302
OTHER OFFICES: LOS ANGELES • HOUSTON
www.greggdrilling.com

DRAFT

Cone Penetration Test Sounding Summary

-Table 1-

CPT Sounding Identification	Date	Termination Depth (Feet)	Depth of Groundwater Samples (Feet)	Depth of Soil Samples (Feet)	Depth of Pore Pressure Dissipation Tests (Feet)
C-2	7/05/11	70	-	-	-
C-8	7/05/11	70	-	-	66.6
C-10	7/05/11	70	-	-	37.6
C-13	7/08/11	70	-	-	-
C-17	7/08/11	70	-	-	-
C-23	7/08/11	69	-	-	-
C-24	7/06/11	74	-	-	-
C-26	7/08/11	70	-	-	-
C-30	7/07/11	52	-	-	-
C-33	7/07/11	70	-	-	-
C-36	7/07/11	38	-	-	-
C-38	7/07/11	70	-	-	38.9

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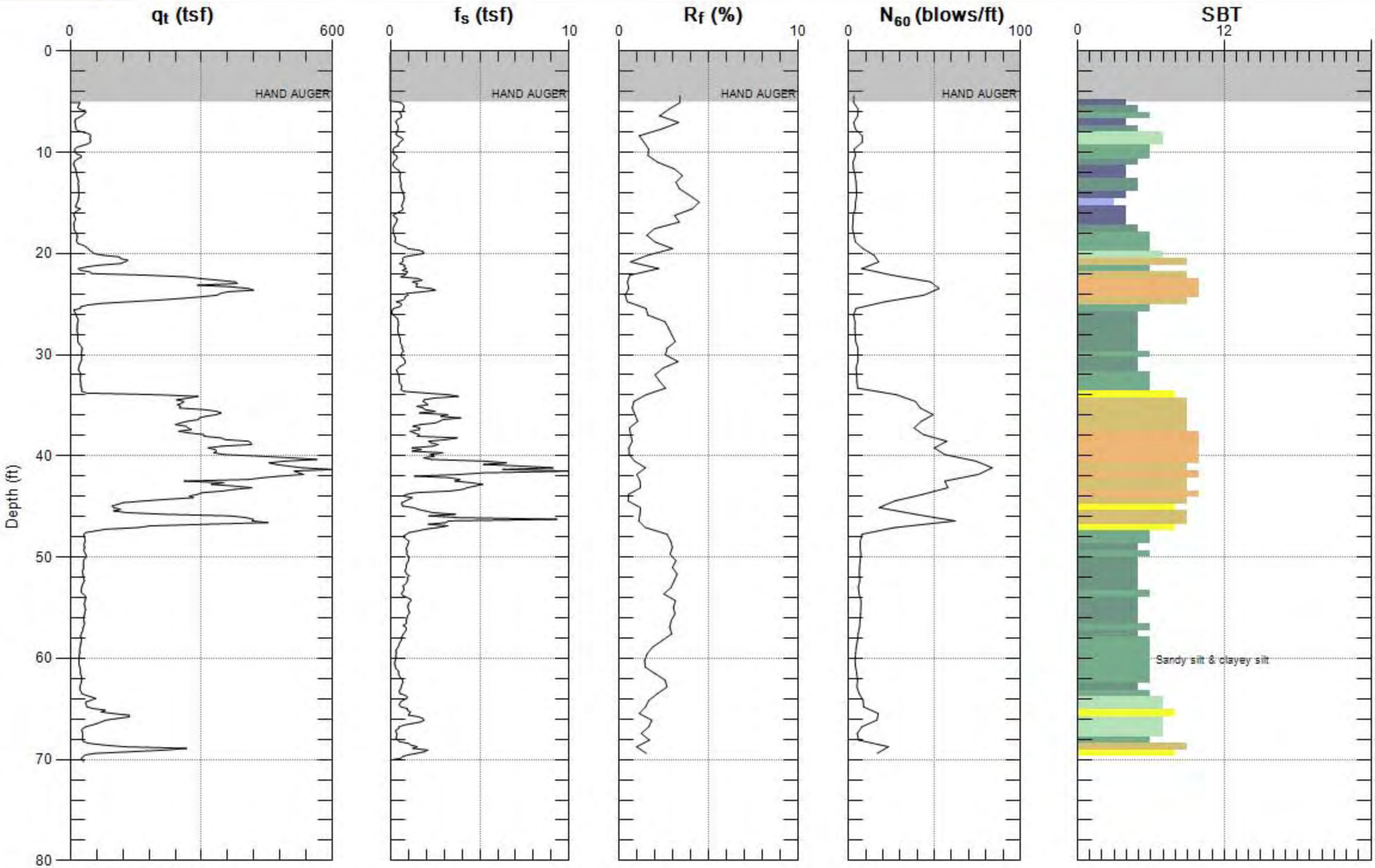
Copies of ASTM Standards are available through www.astm.org

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-10

Engineer: C.HITCHCOCK
Date: 7/5/2011 01:41



Max. Depth: 70.210 (ft)
Avg. Interval: 0.328 (ft)

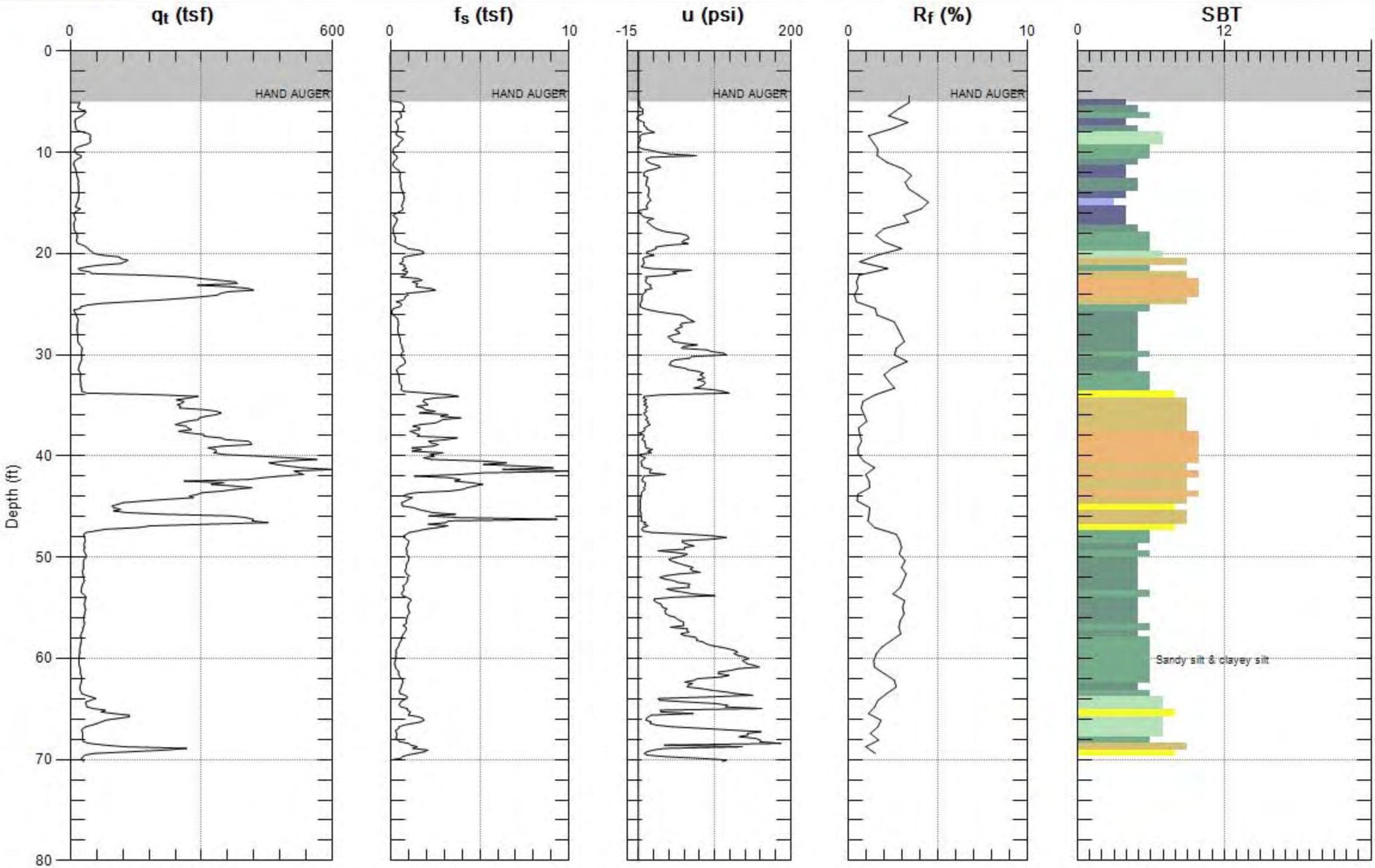
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-10

Engineer: C.HITCHCOCK
Date: 7/5/2011 01:41



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Avg. Interval: 0.328 (ft)

SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

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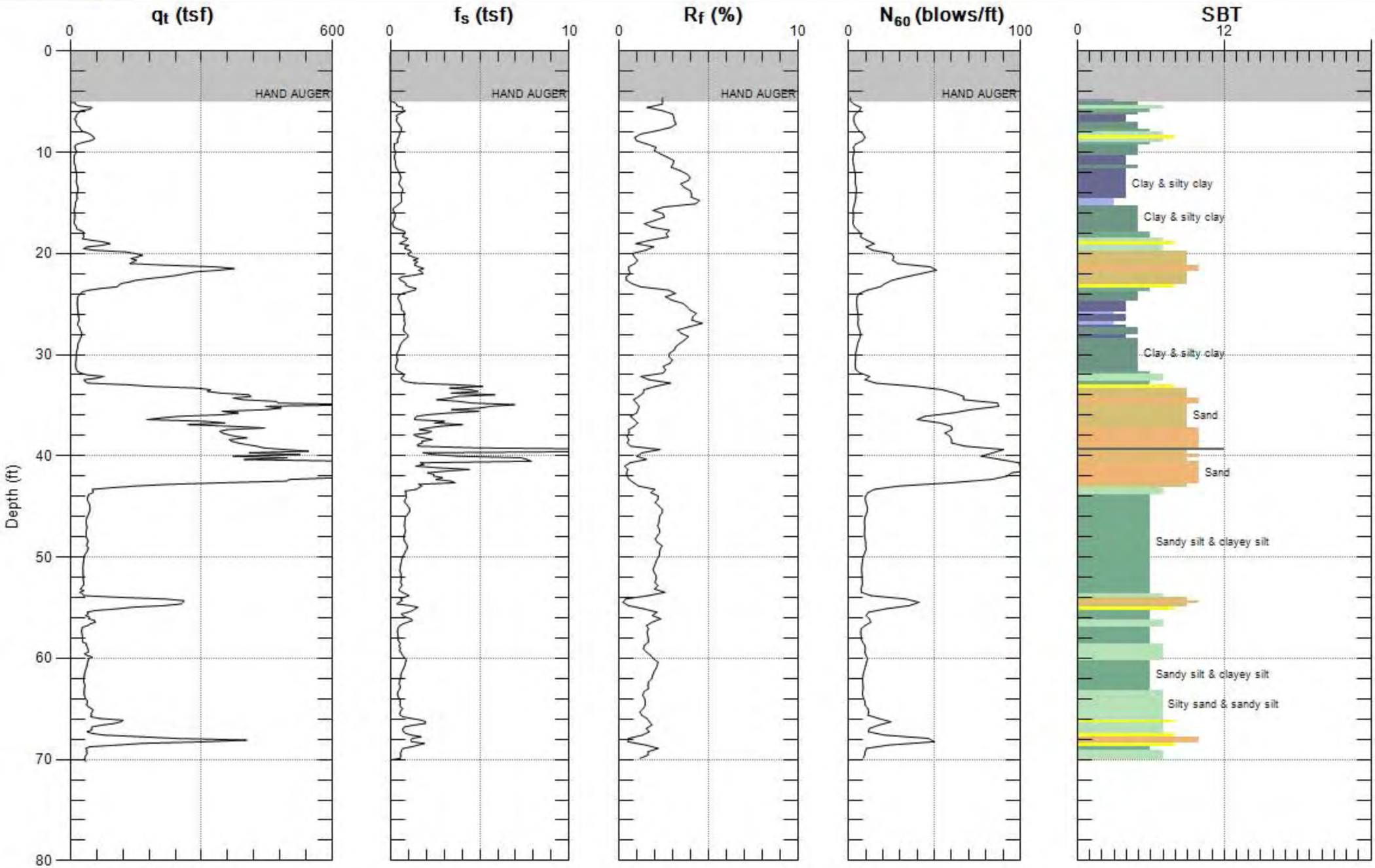
Sounding: C-13

Engineer: C.HITCHCOCK
Date: 7/8/2011 08:47



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Avg. Interval: 0.328 (ft)

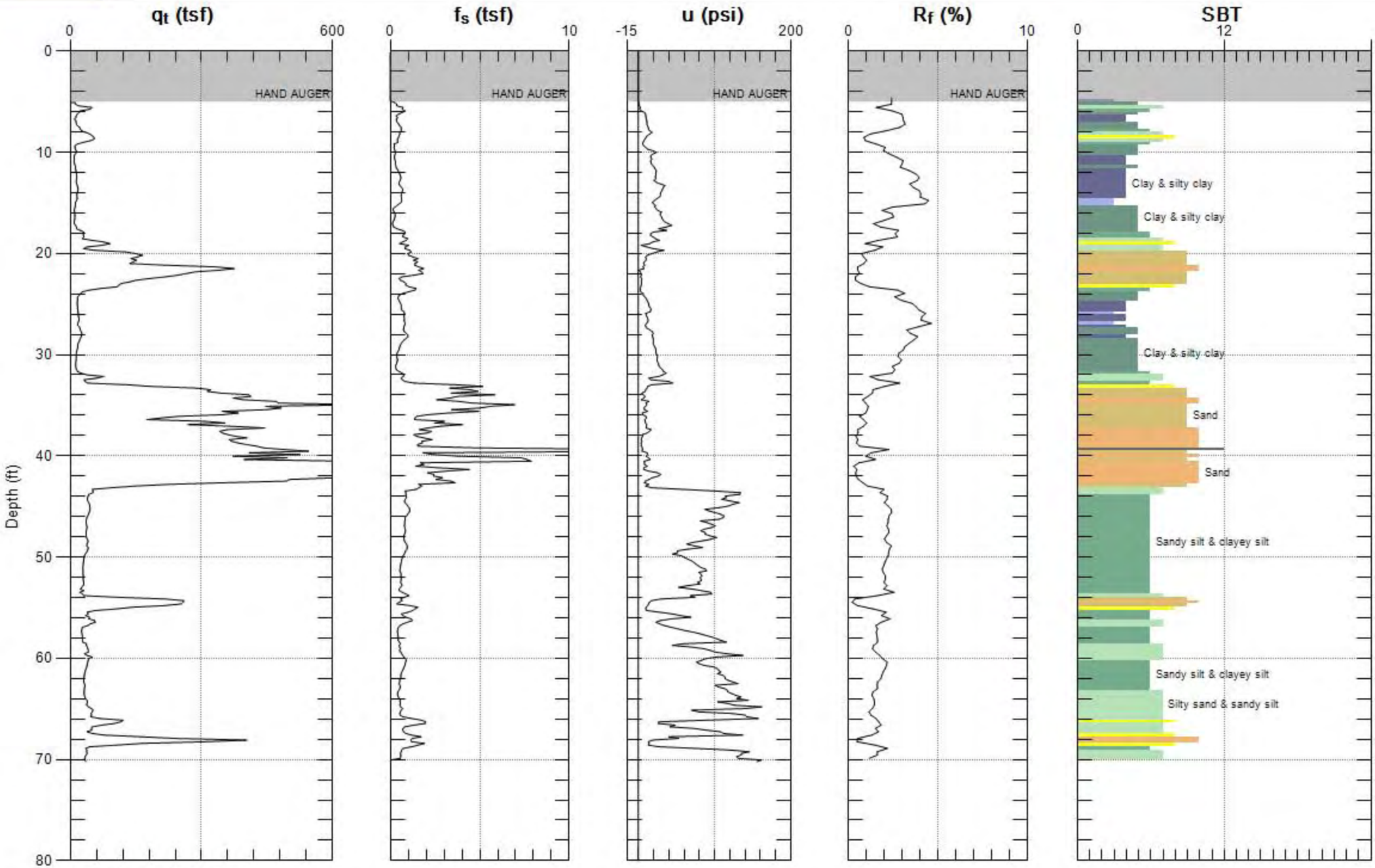
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-13

