ERDC TR-20-19

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Engineer Research and Development Center

Flood and Coastal Storm Damage Reduction

Study of Sand Boil Development at Kaskaskia Island, IL, Middle Mississippi River Valley

Julie R. Kelley, Joseph B. Dunbar, Kevin B. Parkman, Ryan C. Strange, Benjamin R. Breland, Maureen K. Corcoran, Thomas E. Berry, M. Elizabeth Lord, Erin R. Gore, and Isaac Stephens

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Abstract

Mississippi River flooding in 2013 and 2016 caused severe underseepage and development of several medium to large high-energy sand boils behind the landside levee toe at Kaskaskia Island, IL. This levee system is located between St. Louis and Cape Girardeau, MO, and is part of the Kaskaskia Island Drainage and Levee District on the Middle Mississippi River. Flooding on the Mississippi River in 2013 and 2016 was below the design flowline for this levee. This report documents a case history study into the causes of seepage, piping, and sand boil development at a levee reach at Kaskaskia. Site-specific geotechnical data were collected and evaluated to determine the causes for poor performance at the studied levee reach locations. Data collected involved design documents, geologic and geotechnical borings, closely spaced cone-penetrometer tests (CPTs), electrical resistivity surveys, laboratory soil testing of sand boil ejecta, CPT samples from targeted stratigraphic horizons in the subsurface, and both piezometer and river-stage data. These data indicate sand boils present within this levee reach involved a chronic seepage condition that became progressively worse through time. This condition was directly related to the underlying site geology, namely the top stratum thickness and the depositional environment in this levee reach.

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Preface

This study was funded by the Flood and Coastal Storm Damage Reduction Program (FCSDRP), Project Number 405372, under the Project Resilient Infrastructure Work Unit, Remote Monitoring and Sensing and Empirical Study of Internal Erosion on Levees work items. Dr. Julie Rosati was the Technical Director of FCSDRP. The technical monitor for this work unit was Dr. Michael K. Sharp, Technical Director, Water Resources Infrastructure, Geotechnical and Structures Laboratory (GSL), U.S. Army Engineer Research and Development Center (ERDC).

The work was performed by the Geotechnical Engineering and Geosciences Branch (GSG) of the Geosciences and Structures Division (GS) and the Structural Engineering Branch (GSS), Engineering Systems and Materials Division (GM) of ERDC-GSL and the Environmental Systems Branch (EEC) of the Ecosystem Evaluation and Engineering Division (EEED), Environmental Laboratory (ERDC-EL). At the time of publication, Mr. Christopher G. Price was Chief, GSG; Ms. Mariely Mejias-Santiago was Chief, GSS; Mr. James L. Davis was Chief, GS; Mr. Mark Graves was Chief, EEC; and Mr. Mark Farr was Chief, EE. The Deputy Director of ERDC-GSL was Mr. Charles W. Ertle II, and the Director was Mr. Bartley P. Durst; the Acting Deputy Director of ERDC-EL was Dr. Brandon Lafferty, and the Acting Director was Dr. Jack E. Davis.

COL Teresa A. Schlosser was the Commander of ERDC, and Dr. David W. Pittman was the Director.

1 Introduction

1.1 Background

Incidents involving severe underseepage and several large, high-energy sand boils at the landside levee toe occurred during flooding in 2013, 2014, and 2016 on the Middle Mississippi River between St. Louis and Cape Girardeau, MO. These floods varied from moderate to major; however, water levels were well below the design flood the levees were built to withstand. This report documents a case history study into the causes of seepage, piping, and sand boil development at a levee site at Kaskaskia, IL, in the Kaskaskia Drainage and Levee District (Figure 1).

Figure 1. Location of study site in southern Illinois.

1.2 Purpose and scope

The purpose of this report is to examine the geologic and hydrologic conditions responsible for several large sand boils on the eastern and south-eastern sides of Kaskaskia Island, IL. The focus of this investigation was to better understand the factors involved in internal erosion at this location. Activities performed during the course of this study included a literature review, geologic mapping, field investigations involving cone-penetrometer tests (CPTs), laboratory soils testing of sand boil ejecta and selected CPT samples, geophysical exploration, elevation surveys involving Light Detection and Ranging (LiDAR), data analyses and processing, and preparation of this report. The specific purpose for collecting these data was to better understand both geologic and geotechnical parameters responsible for sand boil formation and development.

Collection of site-specific data from the Kaskaskia Island study will be used to identify important geotechnical parameters, such as top stratum or blanket thickness, Unified Soil Classification System (USCS) soil types, engineering soil properties, geologic depositional environments, stratigraphic context, and hydraulic gradients that are responsible for seepage conditions and poor levee performance. Results from this investigation will be used to calibrate laboratory sand boil models and will aid in the development of better predictive tools to evaluate levee performance and to improve on current analytical solutions used by geotechnical engineers.

Dr. Michael Navin, Geotechnical Engineer, U.S. Army Corps of Engineers (USACE), St. Louis Engineer District, Geotechnical Branch, assisted the U.S. Army Engineer Research and Development Center (ERDC) field investigators in 2014 and 2015 at Kaskaskia Island. Dr. Navin provided background information and assisted with access to the area.

1.3 Kaskaskia, IL, study area

Kaskaskia Island is located on the west bank of the Mississippi River midway between St. Louis and Cape Girardeau, MO (Figure 2). Kaskaskia was not an island initially, but large flood events during the late 1800s created an oxbow island and abandonment of the town’s population from the area.

Kaskaskia was an important town in the 18th century and was a center for commerce and transportation along the Mississippi River. Located in Randolph County (Figure 3), it was the first state capital of Illinois and had a population of 7,000 people (McDonough 1883). The town was flooded in 1844 and again in 1881 when the Mississippi River incrementally changed its course, creating an oxbow island and separating the town from the Illinois side of the river (Figure 4). The Mississippi River assumed the lower course of the Kaskaskia River at its mouth near Chester, IL.

Figure 2. Kaskaskia Island is located on the west bank of the Mississippi River, approximately halfway between St. Louis, MO, and Cape Girardeau, MO.