Engineer: C.HITCHCOCK
Date: 7/8/2011 08:47



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Avg. Interval: 0.328 (ft)

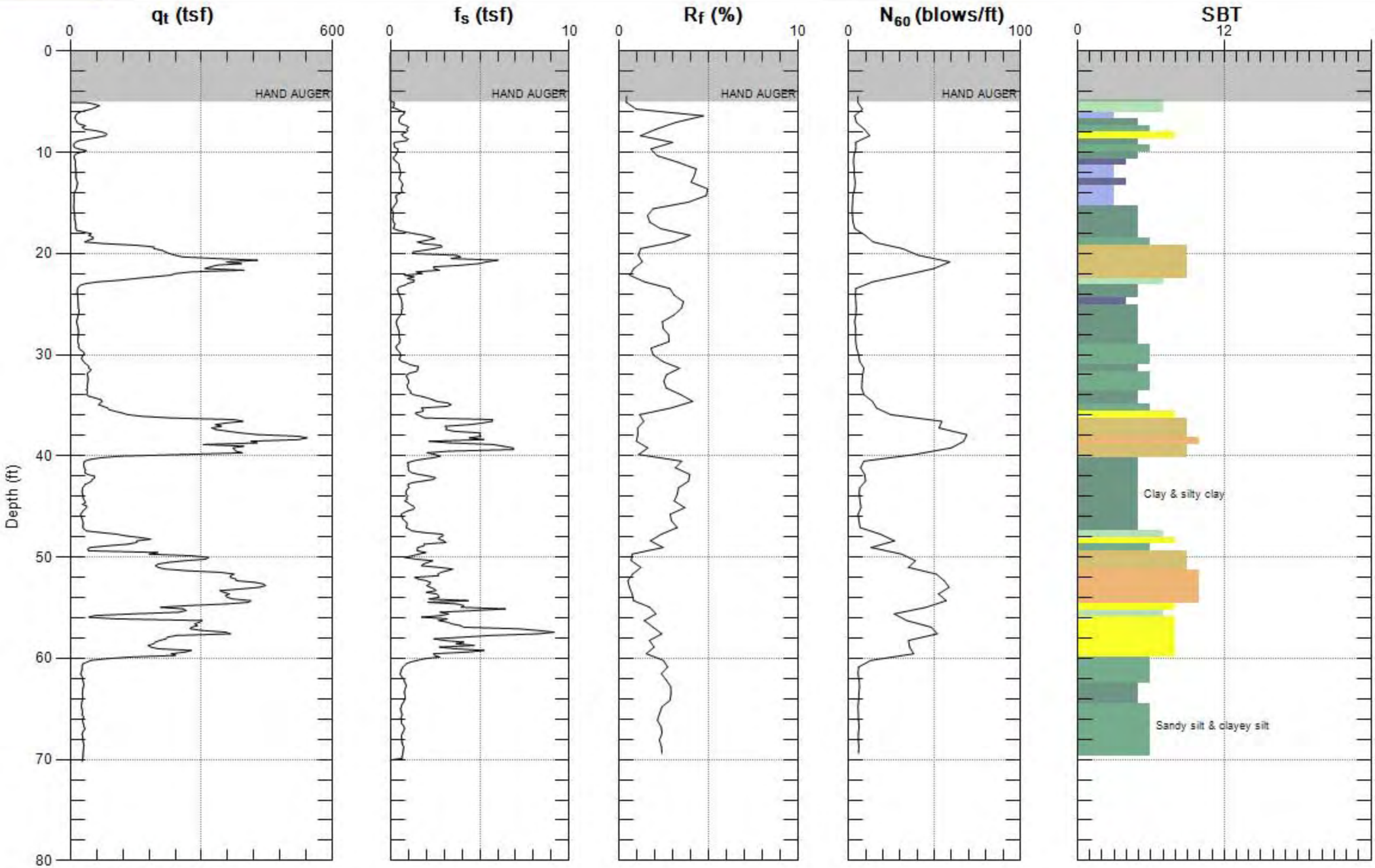
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-17

Engineer: C.HITCHCOCK
Date: 7/8/2011 10:40



Max. Depth: 70.210 (ft)
Avg. Interval: 0.328 (ft)

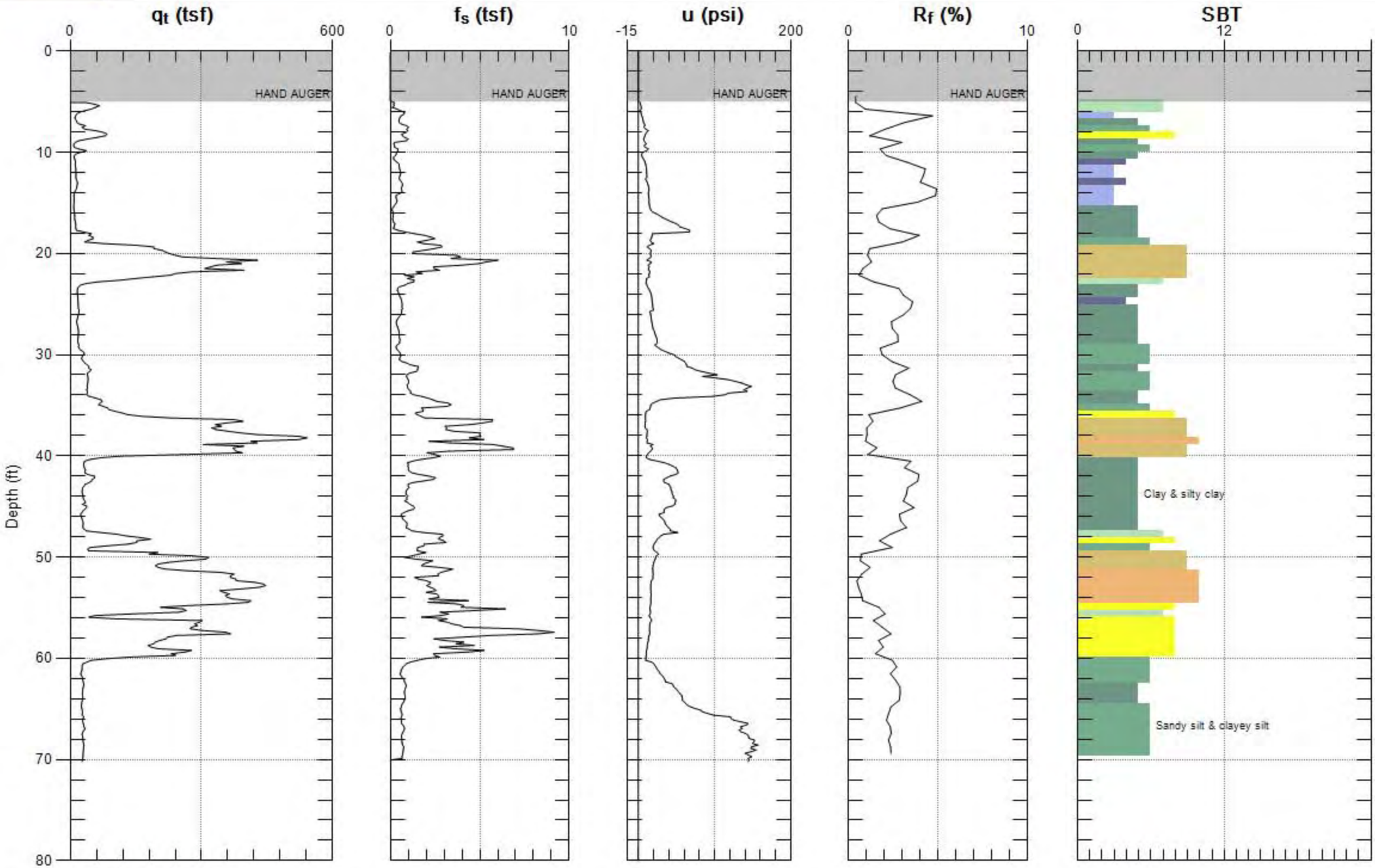
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-17

Engineer: C.HITCHCOCK
Date: 7/8/2011 10:40



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Avg. Interval: 0.328 (ft)

SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

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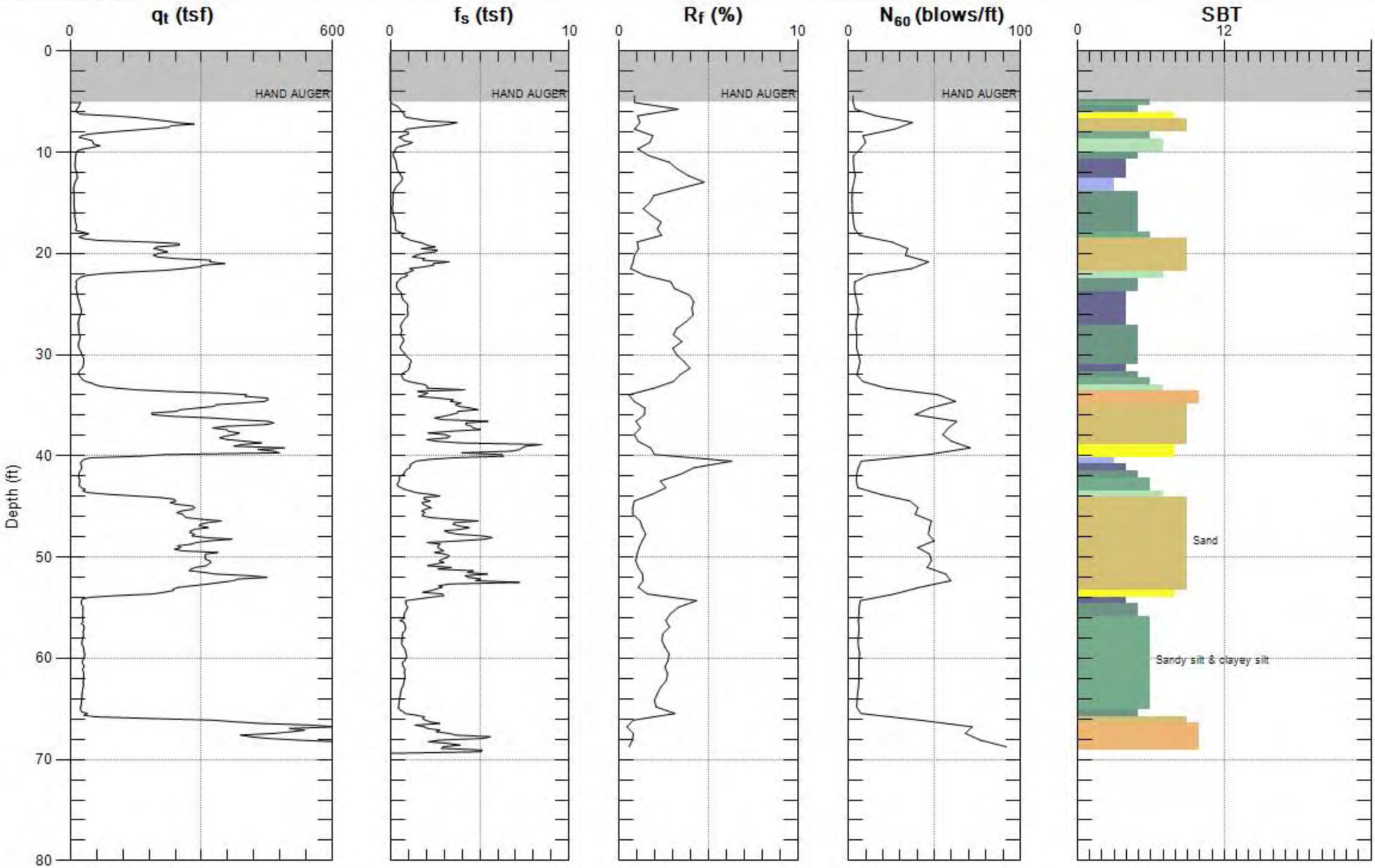
Sounding: C-23

Engineer: C.HITCHCOCK
Date: 7/8/2011 01:03



Max. Depth: 69.554 (ft)
Avg. Interval: 0.328 (ft)

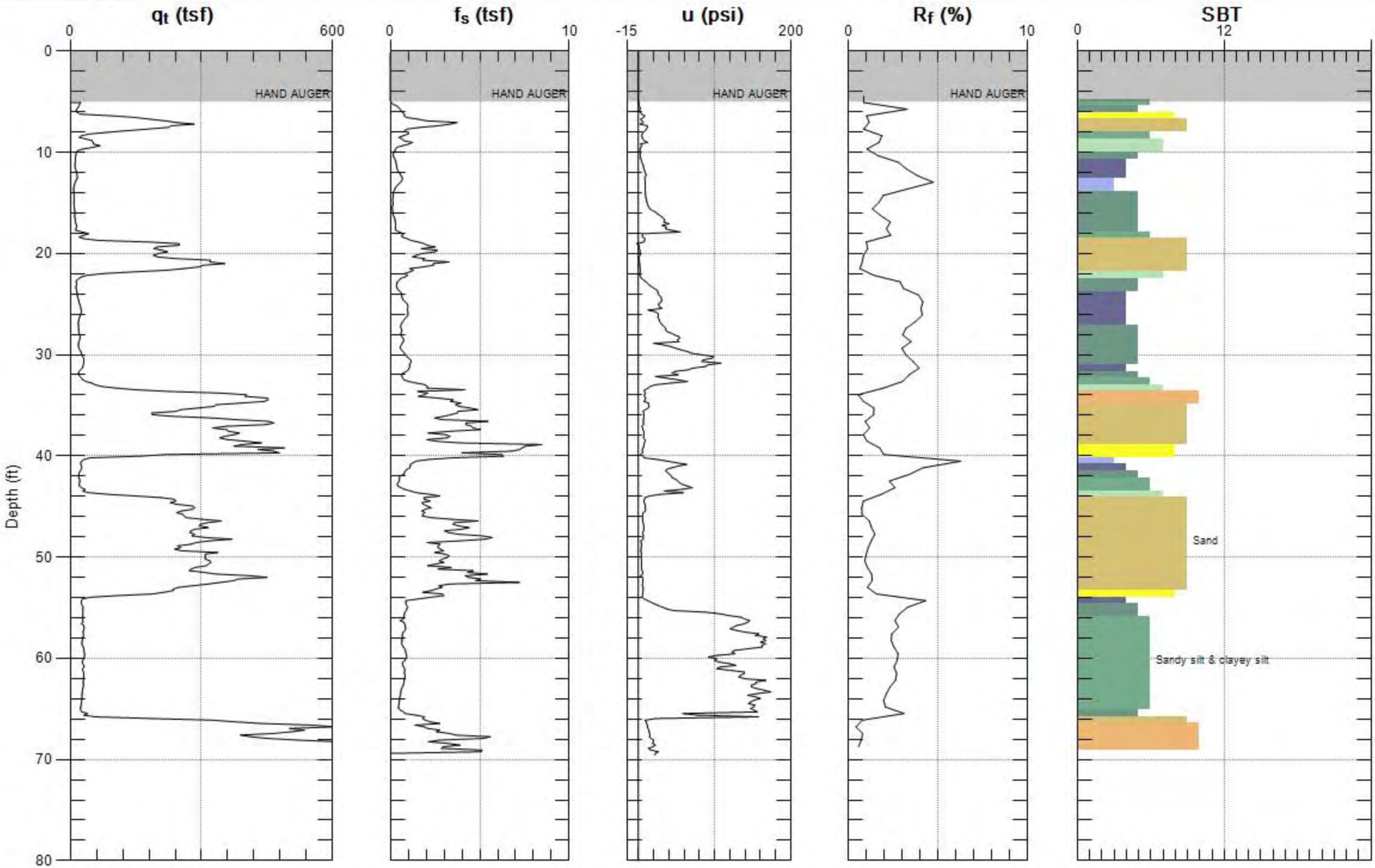
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-23

Engineer: C.HITCHCOCK
Date: 7/8/2011 01:03



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SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

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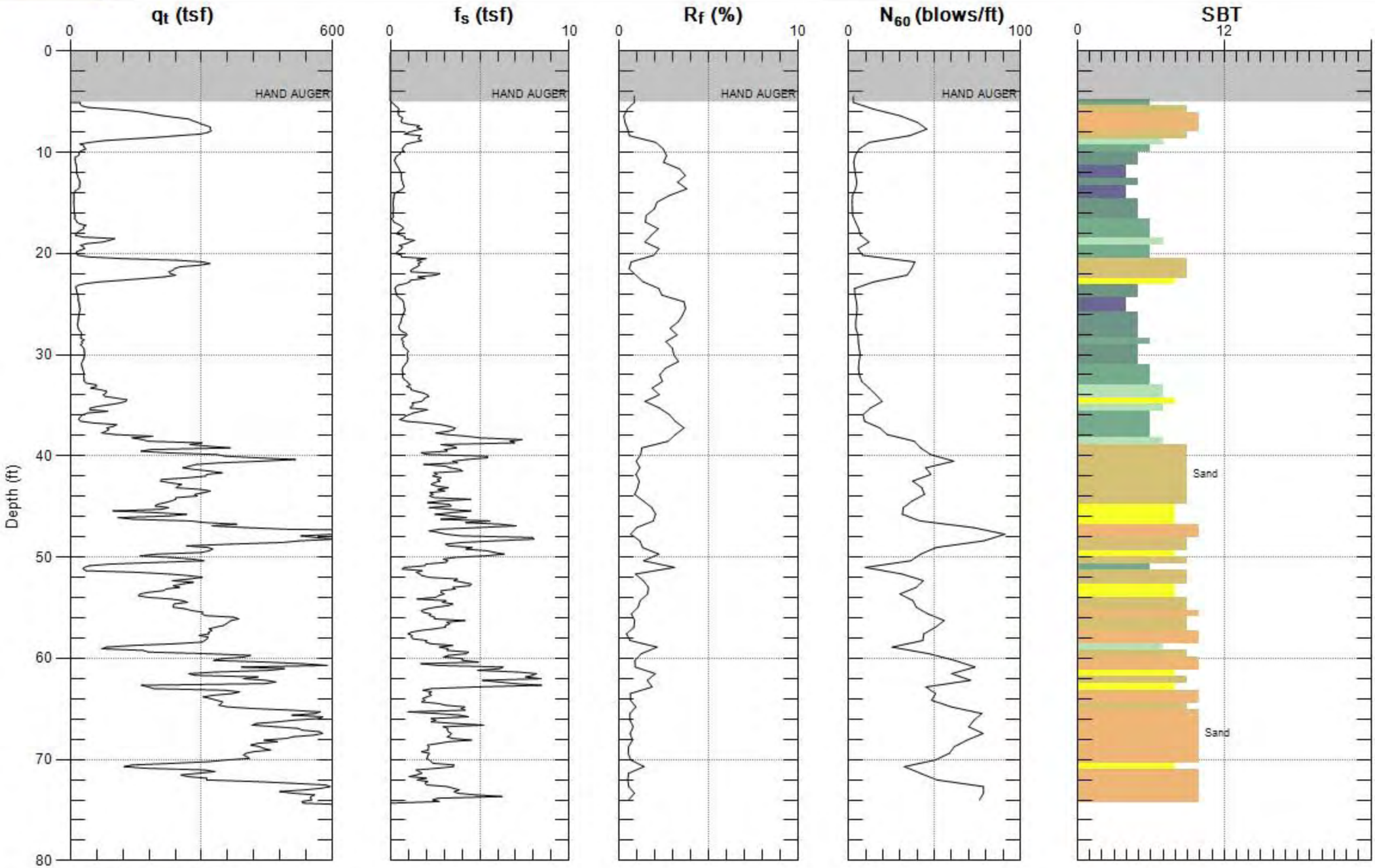
Sounding: C-24

Engineer: C.HITCHCOCK
Date: 7/6/2011 09:00



Max. Depth: 74.475 (ft)
Avg. Interval: 0.328 (ft)

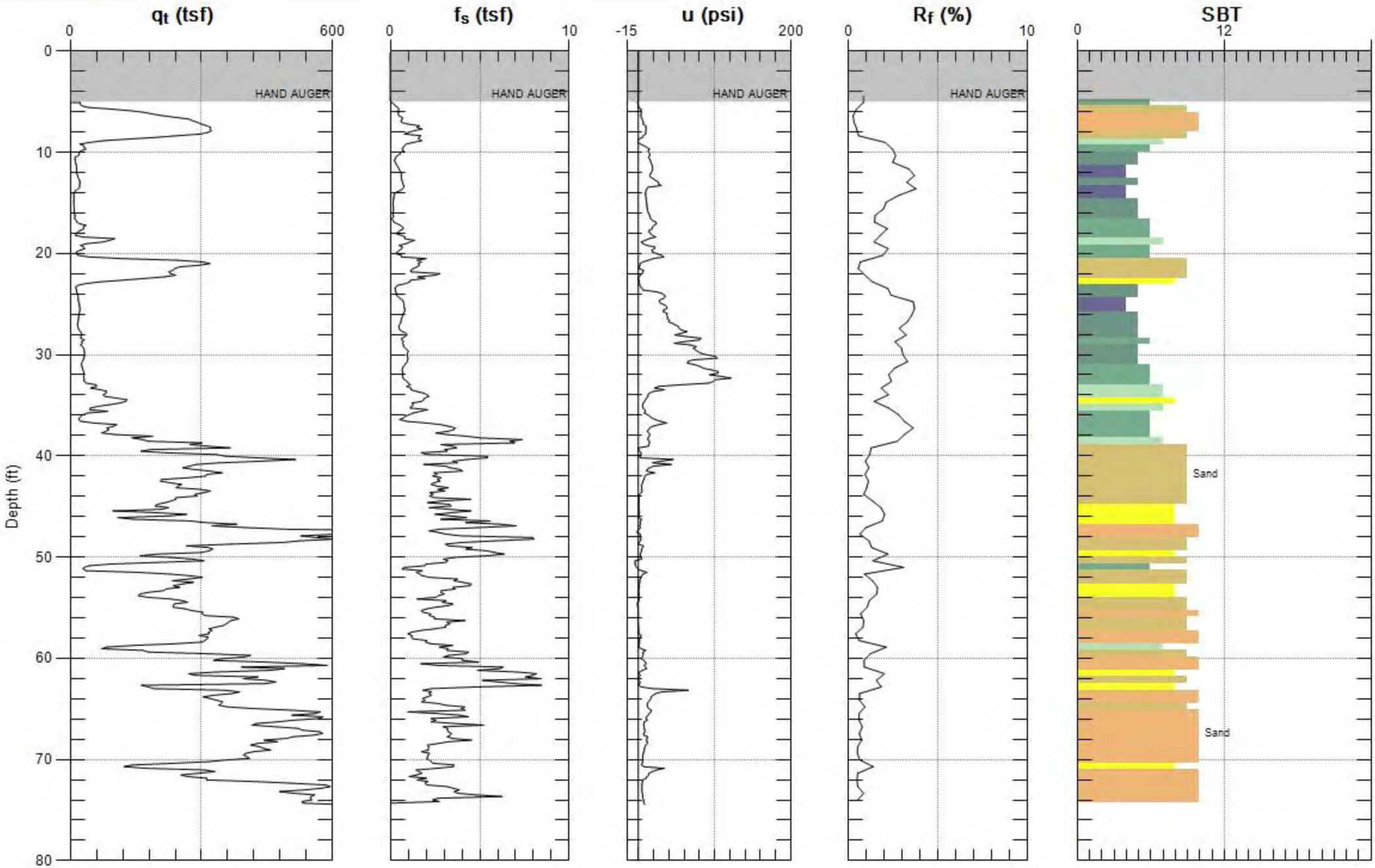
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-24

Engineer: C.HITCHCOCK
Date: 7/6/2011 09:00



Max. Depth: 74.475 (ft)
Avg. Interval: 0.328 (ft)

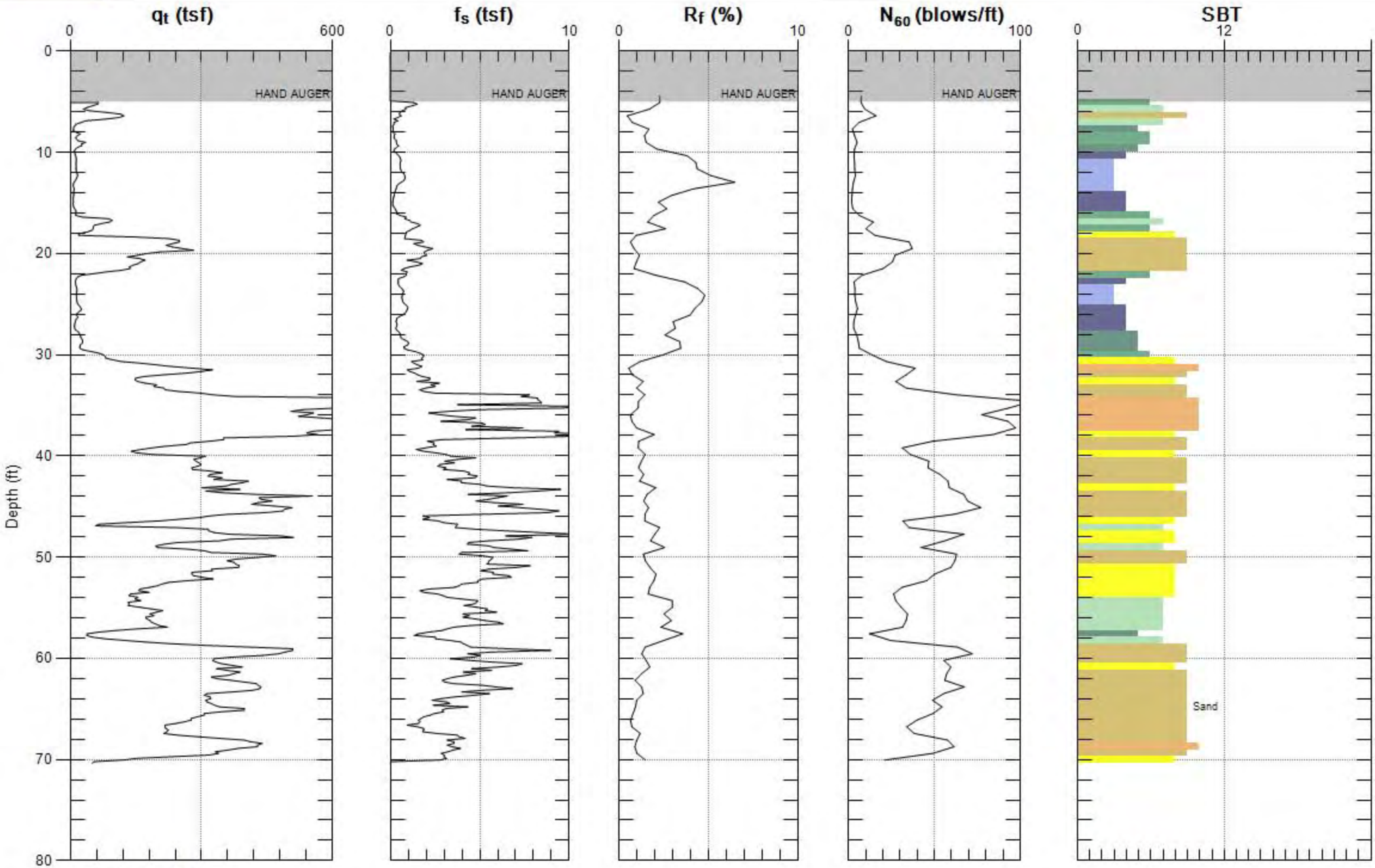
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-26

Engineer: C.HITCHCOCK
Date: 7/8/2011 02:18



Max. Depth: 70.374 (ft)
Avg. Interval: 0.328 (ft)

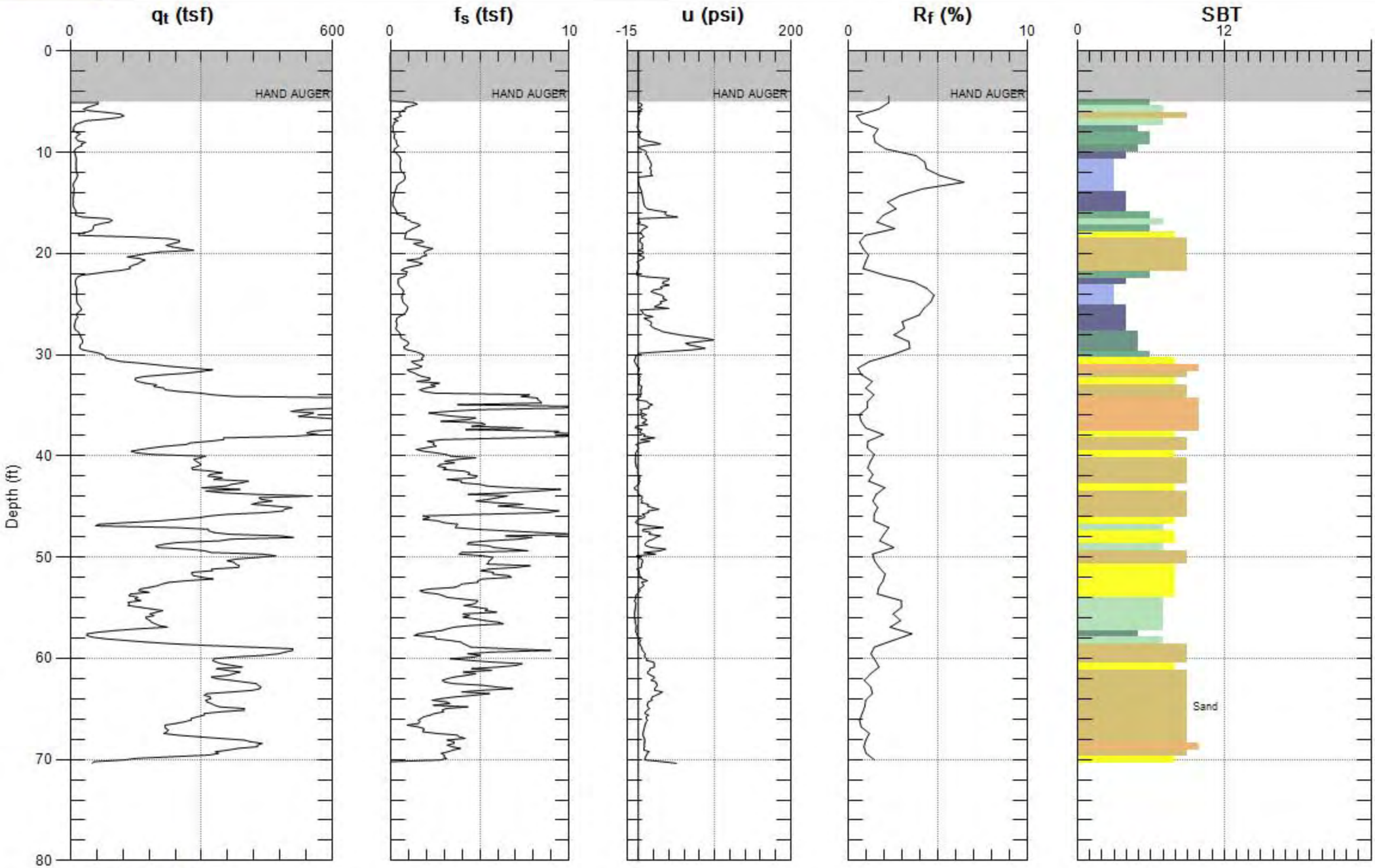
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-26