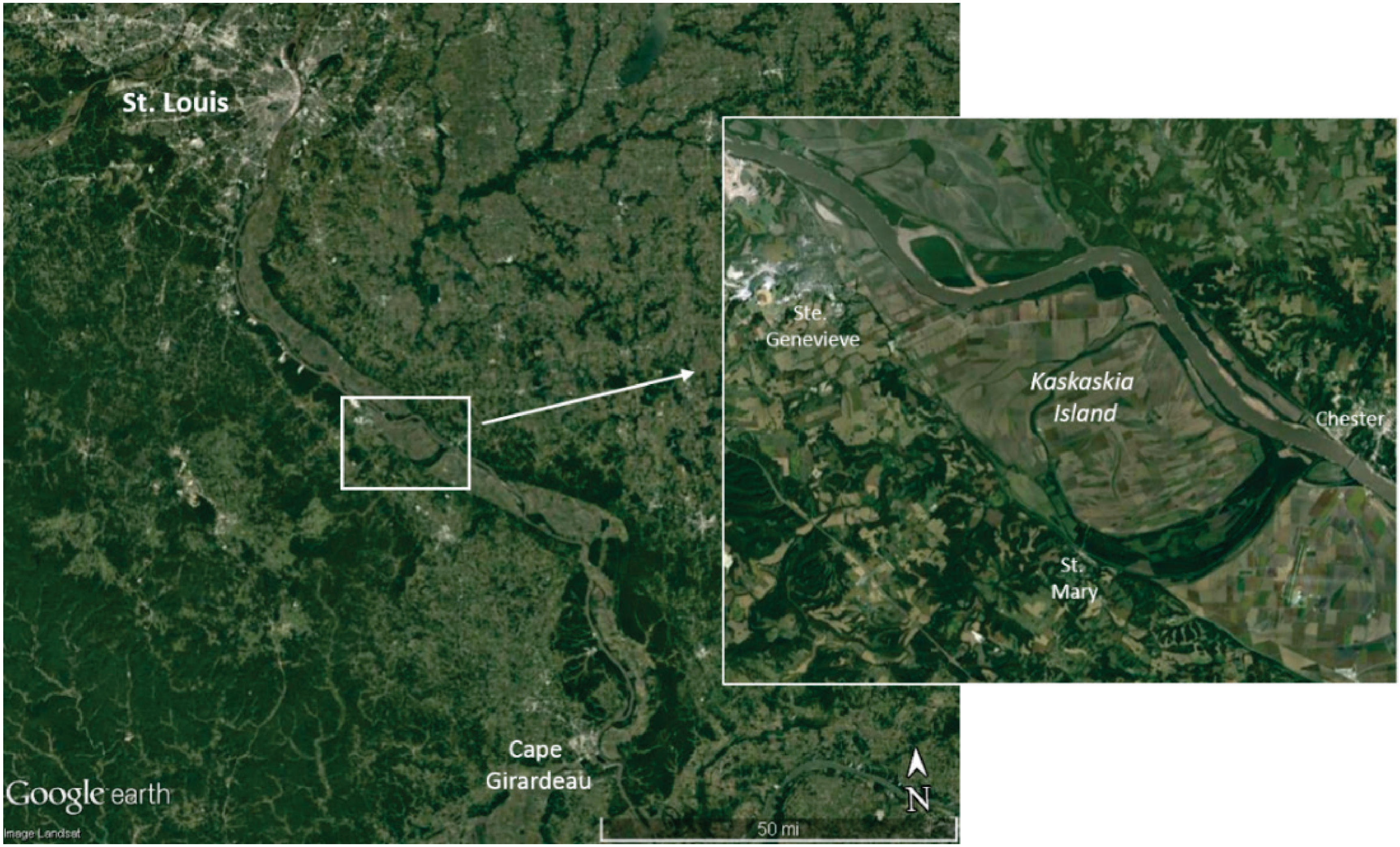


Figure 3. Map of Randolph County, IL, in 1876 before the Mississippi River changed course (Warner and Beers 1876, David Rumsey map collection).

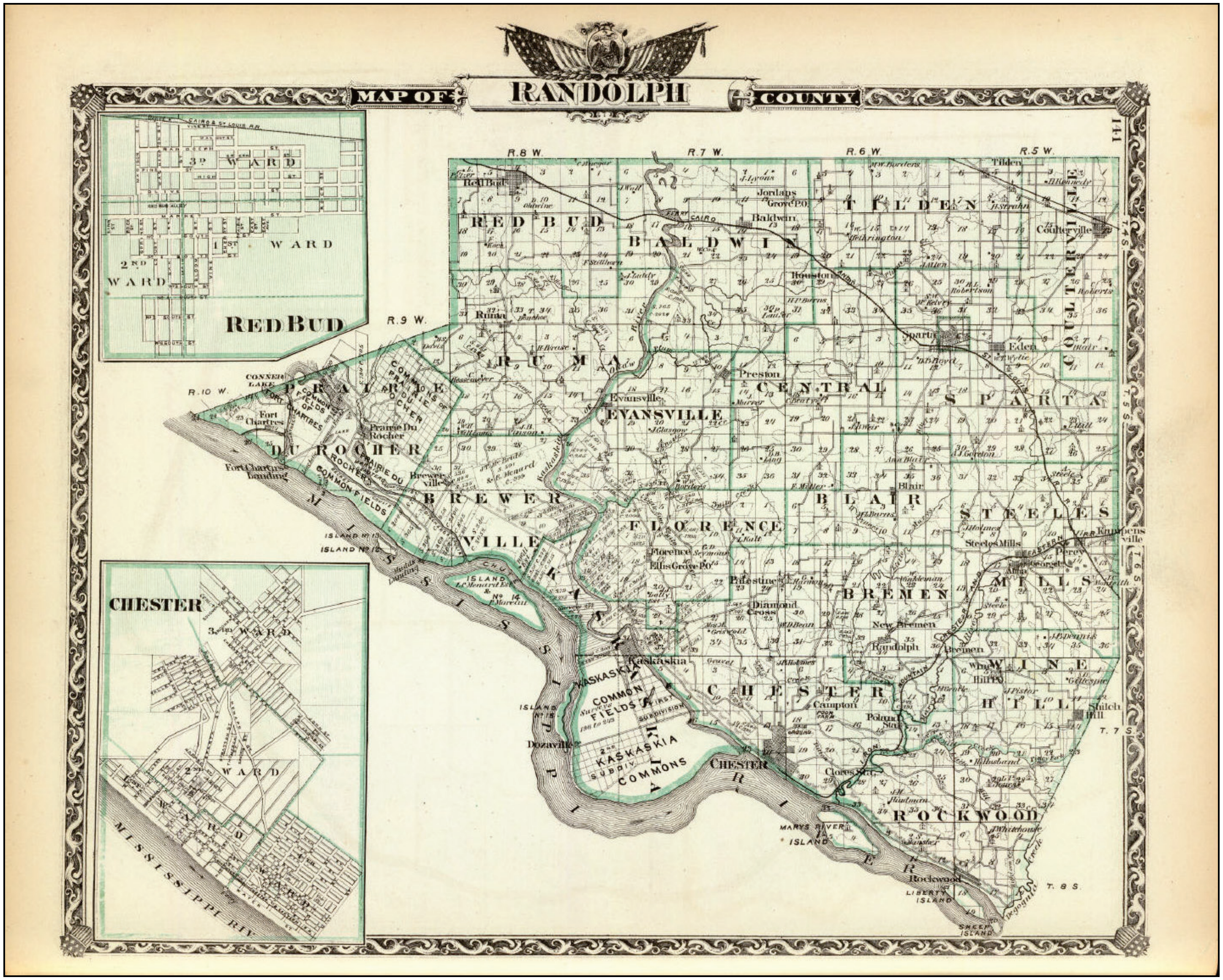
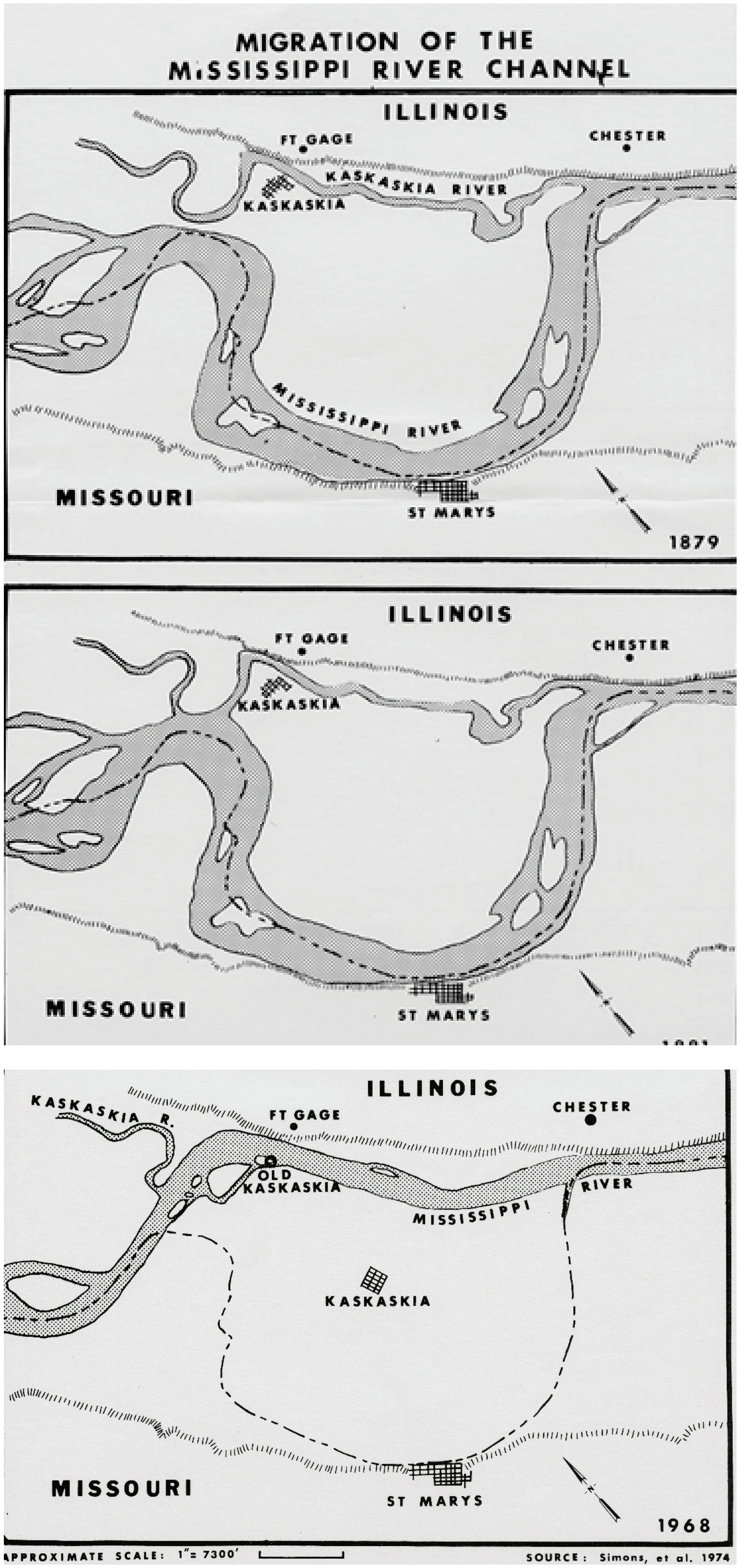


Figure 4. Historic maps of channel changes leading to island development (Simons et al. 1974).



1.4 Flood control history

Flood control was needed on the island, and the Kaskaskia Island Drainage and Levee District was formed in 1916 (Figure 5). The District included levees between river miles 111.6 and 115.5 and reduced the risk of flooding to 9,362 acres of land (Bhowmik et al. 1994).

Figure 5. Proposed levee alignment in a 1914 survey of the island (MRC President's File #547).

After the Flood of 1942, this section of levee was federalized and upgraded to meet the existing design requirements for that time. This upgrade provided protection equivalent to a 10-yr flood (USACE St. Louis District 1977a).

The St. Louis District was authorized in the 1940s and 1950s to raise levees between Alton, IL, and Gale, IL, to meet a 50-yr level flood protection standards (USACE St. Louis District 1976); however, Kaskaskia Island levee was not part of the USACE (1956b) Alton to Gale Investigations because it already had been rehabilitated in 1942. A major flood of record occurred in 1973 and led to overtopping of the levee at Kaskaskia. This flood prompted additional major upgrades to the levee system. The levee was raised to 40.5 ft or an increase in height by 8 ft with a riverside enlargement that included an increase in crown width from 10 ft to 20 ft (Figure 6). Gravity drains were also rebuilt and enlarged (USACE St. Louis District 1979a, 1979b). Seepage berms were constructed in select areas at Kaskaskia to prevent ongoing seepage problems (Figure 7).

A major flood occurred in 1993 that was recorded as the worst flood in Illinois history and led to a levee breach (Figures 8 and 9). There was above normal precipitation during the spring that continued through the summer. A levee breach occurred at Kaskaskia Island that flooded 14,000 acres of land, including the entire island (Bhowmik et al. 1994). Figure 9 shows standing water in the town of Kaskaskia after the breach event.

The maximum depth of the scour hole at Kaskaskia reached 50 ft. About 1 million cubic yards of soil were removed over a period of several days during flooding (Chrzastowski et al. 1994). Figure 10 shows the levee breach during the flood. The Great Flood of 1993 was a flood of record and a 100-yr event on the nearby Chester staff gage (RM 109.9). The levee system was again rebuilt following this flood. Numerous engineering borings and laboratory soil test data are available to characterize the stratigraphy at the breach site and from around the island. Failure of the levee at this location was due to loss of pervious foundation soils by seepage and piping and a large sand boil activity.

Seepage and boil activity (Figure 11) were severe enough to require flood-fighting remediation again during the 2013 high-water event further downstream of the 1993 breach site. The 2013 Flood was approximately a 20-yr event, well below the current design of the levee for a 50-yr event.

Additional sand boils continued to flow during periods of low-level flooding. In 2014, and in the large Flood in 2016, Kaskaskia Island was selected as a study site and was accessible from the levee road; local landowners and the levee district were supportive of ongoing research at this site.

Figure 6. Configuration of the 1978 levee raise at Kaskaskia.

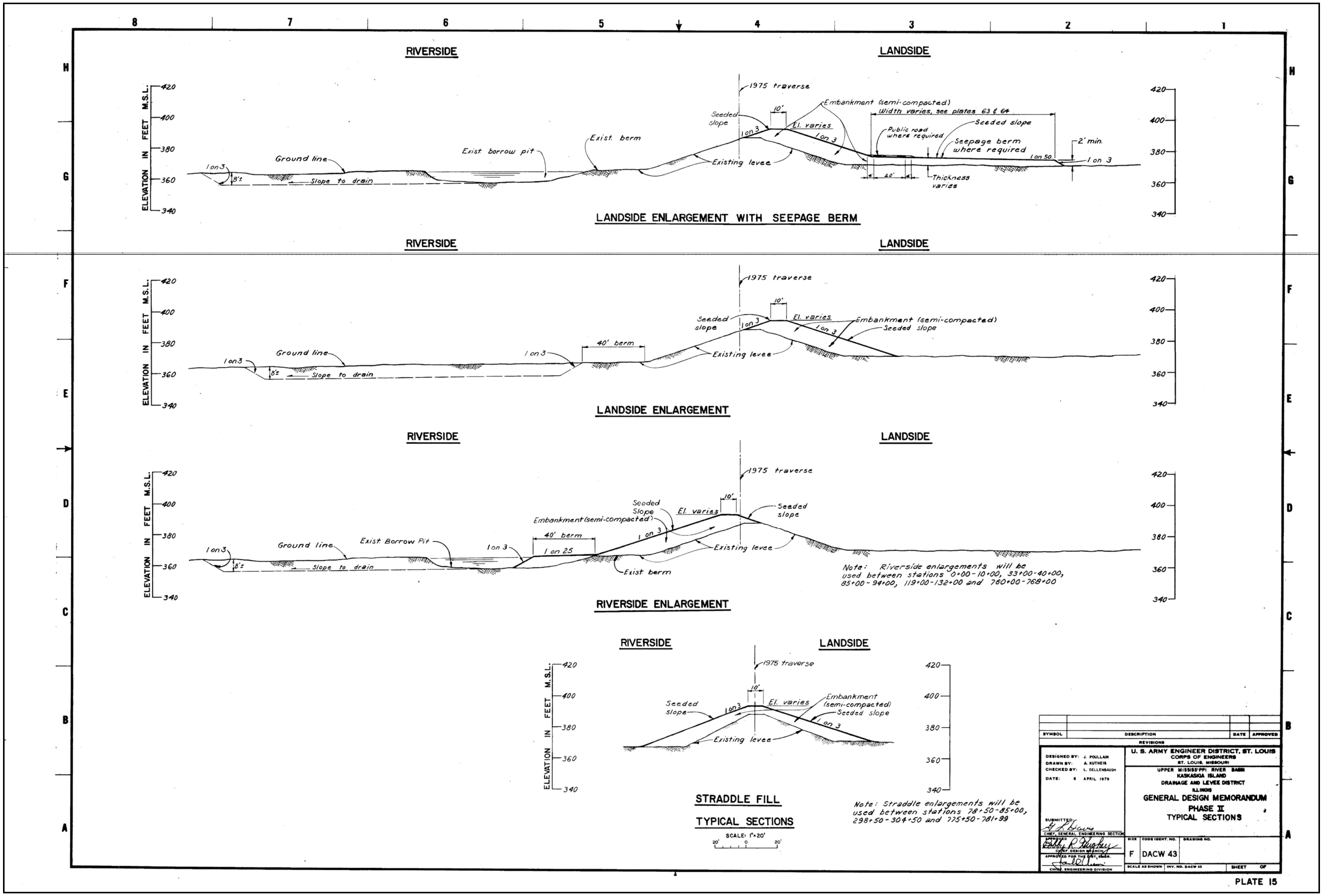


Figure 7. Locations (in red) where seepage berms were constructed during the 1977 levee rehabilitation at Kaskaskia Island.