Engineer: C.HITCHCOCK
Date: 7/8/2011 02:18



Max. Depth: 70.374 (ft)
Avg. Interval: 0.328 (ft)

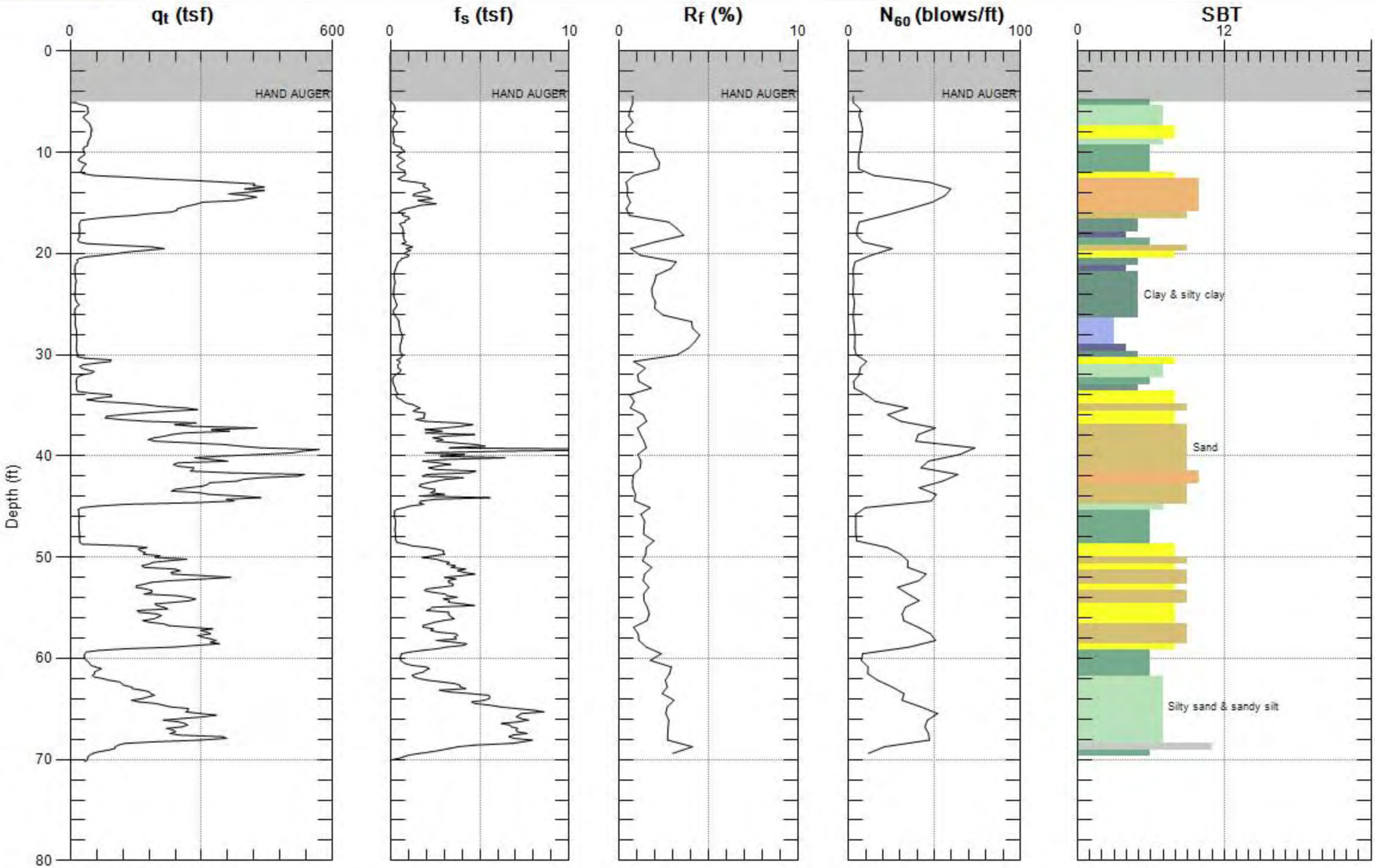
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-2

Engineer: C.HITCHCOCK
Date: 7/5/2011 09:01



Max. Depth: 70.210 (ft)
Avg. Interval: 0.328 (ft)

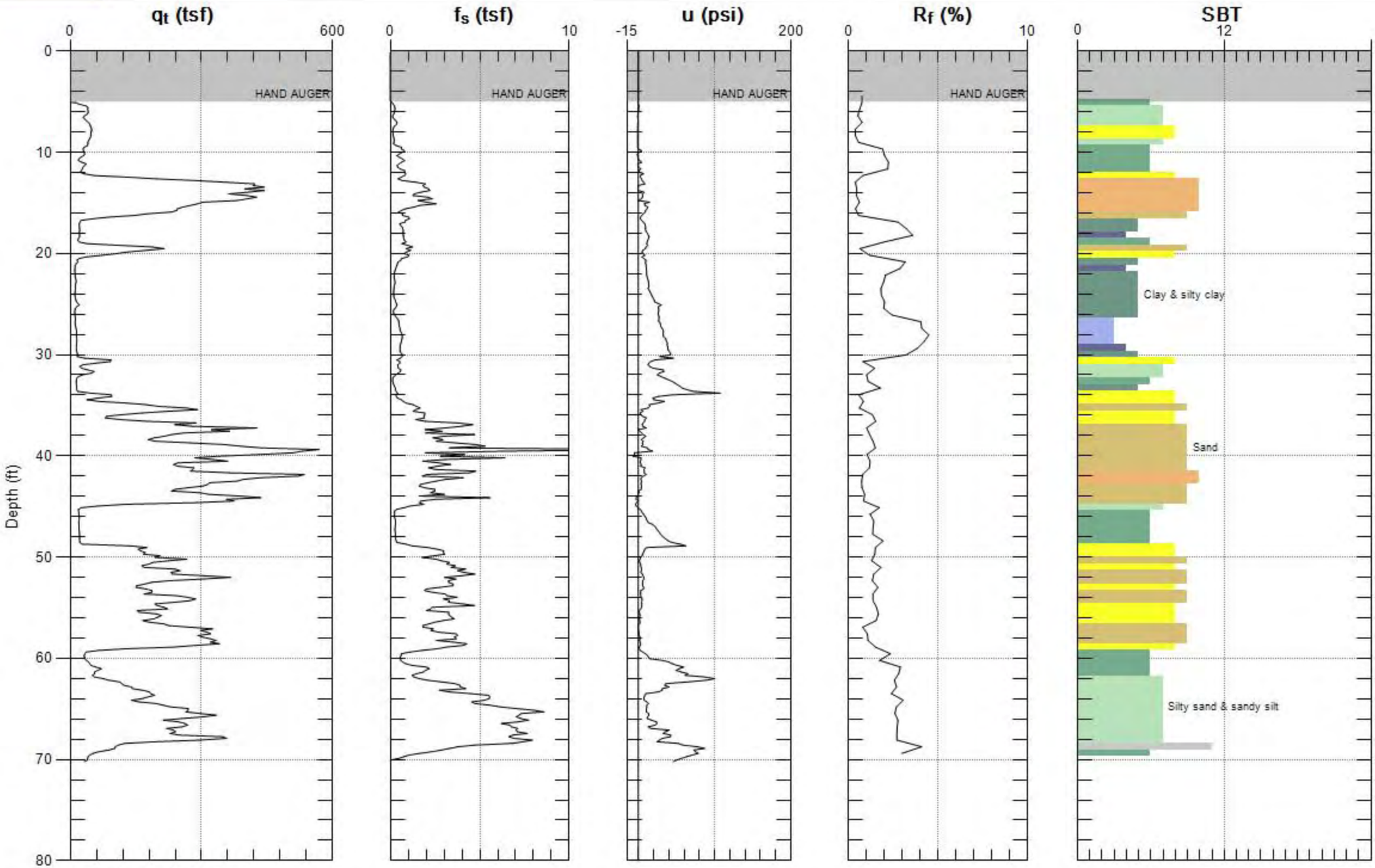
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-2

Engineer: C.HITCHCOCK
Date: 7/5/2011 09:01



Max. Depth: 70.210 (ft)
Avg. Interval: 0.328 (ft)

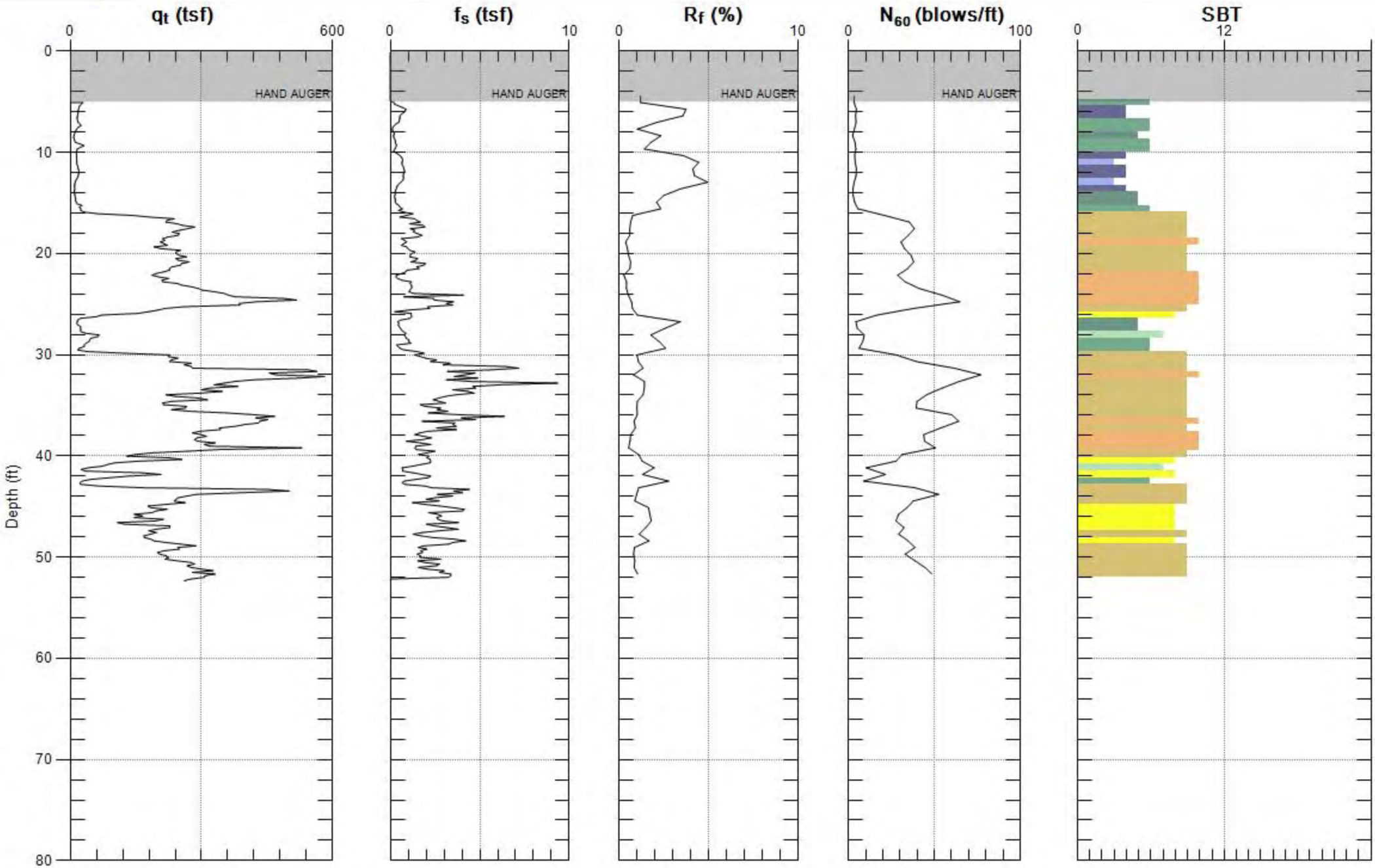
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-30

Engineer: C.HITCHCOCK
Date: 7/7/2011 03:09



Max. Depth: 52.329 (ft)
Avg. Interval: 0.328 (ft)