Figure 8. Location of breach at Kaskaskia levee in 1993.

Figure 9. Floodwater in farming area on Kaskaskia Island in 1993 after levee breach. (Photo courtesy of St. Louis District.)

Figure 10. Levee breach at Kaskaskia in 1993 during flooding.
(Photo courtesy of St. Louis District.)

Figure 11. Active sand boils at Kaskaskia Island at the levee toe
during the 2013 Flood.

1.5 General mechanics of sand boils

Development of sand boils and internal erosion (piping) is considered to be a major failure mechanism of levees. Turnbull and Mansur (1961) summarized the dynamics of sand boil development beneath levees undergoing flood-induced seepage.

> "If the hydrostatic pressure force in the pervious substratum (alluvial aquifer) landward of the levee becomes greater than the submerged weight of the overlying strata, the excess pressure may cause heaving of the upper soil layers and rupture at weak spots with a resulting concentration of seepage flow. Flow from these weakened locations may increase to form sand boils."

Problems with the levee foundations begin to occur once fine particles start to erode and are carried by the seepage flow and eventually break the surface to form a sand boil. An open channel develops with a cone of sandy material being deposited on the landward side of the levee. This opening and sand ejecta cone are referred to as a sand boil. Many corrective measures have been designed to relieve the hydrostatic pressure in the alluvial aquifer to decrease and/or stop this process, including sand bagging around the boil, the placement of relief wells in the reach, construction of seepage berms for added weight and to extend the seepage path, cutoff walls through the foundation, and sublevees to permit a tailwater to form behind the landside area (USACE 1956a, 1956b).

Sand boil activity discovered at the Kaskaskia Island site in 2013 occurred during a low-level flood. A common belief by many USACE levee engineers is that in chronic seepage areas, sand boil activity can form at lower levels of flooding because of the accumulated effects of internal erosion at these locations.

1.6 Focus of case history studies

Answers to questions about internal erosion have historically not been addressed in earlier studies of underseepage (USACE 1956a, 1956b) and are made possible from the current field study. Important questions involving internal erosion to be examined during this investigation of the Kaskaskia Island study site are as follows.

1. What are the engineering and geologic properties of the sand boil ejecta?
2. Where is the source of the ejecta in the stratigraphic column?
3. What are the contributing factors in terms of the geology and associated engineering properties?
4. Is it possible to image active sand boil areas with geophysical methods and identify characteristic signatures?
5. Can geophysical methods be effectively used as a predictive tool for evaluating levee vulnerability?

1.7 Units of measure used in this report

Units of measure reported throughout this document include both English and System International (SI) metric values. Legacy USACE documents and district convention reports English measurements for project description, distance, elevation, river stage, and boring depth. Geophysical data by convention use metric values for measurement of ground resistivity and reporting of survey data. The assimilation of data used in this report incorporated both types of units of measure and their presentation. Thus, data reported herein use the corresponding system representative of their source and age.

2 Geologic Setting

2.1 Introduction

Kaskaskia Island is located in Randolph County, IL, on the west bank of the Mississippi River between river miles 111 and 116. The island is due south of Ste. Genevieve, MO, and east of St. Mary's, MO. The floodplain is approximately 5 miles wide in this area and is bounded by steep, rock-walled bluffs that rise above the alluvial valley 200 to 350 ft (USACE St. Louis District 1977a). The surrounding bluffs are composed primarily of limestone of Mississippian age with a thin covering of Pleistocene loess (USACE St. Louis District 1977a).

Mississippi Valley alluvium, consisting of deposits from the glacial and the modern Mississippi River, covers the bedrock with thicknesses of up to 130 ft. Top stratum in this region consists of clay, silt, and silty sand and ranges from 5 to 30 ft thick. A pervious sand and gravel substratum is present below this layer to more than 100 ft in thickness and overlies rock (USACE St. Louis District 1973). This pervious substratum forms the alluvial aquifer.

2.2 Previous geologic studies

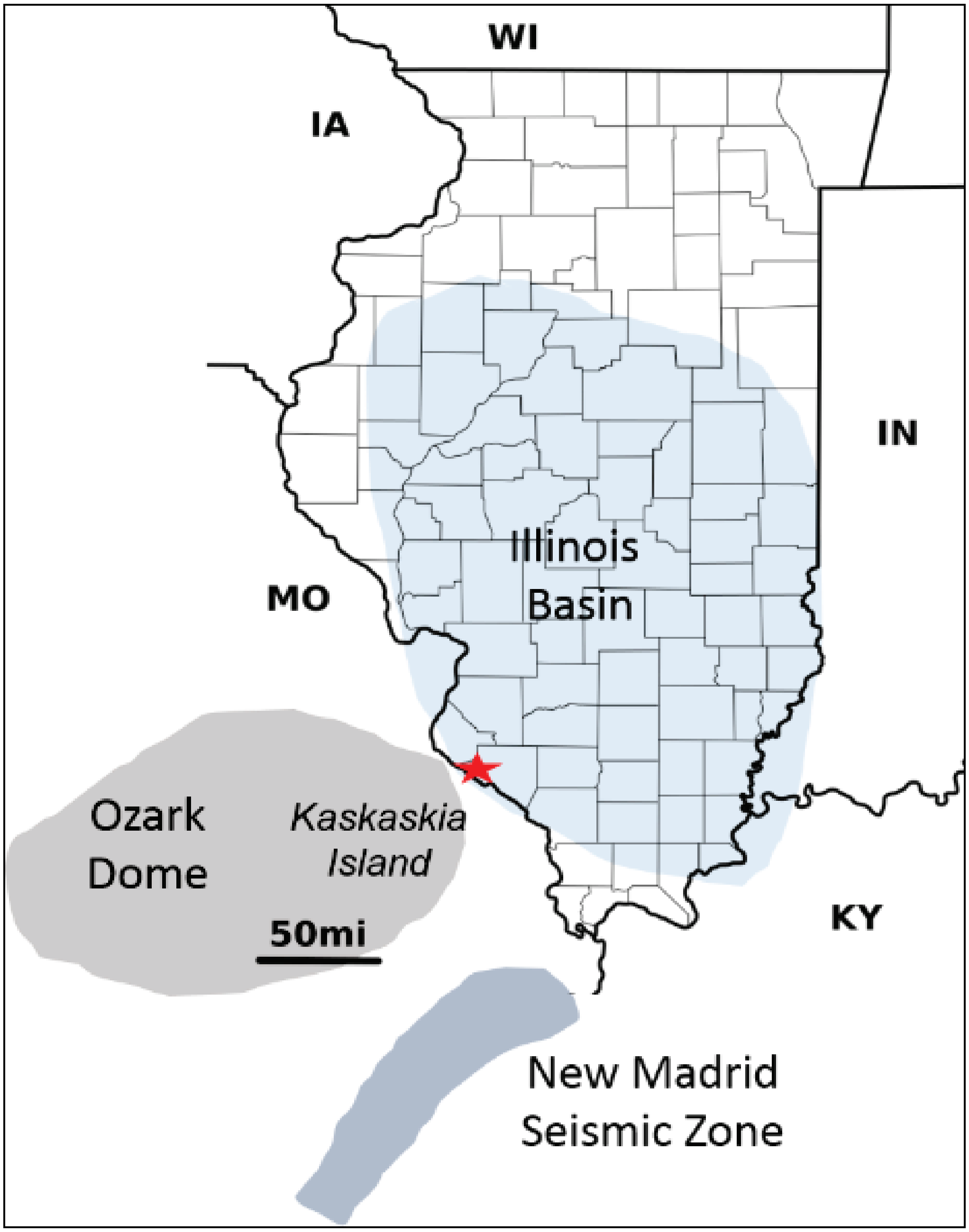
Previous studies of the geology at Kaskaskia Island include a 7 1/2-min quadrangle map by the Illinois State Geologic Survey (IGS) (Seid 2013) and by ERDC at the 15-min scale as surface geologic maps of Holocene-age (less than 10,000 yr) depositional environments (Woerner et al. 2003). IGS mapping by Seid (2013) identifies the surrounding bedrock chronostratigraphy but does not differentiate the Quaternary alluvium in the Kaskaskia Quadrangle. Mapping by Woerner et al. (2003) separates the Quaternary alluvium into distinct depositional environments and provides engineering context to these environments.

Systematic valley-wide geologic mapping of depositional environments along the Middle Mississippi River was not typically performed by USACE until the late 1980s for this reach of the river; however, mapping was performed by USACE geologists in the Lower Mississippi Valley (LMV) to support levee engineering projects.

2.3 Structural setting

The island is located in a complex geologic setting (Figure 12) and rests on the southwestern flank of the sinking Illinois Basin with the uplifted Ozark Dome to the southeast (Seid 2013; USACE St. Louis District 1973). During geologic time, the Mississippi River carved a fairly deep and narrow alluvial valley between 5 to 12 miles (8 to 19 km) wide into the sedimentary rocks, forming the Illinois Basin. Underlying Kaskaskia Island are Quaternary age (less than 2 million yr) Mississippi River alluvial deposits and Silurian to Devonian age (416 to 443 million yr) limestone bedrock (Seid 2013; Woerner et al. 2003).

Figure 12. Study area (indicated with red star) is in a complex geologic setting between the Illinois Basin, the Ozark Dome, and just north of the New Madrid Seismic Zone (Frankie et al. 2008).



Regionally, the study area is 75 miles north of the New Madrid Seismic Zone. Three faults traverse the island, i.e., the east-west trending Ste. Genevieve, the Cottage Grove/Rough Creek fault, and the north-south trending St. Mary's fault (USACE St. Louis District 1973). The faults that cross the island are not considered to be active, i.e., have produced movement and earthquakes during the past 10,000 years, and only a few small-magnitude earthquakes have been recorded in this area in the past.

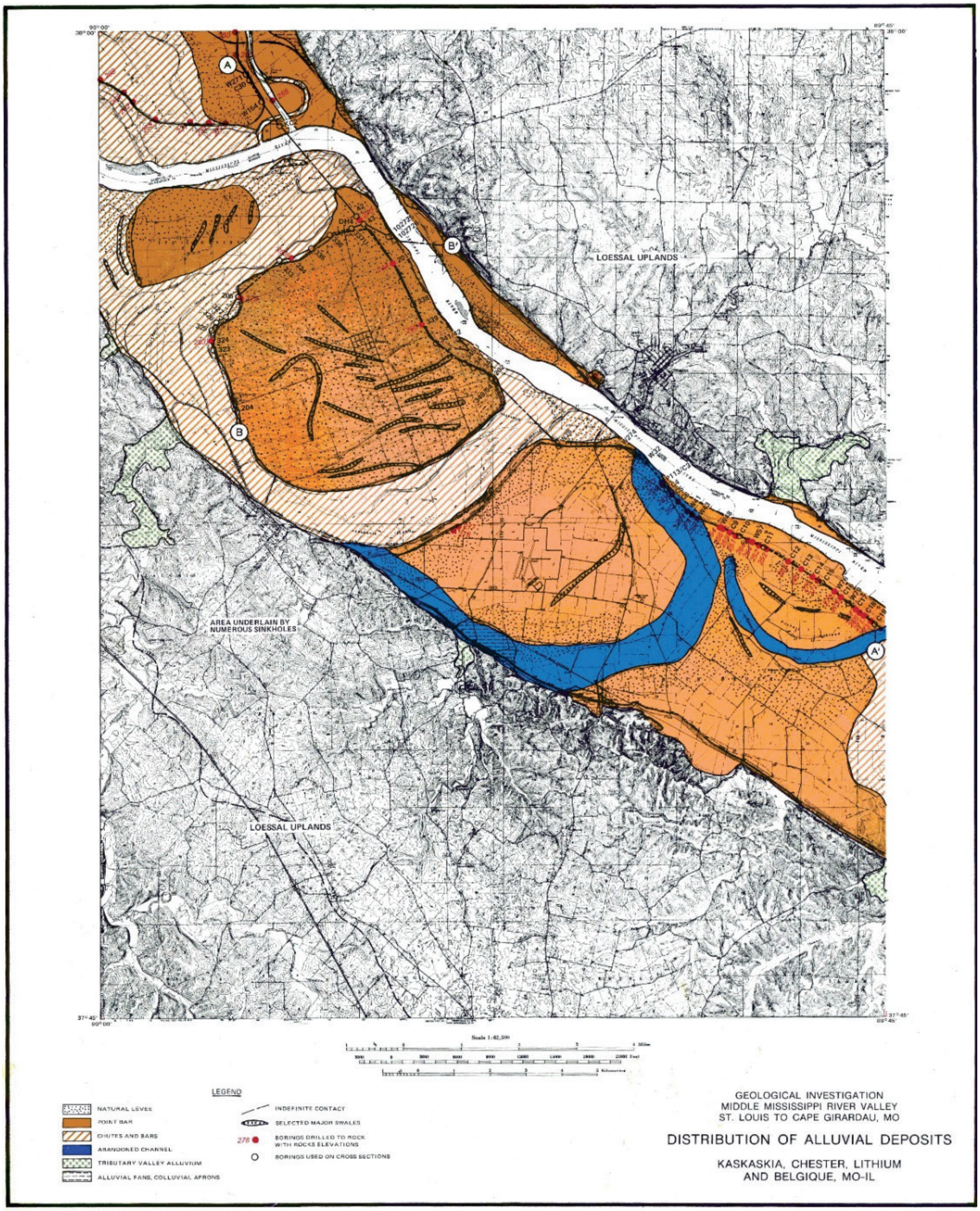
2.4 Holocene depositional environments

Mapping of depositional environments by Woerner et al. (2003) in the Kaskaskia reach indicates that the Mississippi River has shifted courses many times during the Holocene across its narrow alluvial valley. The river through this reach has been a conduit for glacial meltwaters during the Pleistocene (10,000 to 2 million yr). Primary depositional environments in the Kaskaskia levee reach include chutes and bars and point bar deposits (Figure 13).

The major difference between these two depositional environments involves the thickness and character of the top stratum sediments (Woerner et al. 2003). Chutes and bars tend to be much thinner and are typically more apt to be reworked by significant flood events and scouring from overbank flood flows. The development of historic flood control measures (dikes, revetments, and levees) has confined the river to a relatively permanent channel and has prevented rapid channel evolution and migration that was characteristic of this system in the past. Descriptions of the different depositional environments are presented in more detail by Woerner et al. (2003).