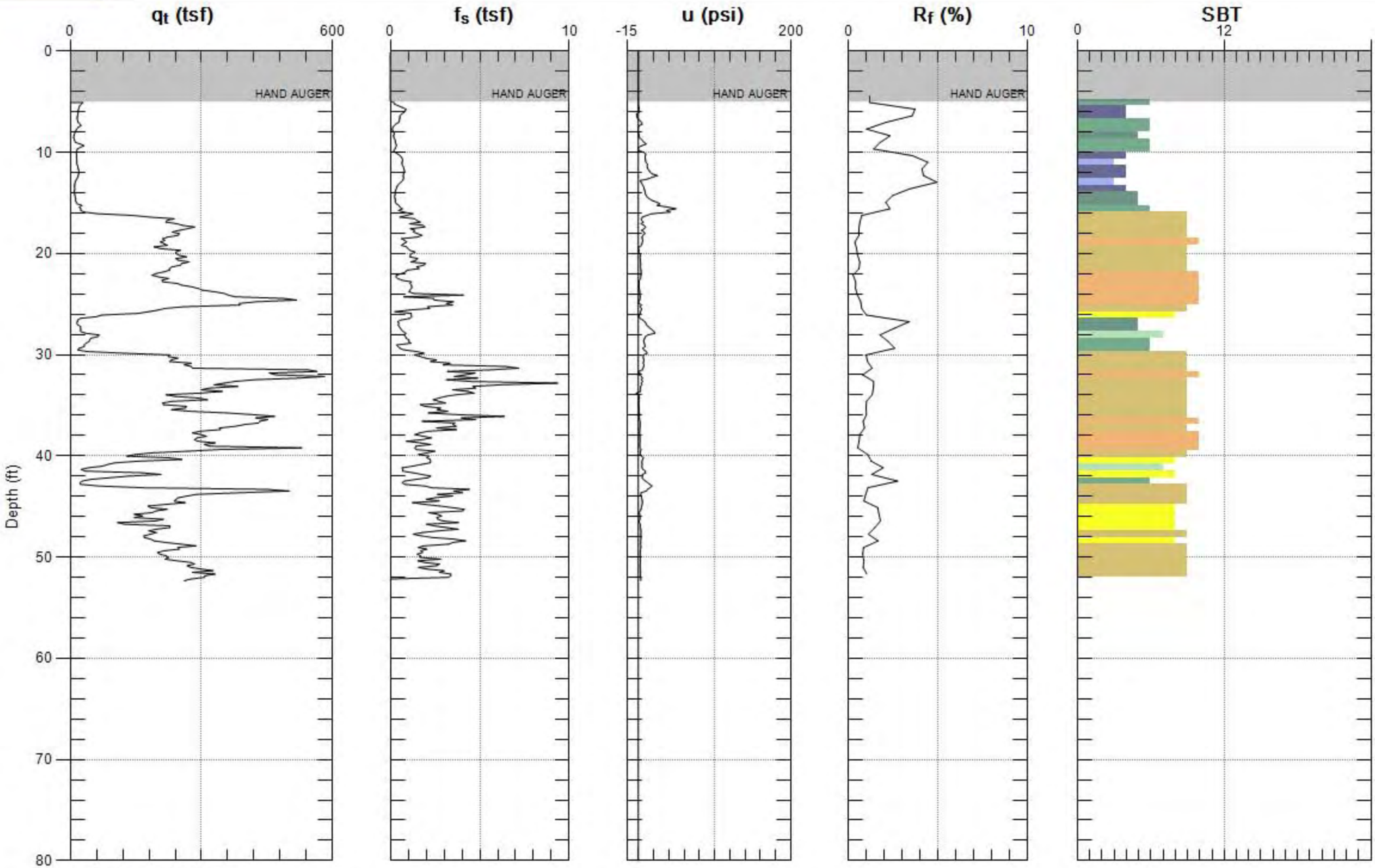
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-30

Engineer: C.HITCHCOCK
Date: 7/7/2011 03:09



Max. Depth: 52.329 (ft)
Avg. Interval: 0.328 (ft)

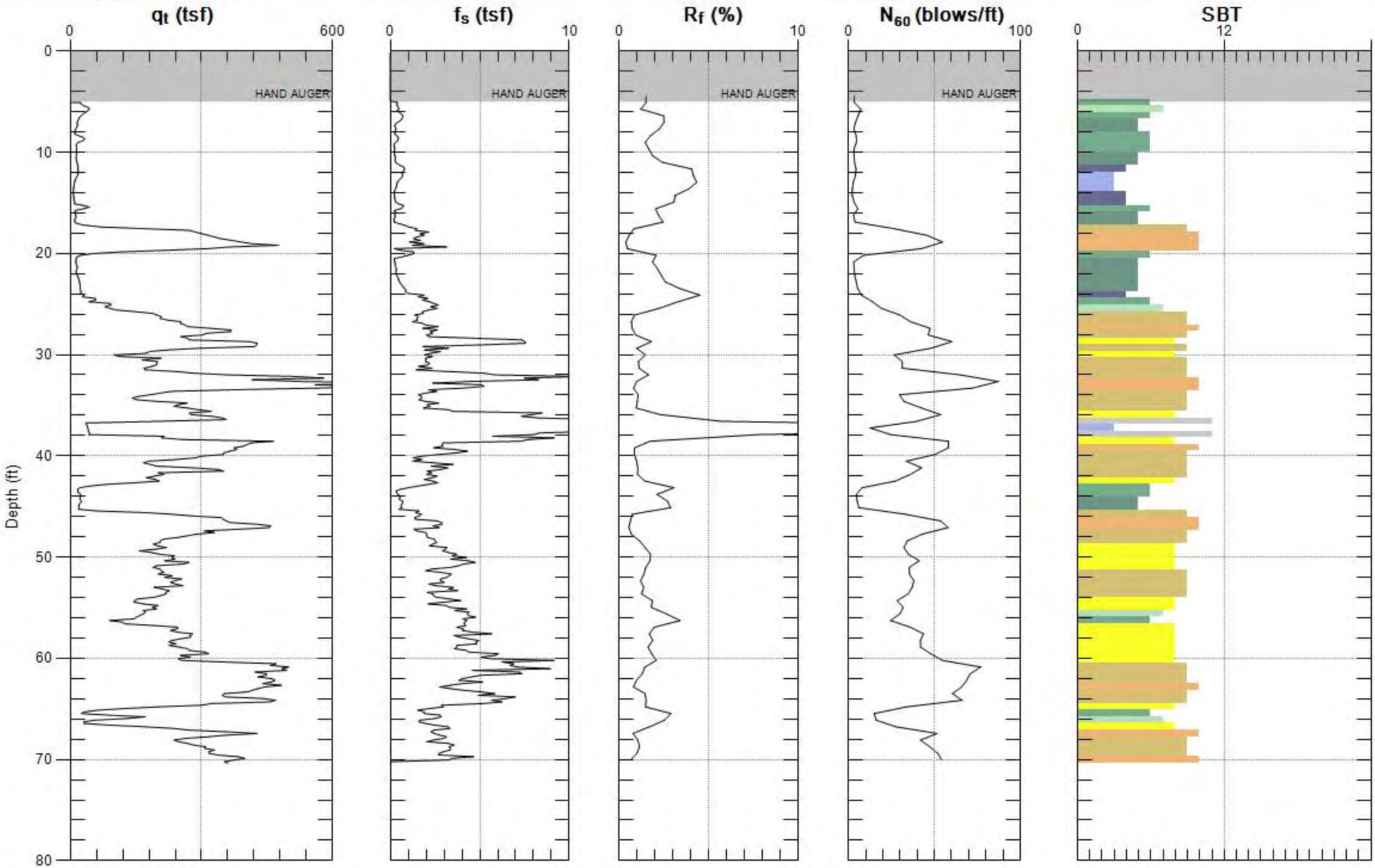
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-33

Engineer: C.HITCHCOCK
Date: 7/7/2011 09:08



Max. Depth: 70.374 (ft)
Avg. Interval: 0.328 (ft)

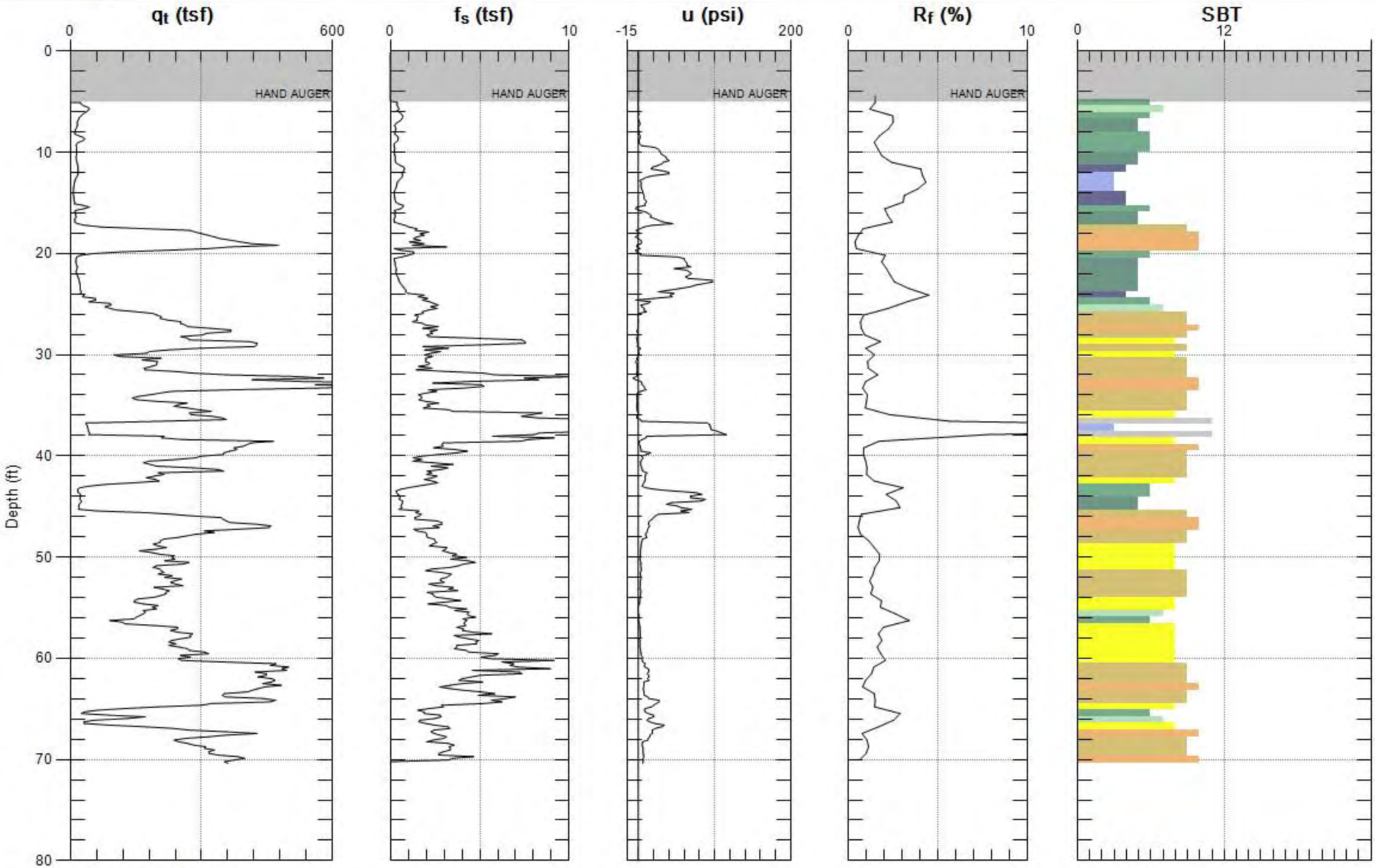
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-33

Engineer: C.HITCHCOCK
Date: 7/7/2011 09:08



Max. Depth: 70.374 (ft)
Avg. Interval: 0.328 (ft)

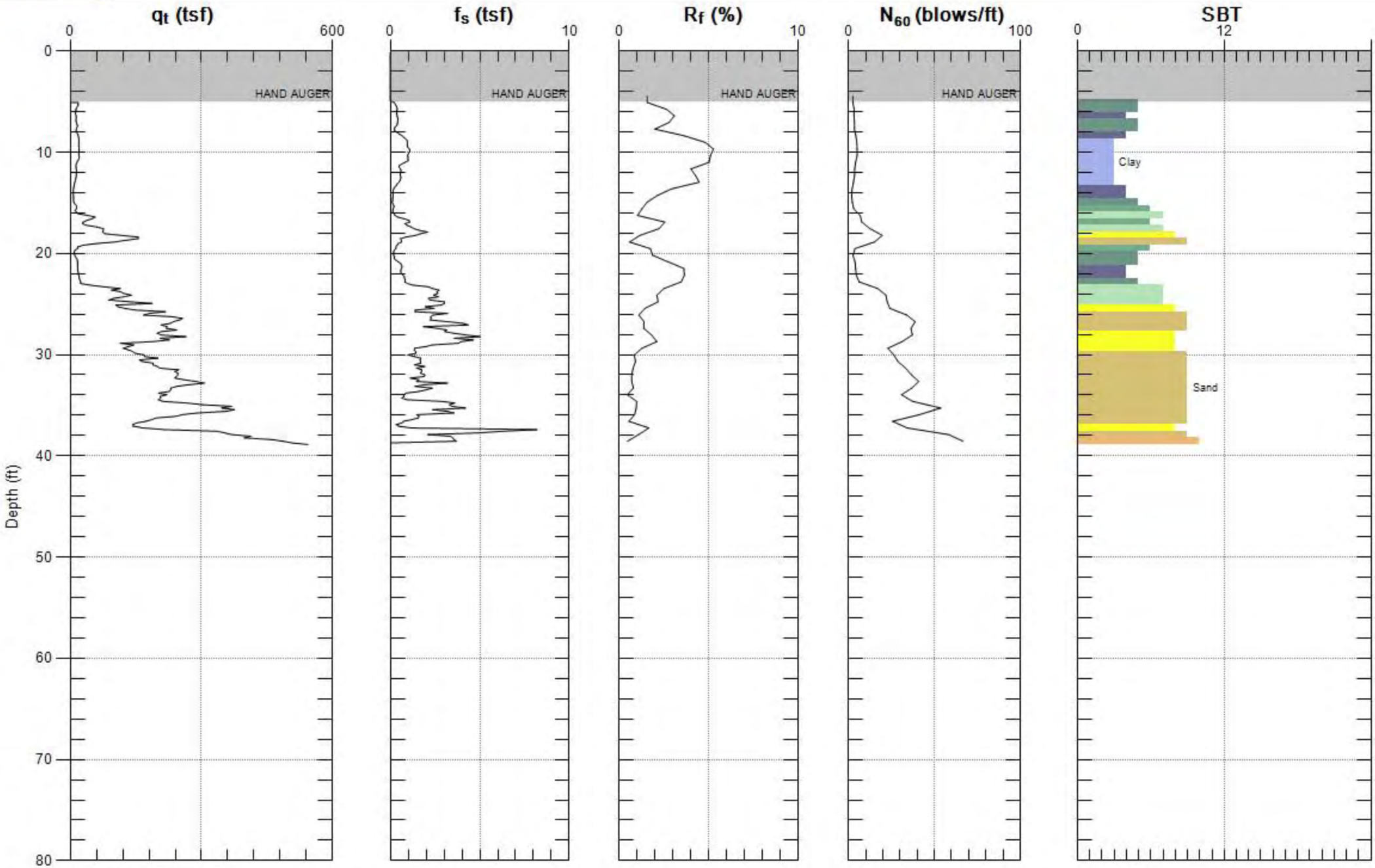
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-36

Engineer: C.HITCHCOCK
Date: 7/7/2011 10:58



Max. Depth: 38.878 (ft)
Avg. Interval: 0.328 (ft)