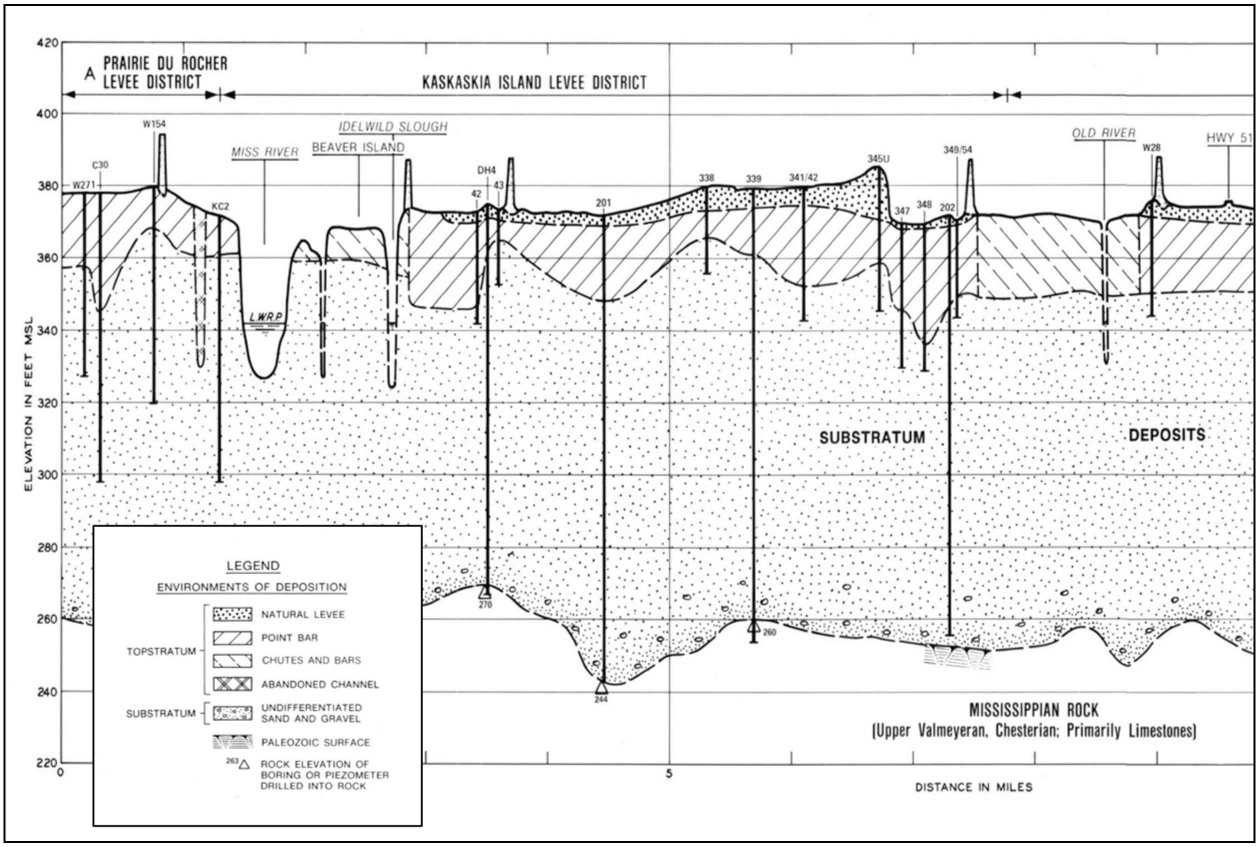
Figure 14 shows a generalized cross section, which is part of A-A′ on Figure 13. This portion of the section crosses the abandoned oxbow channel that forms Kaskaskia Island. The cross section in Figure 14 shows the distribution and thickness of the alluvial deposits in the subsurface based on the widely spaced borings originally presented in USACE (1956a) and compiled by Woerner et al. (2003).

Figure 13. Distribution map of alluvial deposits across Kaskaskia Island Woerner et al. (2003).



KASKASKIA, CHESTER, LITHIUM & BELGIQUE (a)

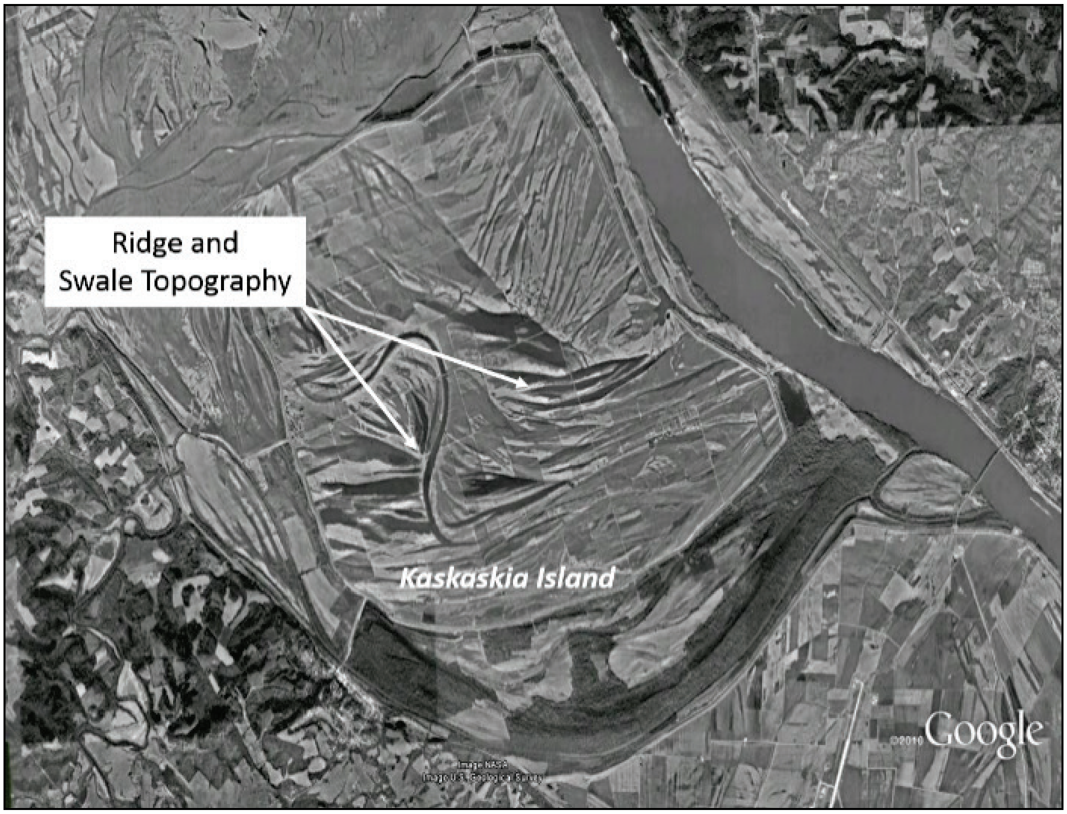
Figure 14. Cross section showing extent of alluvial deposits across Kaskaskia Island (Woerner et al. 2003). Borings were obtained from USACE (1956a). The levee breach in 1993 occurred in vicinity of borings from 339 to 341/342.



Alluvium in the Kaskaskia Island reach consists of both glacial- and Mississippi River fluvial-transported sediments deposited on the limestone bedrock, with combined thicknesses from 100 to 130 ft. The fine-grained top stratum consists of clay, silt, and silty sand and ranges from less than 5 to 30 ft in thickness. Pervious sand and gravel beneath the top stratum comprise the substratum or the alluvial aquifer. The pervious aquifer is more than 100 ft in thickness (USACE 1956b; Woerner et al. 2003).

Figure 15 shows the visible character of the ridge (sand bars) and swale (chutes) topography visible in the 1993 black and white image (Google Earth). Low-lying areas in the image are dark colored and correspond to locations of abandoned swales/chutes. The characteristic topography in Figure 8 illustrates the variable nature of the elevation changes that are characteristic of this landform and the island topography. Ridge and swale topography is associated with bar deposits and includes two types of sedimentary features as described by Woerner et al. 2003.

Figure 15. Ridge and swale topography is present across Kaskaskia Island in this image from 1993.

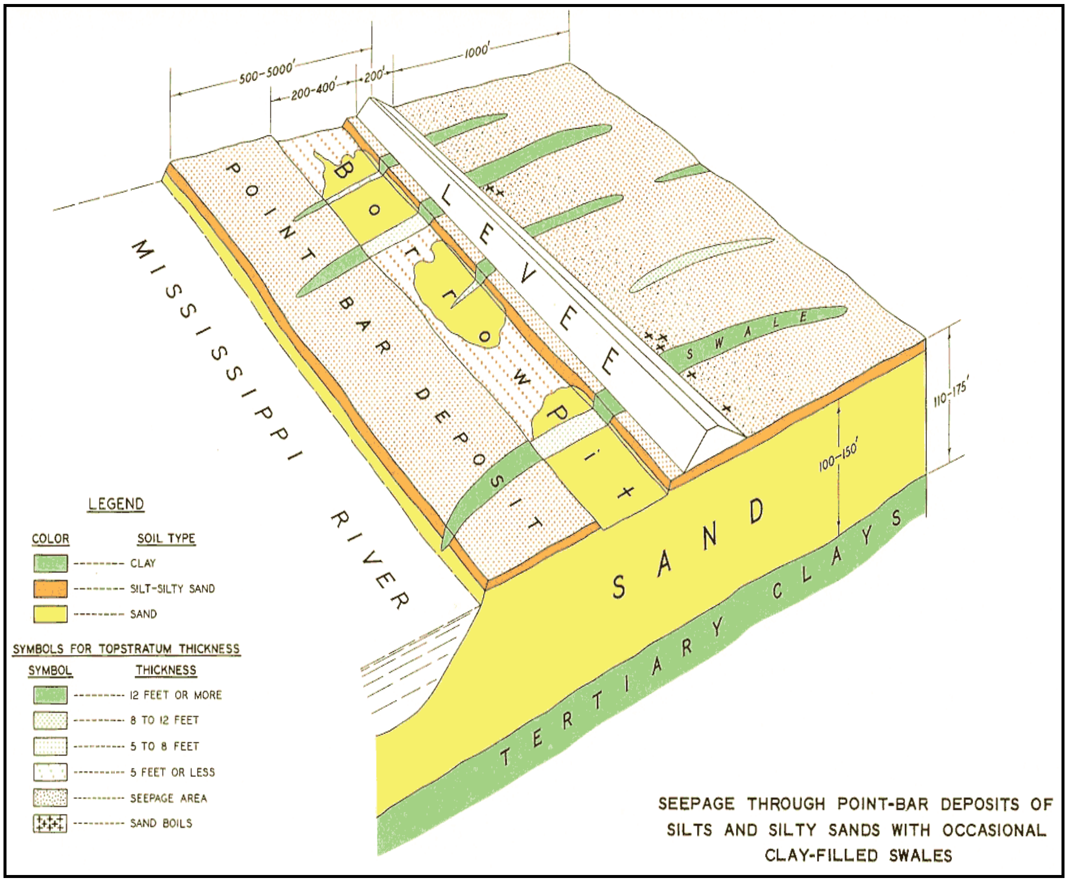


> "…silty and sandy elongate bar deposits or "ridges," which are formed during high stages on the stream, and silty and clayey deposits in arcuate depressions or "swales", which are filled with fine-grained deposits during falling river stages. The ridges and swales form an alternating series, the configuration of which conforms to the curvature of the migrating channel and indicate the direction and extent of meandering."

Ridges in point bar deposits are generally more pervious than the silt- and clay-filled swales, which will retain their moisture and have more organics. Swales correspond to low-lying areas that form lakes during flooding from underseepage that accumulates in these features. There are 5 to 15 ft of relative relief differences between the ridges and swales (USACE St. Louis District 1977b).

Abrupt changes in elevation that occur in a chute/swale environment can have a significant influence on hydraulic pressure in the alluvial aquifer by creating a blocked exit condition locally where low-lying, fine-grained chutes are present (USACE 1956a, 1956b). The presence of blocked exits horizontally can often concentrate seepage pressures locally and contribute to sand boil activity at the edge of these features. Open borrow pits or the presence of a deep channel on the riverside of the levee shorten the seepage path and increase the local hydraulic gradient. This concept is shown by Figure 16.

Figure 16. Abrupt horizontal changes in the depositional environment from low-lying swales can block underseepage in the aquifer locally and promote formation of sand boils. Open borrow pits or presence of a deep channel on the riverside of the levee can also shorten the seepage path and increase the hydraulic gradient locally (USACE 1956a, 1956b).



3 Field Studies

3.1 Approach

The field investigation in order of tasks performed involved an initial site reconnaissance and subsequent return visits during both low-water and flood-stage conditions. Soil samples were collected for determination of laboratory particle-size texture and evaluation of mineralogy during the initial reconnaissance to better understand the source of the ejecta from the underlying soil column.

Return visits to the island involved targeted data collection methods to characterize both the surface and subsurface geologic conditions. Data collection methods involved CPTs, geophysical surveying using electrical resistivity imaging of selected sand boils, and a LiDAR survey of different sand boil sites.

CPTs of sand boil sites were performed in the next phase during low-water conditions to characterize the stratigraphy beneath the sand cones and conduct selected soil sampling at the studied sand cone sites to understand the distribution of soil types vertically. As part of the CPT site characterization, laboratory soil testing of additional ejecta samples was performed to derive grain size and mineral properties.

CPT technology is a proven subsurface characterization tool used by the geotechnical community on earthen dams and levees for years. Data are collected by an instrumented cone being pushed into the ground at a constant rate. The cone contains electrical sensors at the tip and side of the cone that measure values of voltage for the force acting on the tip resistance while pushing and side-sleeve friction. The cone resistance value is obtained by dividing the total force acting on the cone by the projected surface area. This information is compared to well-established calibration charts of tip resistance and sleeve friction to determine soil engineering properties, including strength, soil type, and soil layering (Robertson and Cabal 2010).

Geophysical surveys were performed as the third task to image selected sand cones to observe signatures and layering of the stratigraphy beneath the cones studied. This effort was followed up with LiDAR surveys of the levee surface and sand boil sites to get accurate surface conditions for subsequent modeling and analysis of the areas studied. Field activities are presented in this section in their general order of occurrence to this study. A third, and final, site visit was conducted during the January 2016 Flood.

3.2 Initial site reconnaissance

An initial survey of Kaskaskia Island sand boil locations was led by Dr. Mike Navin in June 2014. The survey included a trip around the island to view observed sand boils during the 2013 and 2014 high water as well as the repaired site of the 1993 levee breach. Plans were subsequently made to return later to conduct CPT soundings (total of 23 soundings later performed) as part of a focused study of selected sand boil areas.

During the initial site visit, a total of five sand boils was identified around both the eastern and southern sides of the island for further study (Figure 17). Most of the recent sand boil activity was located on the southeastern side of the island at the edge of a seepage berm (Figure 17).

Figure 17. Locations of recent sand boils from 2013 and 2014.

Sand boil location and relevant characteristics were collected using a GeoXH 6000 handheld global positioning system (GPS) device and the Mobile Information Collection Application (MICA) software. Measurements of cone height and inside throat diameter were recorded.

Soil samples of the ejecta material were collected during the first visit. Approximately 1 gal-sized soil samples of the ejecta material were taken from the center of each sand boil with a hand auger (Figure 18).

Figure 18. Soil samples taken with a hand auger from Sand Boil No. 1 for laboratory soil analysis.

A second gal-sized soil sample was taken from the blanket material nearby. Both samples were wrapped in plastic and sealed for transport to ERDC for particle-size analysis and mineralogy. Results of the laboratory testing of the ejecta and blanket samples are presented in Table 1. Curves of the grain-size data from laboratory testing of these samples are presented in Appendix A.