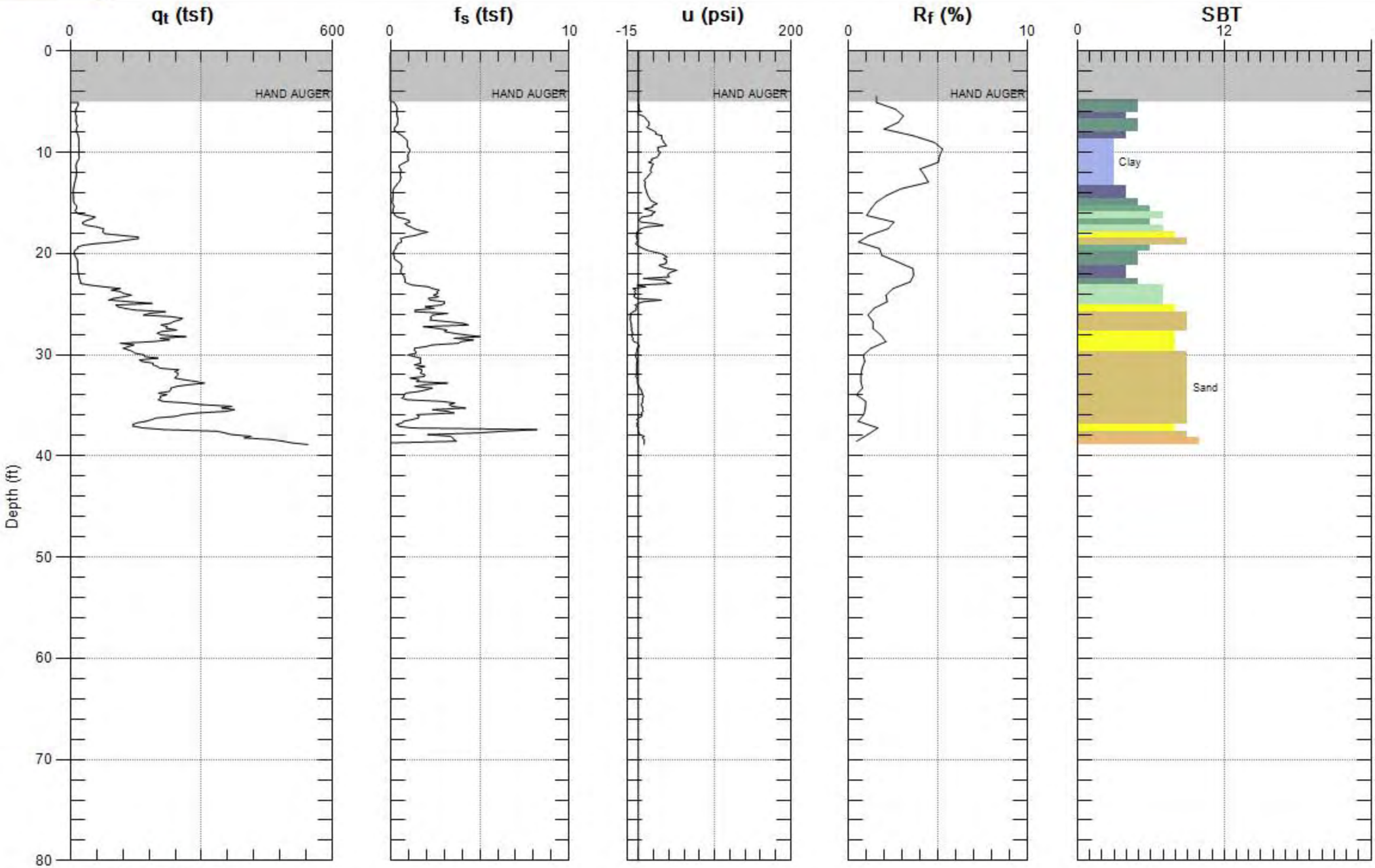
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-36

Engineer: C.HITCHCOCK
Date: 7/7/2011 10:58



Max. Depth: 38.878 (ft)
Avg. Interval: 0.328 (ft)

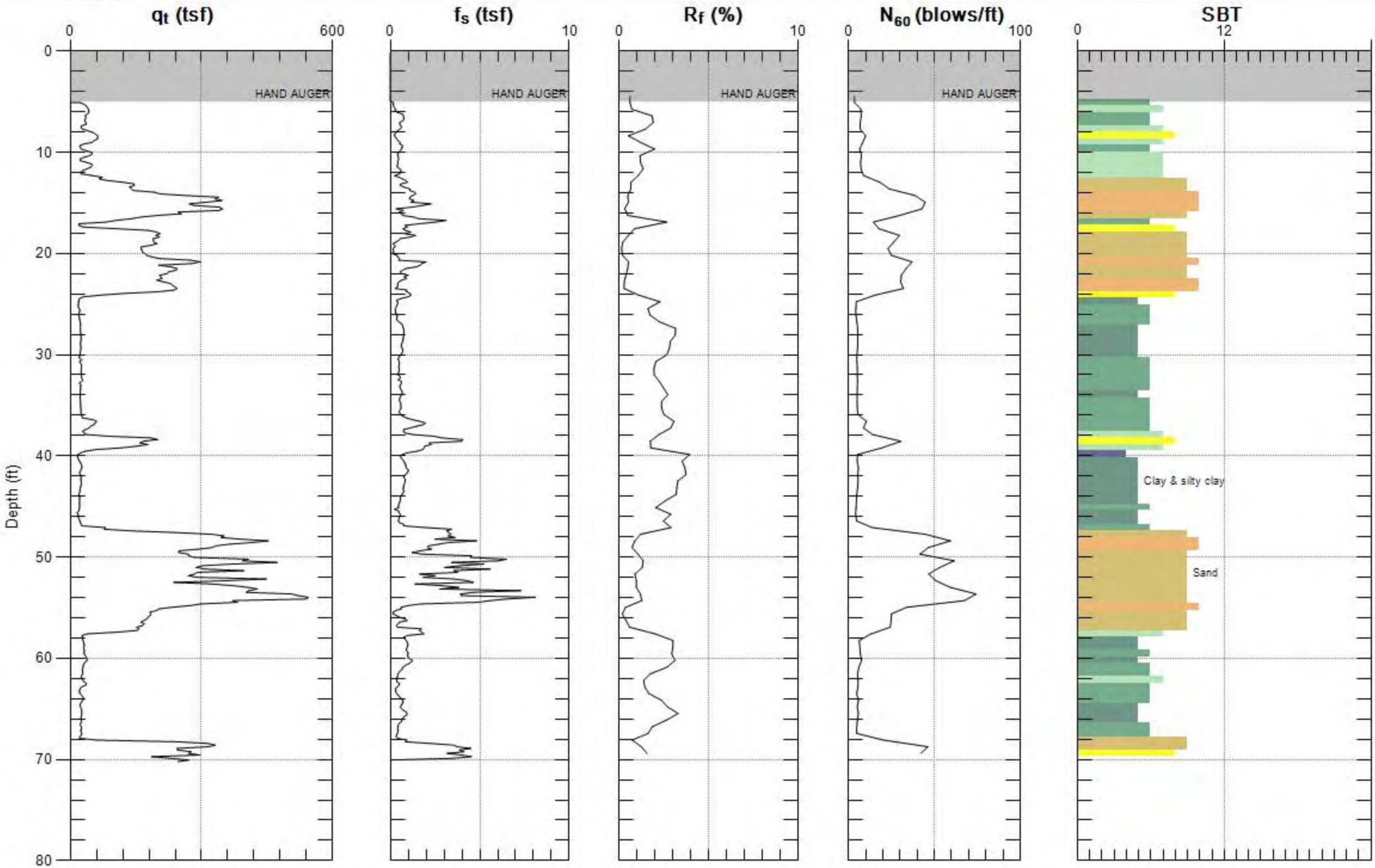
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-38

Engineer: C.HITCHCOCK
Date: 7/7/2011 12:29



Max. Depth: 70.210 (ft)
Avg. Interval: 0.328 (ft)

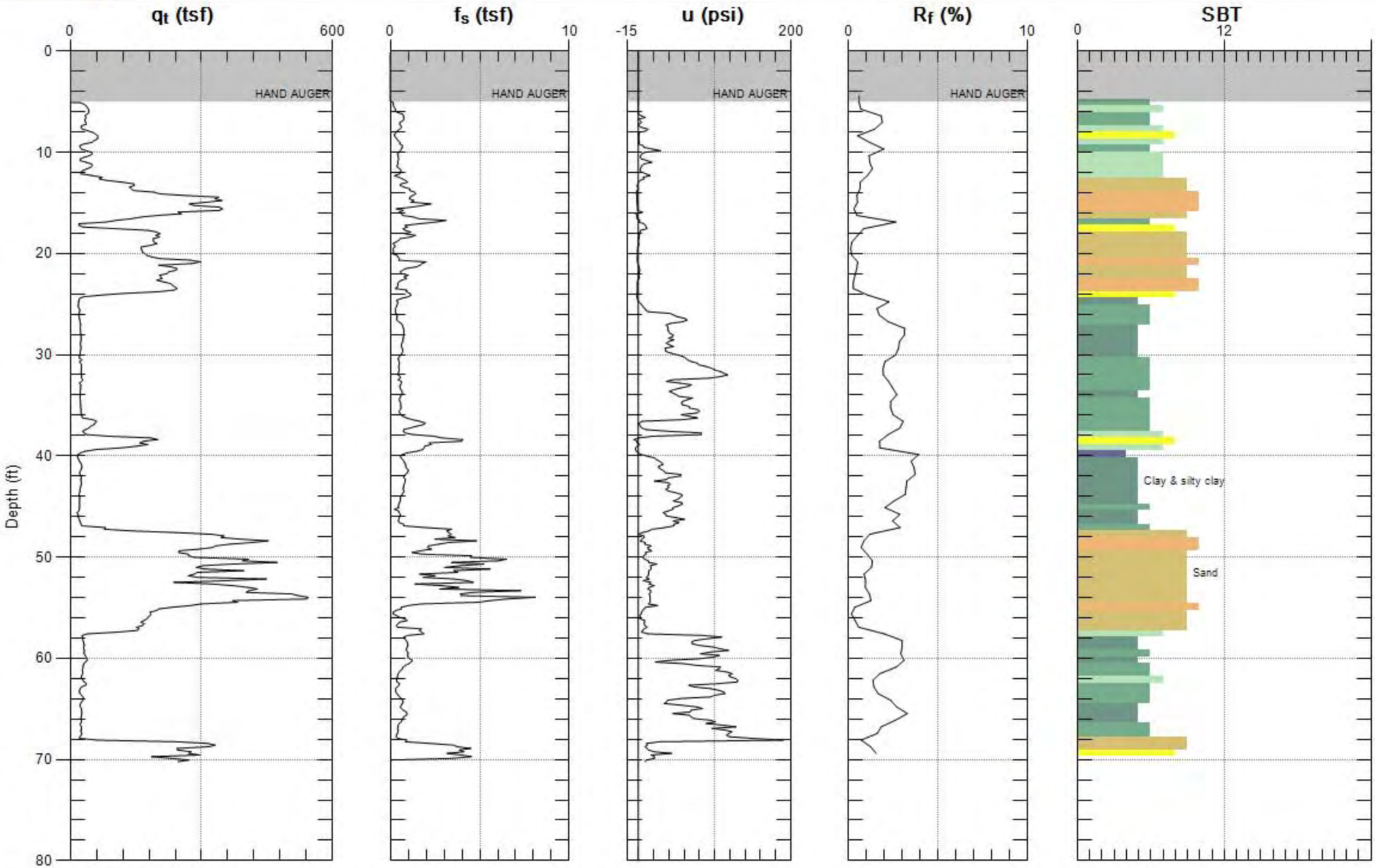
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-38

Engineer: C.HITCHCOCK
Date: 7/7/2011 12:29



Max. Depth: 70.210 (ft)
Avg. Interval: 0.328 (ft)

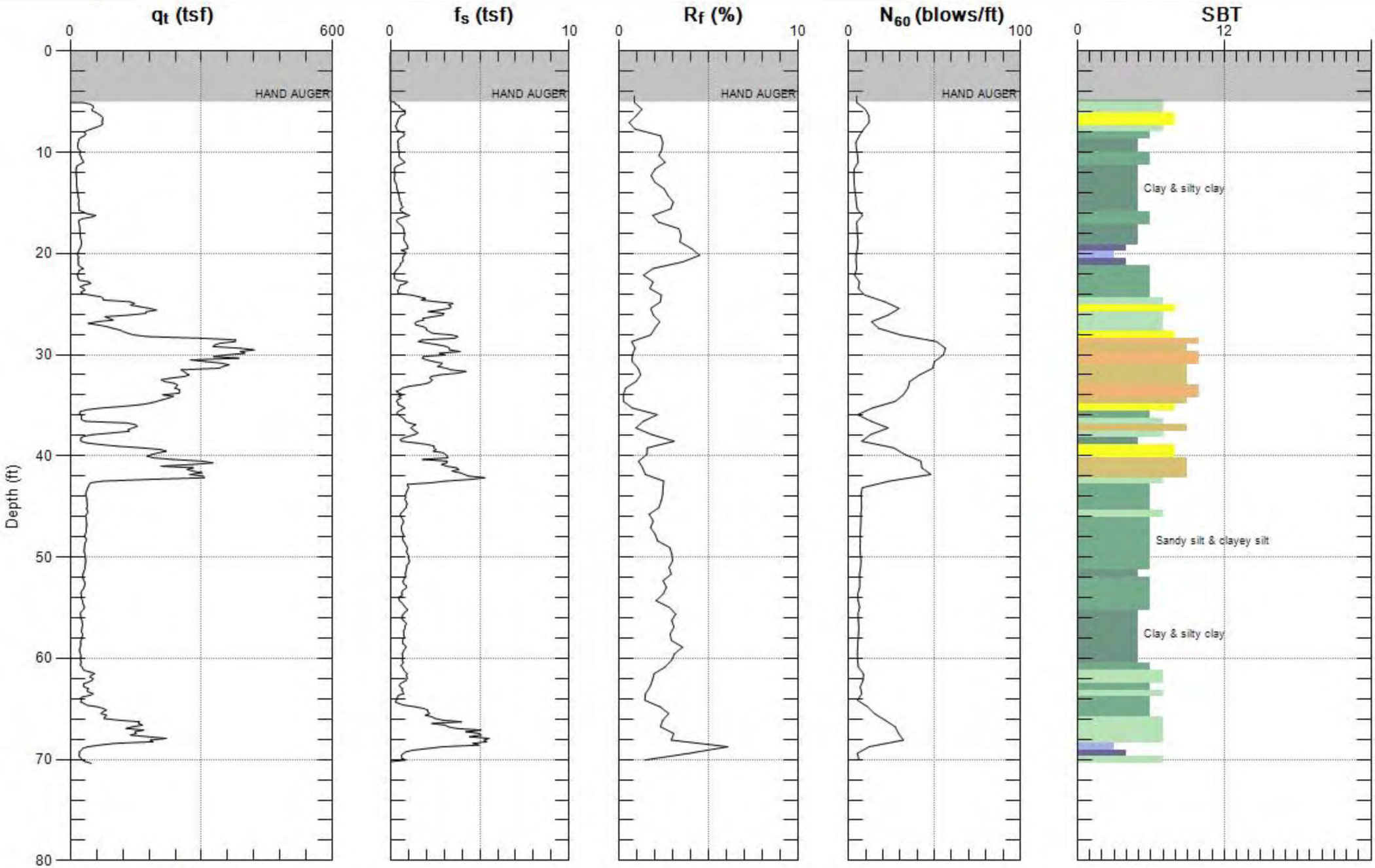
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-8

Engineer: C.HITCHCOCK
Date: 7/5/2011 11:32



Max. Depth: 70.374 (ft)
Avg. Interval: 0.328 (ft)

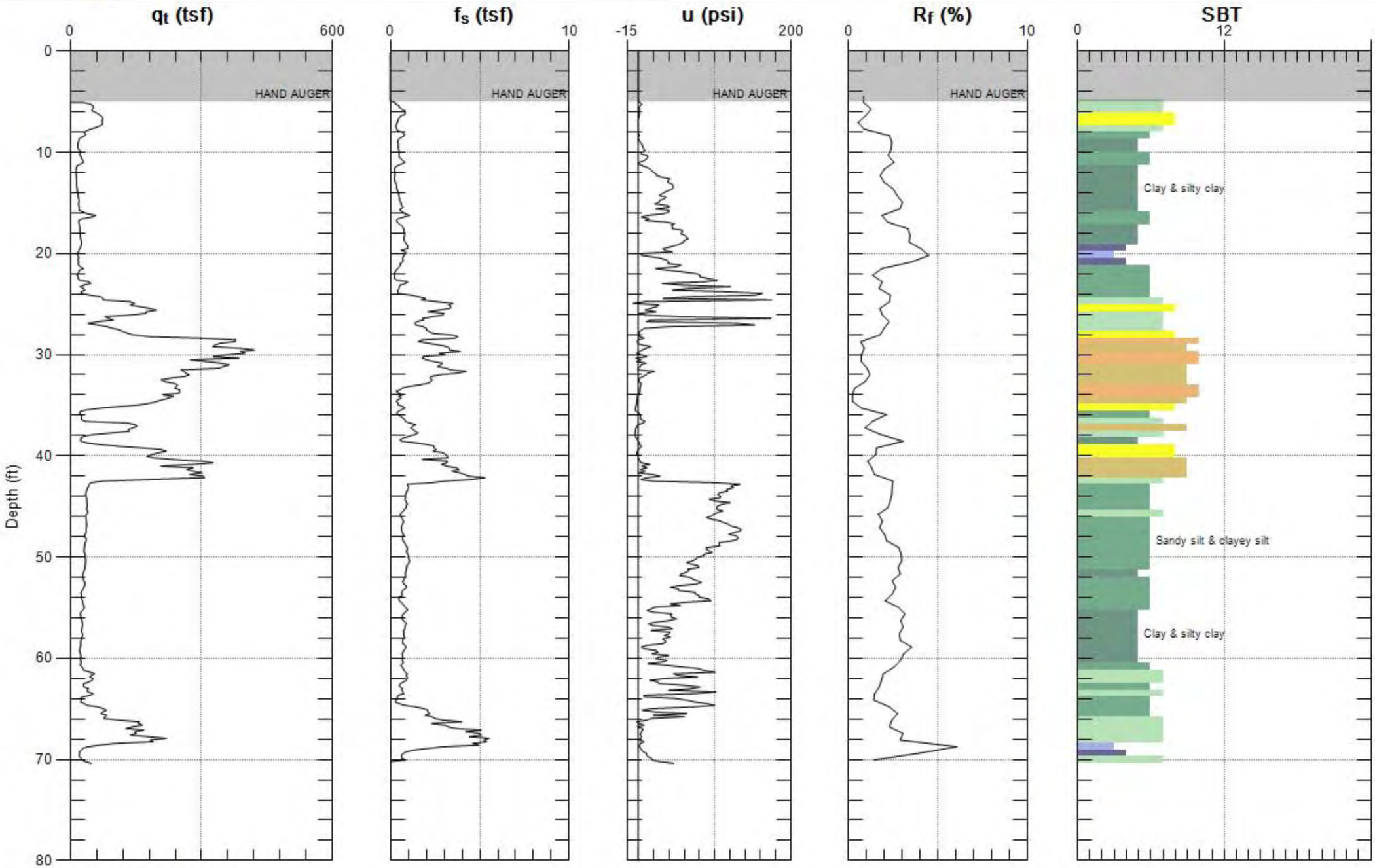
SBT: Soil Behavior Type (Robertson 1990)

GREGG FUGRO

DRAFT

Site: SCWA AQUEDUCT
Sounding: C-8

Engineer: C.HITCHCOCK
Date: 7/5/2011 11:32



Max. Depth: 70.374 (ft)
Avg. Interval: 0.328 (ft)

SBT: Soil Behavior Type (Robertson 1990)

APPENDIX B

GEOTECHNICAL BORING

The attached exploratory Boring B-1 was performed by Fugro on July 8, 2011. The exploratory boring was conducted in the area of the proposed project site using a truck mounted Versa Drill V100M drilling rig, provided by Gregg Drilling based out of Martinez, CA. The approximate locations of the exploratory boring are shown on the Site Plan. The log of this boring, as well as a key for the classification of the soil (Plate A-1) are included as part of this appendix.

Boring B-1 was advanced using mud rotary drilling techniques Driven samples were collected with an automatic hammer, at roughly 5 foot intervals, using a Standard Penetration Test (SPT) split-barrel drive sampler (outside diameter of 2.0 inches, inside diameter of 1.375 inches). Push samples were collected using a thin walled Shelby Tube sampler at the approximate depth for the proposed depth of the pipeline alignment. Additionally, continuous soil core samples were collected. Fugro Project Geologist Adam Wade was on site to supervise the drilling operation, and to collect and log soil samples.

All samples were transmitted to Fugro Laboratories for evaluation and appropriate testing. Sampler types are indicated in the "Sampler" column of the boring logs. In the field, our geologist visually examined and classified the samples. Resistance blow counts were obtained with the samplers by dropping a 140-pound hammer through a 30-inch free fall using a down-hole hammer system. The sampler was driven 18 inches and the number of blows were recorded for each 6 inches of penetration. The blows per foot recorded on the boring logs represent the accumulated number of blows that were required to drive the last 12 inches. The attached boring logs and related information show our interpretation of the subsurface conditions at the date and location indicated, and it is not warranted that they are representative of subsurface conditions at other locations and times.

Project No. 1860

DRAFT

MAJOR DIVISIONS			GROUP NAMES	
COARSE-GRAINED SOILS More than 50% retained on the No. 200 sieve	GRAVELS MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	Clean gravels less than 5% fines	GW	Well-Graded Gravel
			GP	Poorly Graded Gravel
		Gravels with more than 12% fines	GM	Silty Gravel
			GC	Clayey Gravel
	SANDS MORE THAN 50% OF COARSE FRACTION PASSING NO. 4 SIEVE	Clean sand less than 5% fines	SW	Well-Graded Sand
			SP	Poorly Graded Sand
		Sands with more than 12% fines	SM	Silty Sand
			SC	Clayey Sand
FINE-GRAINED SOILS 50% or more passes the No. 200 sieve	SILTS AND CLAYS Liquid Limit Less than 50%		ML	Silt
			CL	Lean Clay
			OL	Organic Silt
	SILTS AND CLAYS Liquid Limit Greater than 50%		MH	Elastic Silt
			CH	Fat Clay
			OH	Organic Clay
HIGHLY ORGANIC SOILS			PT	Peat or Highly Organic Soils
			FILL	Debris or Mixed Fill
			AC	Asphalt Concrete Pavement with Aggregate Base

GENERAL NOTES

Classification of Soils in general accordance with ASTM D2487 or D2488 (based on the Unified Soil Classification System)

Geologic Formation noted in bold font at the top of interpreted interval
Sloped line in break column indicates transitional boundary

Blow counts for modified California Liner Sampler shown in ( )

SAMPLER DRIVING RESISTANCE

Number of blows with 140 lb. hammer, falling 30-in. to drive sampler 1-ft. after seating sampler 6-in.; for example,

Blows/ft	Description
25	25 blows drove sampler 12" after initial 6" of seating
50/7"	50 blows drove sampler 7" after initial 6" of seating
Ref/3"	50 blows drove sampler 3" during initial 6" seating interval (Ref=Refusal)

STRENGTH TEST METHOD

U = Unconfined Compression
Q = Unconsolidated Undrained Triaxial
T = Torvane
P = Pocket Penetrometer
M = Miniature Vane
F = Field Vane

OTHER TESTS

k = Permeability
Consol = Consolidation
Gs = Specific Gravity
MA = Particle Size Analysis
EI = Expansion Index
OVM = Organic Vapor Meter

WATER LEVEL SYMBOLS

Initial or perched water level
Final ground water level
Seepages encountered

SAMPLER TYPE AND RECOVERY

1	2	3	4	5	6	7	8	9	10	11	12	13
SPT	MC	CA	SH	BB	HA	LS	PS	VS	NR	RC	DP	ES

Samplers and sampler dimensions (unless otherwise noted in report text) are as follows:

1 SPT Sampler, driven 1 3/8" ID, 2" OD
2 MOD CA Liner Sampler 2 3/8" ID, 3" OD
3 CA Liner Sampler 1 7/8" ID, 2.5" OD
4 Thin-walled Tube, pushed 2 7/8" ID, 3" OD
5 Bulk Bag Sample (from cuttings)
6 Hand Auger Sample
7 Lexan Sample
8 Pitcher Sample
9 Vibracore Sample
10 No Sample Recovered
11 Rock Core
12 Direct Push
13 Enviromental Sample

Retained samples listed in Sample No. column

SOIL STRUCTURE

Fissured: Containing shrinkage or relief cracks, often filled with fine sand or silt, usually more or less vertical.

Pocket: Inclusion of material of different texture that is smaller than the diameter of the sample.

Parting: Inclusion less than 1/8 inch thick extending through the sample.

Seam: Inclusion 1/8 inch to 3 inches thick extending through the sample.

Layer: Inclusion greater than 3 inches thick extending through the sample.

Laminated: Soil sample composed of alternating partings or seams of different soil types.

Interlayered: Soil sample composed of alternating layers of different soil type.

Intermixed: Soil sample composed of pockets of different soil type, and layered or laminated structure is not evident.

CONSISTENCY (1)

Clays	Blows/Foot SPT	Undrained Shear Strength (ksf)
Very Soft	**0 - 2**	**0 - 0.25**
Soft	**2 - 4**	**0.25 - 0.5**
Firm	**4 - 8**	**0.5 - 1**
Stiff	**8 - 15**	**1 - 2**
Very Stiff	**15 - 30**	**2 - 4**
Hard	**Over 30**	**Over 4**

RELATIVE DENSITY (1)

Sands and Gravels	Blows/Foot SPT
Very Loose	**0 - 4**
Loose	**4 - 10**
Medium Dense	**10 - 30**
Dense	**30 - 50**
Very Dense	**Over 50**

INCREASING VISUAL MOISTURE CONTENT

Dry
Moist
Wet

Information on each boring log is a compilation of subsurface conditions and soil or rock classifications obtained from the field as well as from laboratory testing of samples. Strata have been interpreted by commonly accepted procedures. The stratum lines on the logs may be transitional and approximate in nature. Water level measurements refer only to those observed at the time and places indicated, and can vary with time, geologic condition, or construction activity.

(1) Terzaghi and Peck 1967

TERMS AND SYMBOLS USED ON BORING LOGS

PLATE B-1

Project No. 1860

DRAFT

LOCATION: Santa Rosa
N 38 W 123

SURFACE EL: ft +/- (rel. MSL datum)

ELEVATION, ft	DEPTH, ft	MATERIAL SYMBOL	SAMPLE NO.	SAMPLERS	SAMPLER BLOW COUNT	MATERIAL DESCRIPTION	UNIT WET WEIGHT, pcf	UNIT DRY WEIGHT, pcf	WATER CONTENT, %	% PASSING #200 SIEVE	LIQUID LIMIT, %	PLASTICITY INDEX, %	UNDRAINED SHEAR STRENGTH, S_u, ksf
						Qaf Asphalt; Gravel base; Gravely Lean CLAY							
	2												
			01			**Qal** Lean CLAY (CL): soft, very dark grayish brown, (2.5Y 3/2), dry to moist, medium plasticity, medium dry strength, not to slow dilatency, medium toughness;			20				
	4					Clayey SAND (SC): soft, olive brown, dry to moist, 65% sand, find to coarse grained, subangular to subrounded; 35% fines, medium plasticity, medium dry strength, slow dilatency, low toughness; reddish brown mottling;							
	6		02		2				22	35			
	8					Lean CLAY (CL): soft to firm, very dark gray to black (2.5Y 3/1 - 2.5Y 2.5/2), moist, 5% sand; 95% fines, medium to high plasticity, medium dry strength, low to medium toughness, no dilatency;							
	10		03										
	12												
						Lean CLAY with sand (CL): soft, very dark greenish gray (GLEY 1 3/5GY), moist to wet, 15%-20% sand, find sand; 80%-85% fines, medium to high plasticity, medium dry strength, medium toughness, slow dilatency;							
	14												
			04		2								
	16												
	18					- rig chatter at 18'; Well-graded GRAVEL with clay and sand (GW-GC): medium dense, very dark greenish gray (GLEY 1 3/5GY), wet, 48% gravels, find to coarse, subangular to angular, gravel clasts consist primarily of greenstone; 41% sand, fine to coarse grained, subrounded to subangular; 11%fines;							
	20		05		19				9	11			

The log and data presented are a simplification of actual conditions encountered at the time of drilling at the drilled location. Subsurface conditions may differ at other locations and with the passage of time.

COMPLETION DEPTH: 41.5 ft
DEPTH TO WATER: Not Measured
BACKFILLED WITH: Neat Cement
DRILLING DATE: July 8, 2011

DRILLING METHOD: 4-inch-dia. Mud Rotary
HAMMER TYPE: Automatic Trip
DRILLED BY: Robert
LOGGED BY: A.Wade
RIG TYPE: Versa Drill V-100

LOG OF BORING NO. B-1

SCWA Rodgers Creek Fault
Santa Rosa, California

PLATE B-2

Project No. 1860

DRAFT

LOCATION: Santa Rosa
N 38 W 123

SURFACE EL: ft +/- (rel. MSL datum)

ELEVATION, ft	DEPTH, ft	MATERIAL SYMBOL	SAMPLE NO.	SAMPLERS	SAMPLER BLOW COUNT	MATERIAL DESCRIPTION	UNIT WET WEIGHT, pcf	UNIT DRY WEIGHT, pcf	WATER CONTENT, %	% PASSING #200 SIEVE	LIQUID LIMIT, %	PLASTICITY INDEX, %	UNDRAINED SHEAR STRENGTH, S_u, ksf
						Lean CLAY (CL): firm, very dark greenish gray (GLEY 1 3/5GY), wet, 5% sand; 95% fines, medium plasticity, medium dry strength, slow dilatency, low to medium toughness;							
	24												
			06		5						48	34	
	26												
			07		100%								
	28												
						- increase in sand with depth							
	30		08		3	- thin (1mm) layers of organics							
			09		100%								
	32												
			10		100%								
	34												
			11		17								
			12			Well-graded SAND with clay and gravel (SW-SC): medium dense, very dark greenish gray (GLEY 1 3/5GY), wet, 44% gravel, fine to coarse, subangular to subrounded, consists primarily of 0.25" to 0.5" greenstone clasts; 46% sand, fine to coarse, subrounded to subangular;10% fines.			10	10			
	36												
			13		100%	Well-graded GRAVEL with clay and sand (GW-GC): medium dense, very dark greenish gray (GLEY 1 3/5GY), wet, 56% gravel, fine to coarse, subangular to subrounded, consists primarily of 0.25" to 0.5" greenstone clasts; 38% sand, fine to coarse, subrounded to subangular; 6% fines.			11	6			
	38												
	40		14		11	- gravel clasts increase in size between 1" and 2" clasts with trace amount of chert;							
						- 1455: terminate boring at 41.5'							
	42												

The log and data presented are a simplification of actual conditions encountered at the time of drilling at the drilled location. Subsurface conditions may differ at other locations and with the passage of time.

COMPLETION DEPTH: 41.5 ft
DEPTH TO WATER: Not Measured
BACKFILLED WITH: Neat Cement
DRILLING DATE: July 8, 2011

DRILLING METHOD: 4-inch-dia. Mud Rotary
HAMMER TYPE: Automatic Trip
DRILLED BY: Robert
LOGGED BY: A.Wade
RIG TYPE: Versa Drill V-100

LOG OF BORING NO. B-1

SCWA Rodgers Creek Fault
Santa Rosa, California

PLATE B-2

DRAFT

APPENDIX C

LABORATORY TEST RESULTS

DRAFT

Project No. 1860

DRILL HOLE	DEPTH, ft	SAMPLE NUMBER	MATERIAL DESCRIPTION	UWW pcf	UDW pcf	MC %	FINES %	ATTERBERG LIMITS		COMPACTION TEST		DIRECT SHEAR		COMPRESSIVE STRENGTH TESTS		CORROSIVITY TESTS				R-VALUE	EXPANSION INDEX	SAND EQUIVALENT (SE)	SPECIFIC GRAVITY
								LL	PI	MAX DD pcf	OPT MC %	C ksf	PHI deg	Qu, ksf	S_u (Cell Prs.) ksf	R	pH	Cl	So_4 (%)				
B-01	3.0	1	Very dark brown SANDY Lean CLAY (CL)			20																	
B-01	6.0	2	Dark yellowish brown CLAYEY SAND (SC)			22	35																
B-01	11.1		Dark brown fat CLAY (CH)	114	84	36		58	42														
B-01	20.0	5	Very dark grayish brown Well-graded GRAVEL with CLAY and			9	11																
			SAND (GW-GC)																				
B-01	25.0	6	Black Lean CLAY (CL)					48	34														
B-01	35.5	12	Very dark gray Well-graded SAND with CLAY and GRAVEL			10	10																
			(SW-SC)																				
B-01	37.5	13	Very dark gray Well-graded GRAVEL with CLAY and SAND			11	6																
			(GW-GC)																				

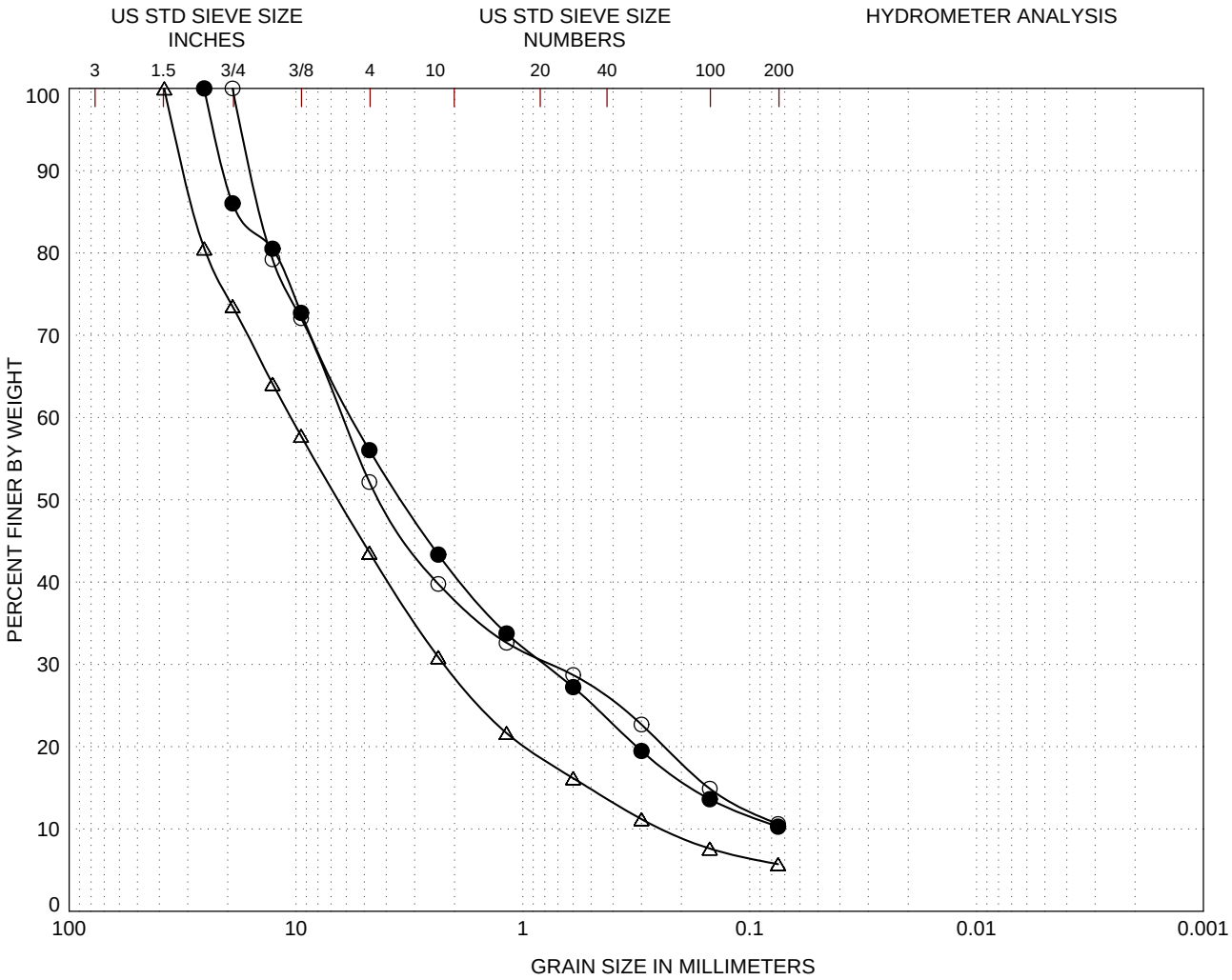
SUMMARY OF LABORATORY TEST RESULTS

SCWA Rodgers Creek Fault Study
Santa Rosa, California

PLATE C-1

Project No. 1860

DRAFT



GRAVEL		SAND			SILT or CLAY
Coarse	Fine	Coarse	Medium	Fine	

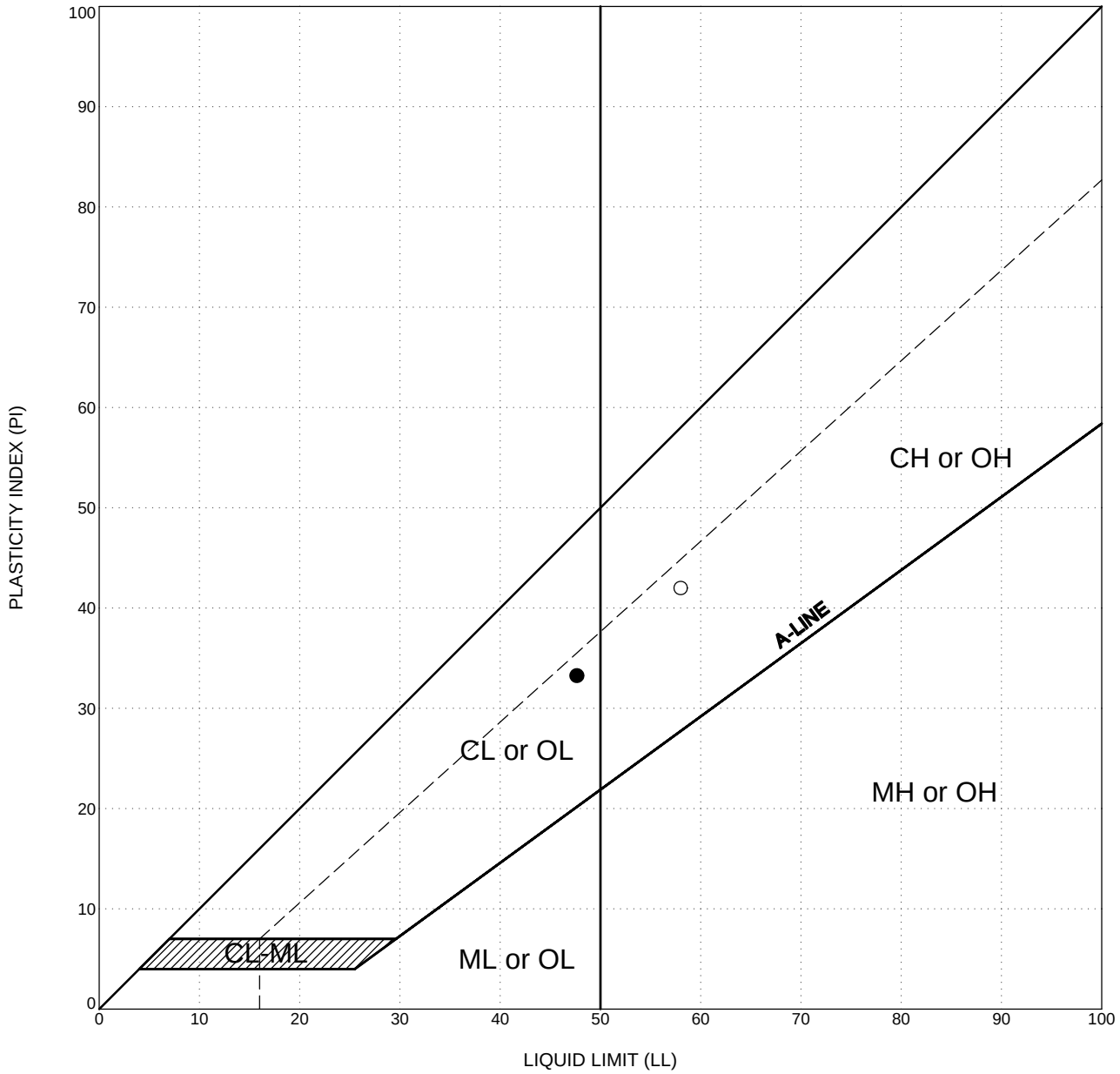
LEGEND	(location)	(depth,ft)	CLASSIFICATION	Cc	Cu
○	B-01	20.0	V. dk. gray brn. Well-graded GRAVEL w/ CLAY & SAND (GW-GC)	1.3	91.9
●	B-01	35.5	Very dark gray Well-graded SAND w/ CLAY & GRAVEL (SW-SC)	1.6	79.2
△	B-01	37.5	Very dark gray Well-graded GRAVEL w/ CLAY & SAND (GW-GC)	1.9	44.2

GRAIN SIZE CURVES
SCWA Rodgers Creek Fault Study
Santa Rosa, California

PLATE C-2

Project No. 1860

DRAFT



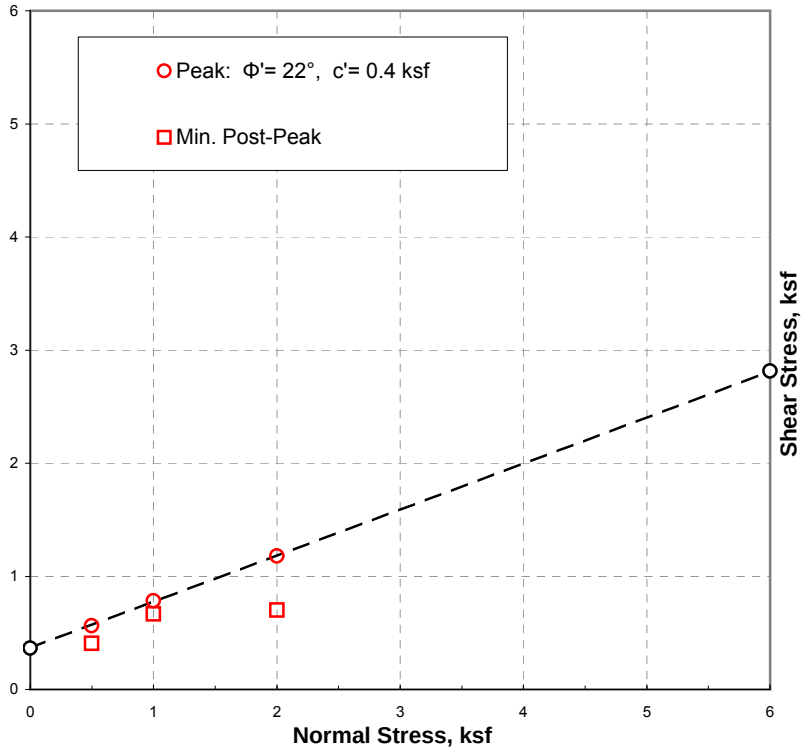
LEGEND	location	depth, ft	CLASSIFICATION	ATTERBERG LIMITS TEST RESULTS LIQUID LIMIT(LL)	PLASTIC LIMIT(PL)	PLASTICITY INDEX (PI)
○	B-01	11.1	Dark brown fat CLAY (CH)	58	16	42
●	B-01	25.0	Black Lean CLAY (CL)	48	14	34

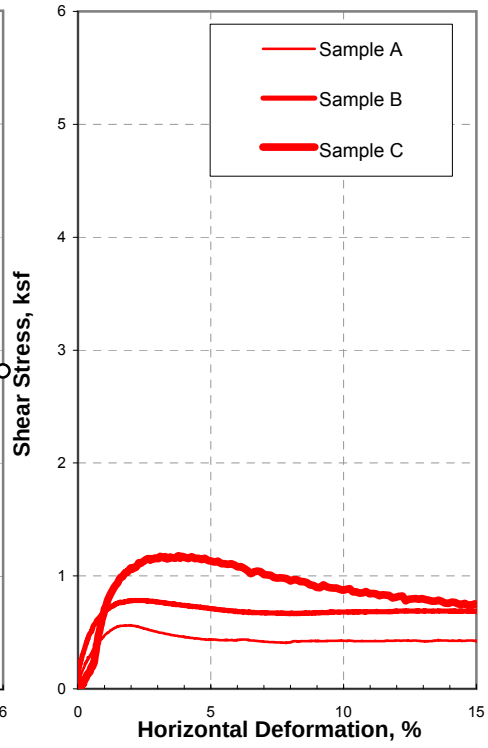
PLASTICITY CHART
SCWA Rodgers Creek Fault Study
Santa Rosa, California

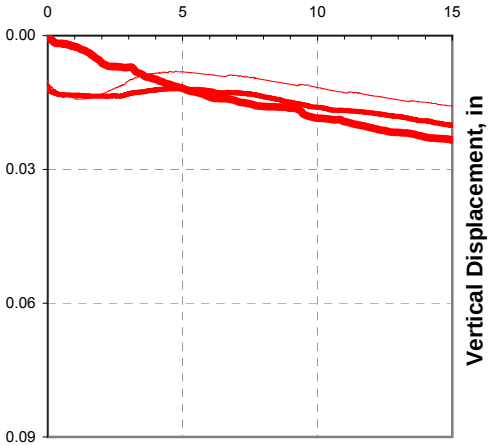
PLATE C-3

MMI Engineering
Project No. 04.7921.8600

DRAFT







SAMPLE ID	Boring Number:	B-01			
	Sample Number:	#3			
	Sample Depth:	11.1 ft			
	USCS Classification:	Fat CLAY (CH): dark brown, moist			
INITIAL	Sample No.	A	B	C	D
	Water Content, %	35.9%	35.9%	35.9%	
	Dry Unit Weight, pcf	84.1	84.1	84.7	
	Saturation, %	97%	97%	98%	
	Void Ratio	1.00	1.00	0.99	
	Diameter, in	2.42	2.42	2.42	
	Height, in	1.00	1.00	1.00	
FINAL	Water Content, %	38.0%	37.2%	35.8%	
	Dry Unit Weight, pcf	82.6	83.0	85.3	
	Void Ratio	1.04	1.03	0.98	
TEST SUMMARY	Deformation at Peak, %	1.94	2.14	3.78	
	Displacement Rate, in/min	0.0003	0.0003	0.0003	
	Normal Stress, ksf	0.5	1.0	2.0	
	Peak Shear Stress, ksf	0.56	0.78	1.18	
	Min. Post-Peak Stress, ksf	0.41	0.67	0.70	
REMARKS	Test Method: ASTM D3080				

CLASSIFICATION

Sieve Size	% Passing
3/8-in. (9.5mm)	---
#4 (4.75mm)	---
#16 (1.18mm)	---
#30 (0.6mm)	---
#100 (0.150mm)	---
#200 (0.075mm)	---

Atterberg Limits	
Liquid Limit, %	58
Plastic Limit, %	16
Plasticity Index, %	41
Estimated Gs	2.7
k_{avg} 20ºC, cm/sec	---

DIRECT SHEAR TEST RESULTS
SCWA Rogers Creek Fault Study