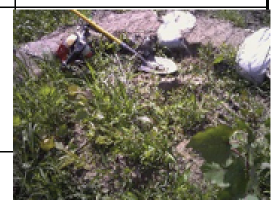
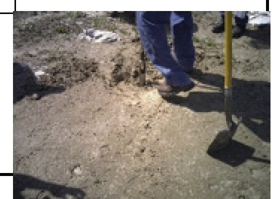
Laboratory classification of sand boil ejecta identifies a silt to fine sand (ML to SM). The upper blanket material corresponds to a clay (CL and CH). The mineralogy of the ejecta from examination of field samples is estimated to be more than 96 percent quartz sand, with minor amounts of mica, feldspars, and less than 1 percent unidentified heavy minerals.

3.3 CPT data collection at Kaskaskia Island

3.3.1 Introduction

ERDC personnel returned to Kaskaskia Island during July and August 2014 to obtain CPT data from selected sites. Low water conditions occurred during this site visit. Flags were initially placed at planned CPT locations, starting with the 23 general locations previously identified.

Table 1. Summary of laboratory test results from ejecta samples taken during initial site visit. Second sample for each sand boil number identified was obtained from the blanket. Sample 2C from Sand Boil No. 2 is a second sample from ejecta.

Ejecta Samples			
Sand Boil #	**Sample Name**	**Soil Classification**	**Photo**
1 Ejecta	MD1514 KK-1 (1-2")	SM	
1 Blanket	MD1514 KK-1 (1.5-2.5")	CH	
2 Ejecta	MD1514 KK-2A	ML	
Blanket	MD1514 KK-2B	CL	
2 Ejecta	MD1514 KK-2C	SM	
3 Ejecta	MD1514 KK-3 (0-8")	ML	
3 Blanket	MD1514 KK-3 (0-22")	CL	
4 Ejecta	MD1514 KK-4 (0-8")	ML	
4 Blanket	MD1514 KK-4 (8-24")	CL	

Three main study sites were selected for focused study based on observations from both the previous and current site visits to the island (Figure 19).

Figure 19. Three study sites were selected along the levee on Kaskaskia Island.

Three locations were targeted for follow-up study with CPT borings for site characterization. The first area (No. 1 on Figure 19) was where the breach had occurred in 1993. Site No. 2 was located at an existing sand boil area (Sand Boil No. 1). Site No. 3 on the southeastern part of the island was referred to as the “Sand boil study area.” Several sand boils were concentrated at this location (sand boils Nos. 2, 3, and 4; Figures 11 and 17). Also present at this location was an area of minor subsidence, referred to as the “slump” area. This slump indicates ground settlements might have occurred at this location due to loss of foundation material.

A Vicksburg District CPT truck and crew (Operators Rusty Penley and James Cumberland) were used for obtaining CPT data from Kaskaskia Island (Figure 20). A total of 71 CPT pushes were completed during the second phase of this study. Individual CPT logs are presented in Appendix B. Most of the CPT pushes were made within the sand boil and slump area identified as area 3 in Figure 19.

Figure 20. Operators Rusty Penley and James Cumberland prepare the probe to collect CPT data (left). The probe is lowered through the truck floor and pushed into the soil at a constant rate (right).

3.3.2 Breach Area Site 1

Three CPT soundings were placed around the repaired 1993 breach area for direct comparison to subsurface conditions and soil layers in the other active sand boil areas studied (Figure 21). The scour hole created during the 1993 breach was filled with hydraulic-placed materials. Figure 22 shows the sounding locations made on a current day image as they relate to the area affected by the breach in 1993.

Figure 21. Locations of CPT soundings within study area No. 1. Soundings are overlaid on 1993 imagery of the levee breach.

3.3.3 Sand Boil Site 2

The second area studied is a single large boil (designated as Sand Boil No. 1) on Figure 23 (yellow circle). This sand boil was still flowing in spite of the low water stage. Soundings here were intended to investigate the thickness of the blanket around this flowing sand boil.

3.3.4 Sand Boil Site 3

Location of CPT soundings at study area 3 is shown in Figure 24. Sand boils numbered as 2, 3, and 4 are identified in Figure 24. This location contained an area of noticeable subsidence that was designated as the “slump” area and a control area outside both of these affected areas. CPT locations at these different areas are shown in Figures 25 to 27. These areas are further described below.

Figure 22. CPT soundings in old, repaired breach location on current image of area.

Figure 23. CPT sounding locations near Sand Boil (SB) No. 1 (yellow) and within designated study area No. 2.

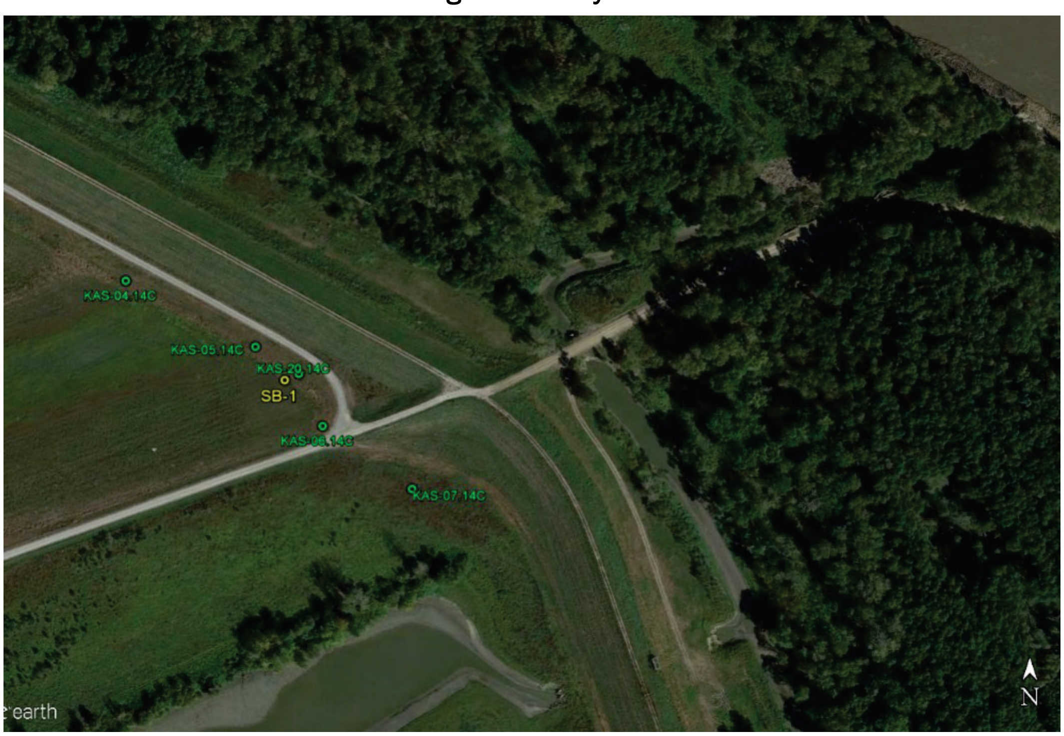


Figure 24. CPT soundings in three areas at the southern end of Kaskaskia Island at study area No. 3 (Figure 19).

3.3.5 CPT field strategy and location

CPT soundings at Site 3 were closely spaced, from 6 to 15 ft (2 to 5 m) apart, and pushed to approximately 50 ft in depth, well into the aquifer sand, in an effort to investigate blanket thickness and possible subsurface erosion conditions at the levee toe in the "slump" and "sand boil" areas. Figure 25 shows the location of 26 soundings that were made in the Sand Boil Area (in pink) and the general sounding (in green). Figure 26 shows the locations of 18 soundings that were made in the slump or depression area. Figure 27 shows the locations of four soundings that were made in the control area, where no visible subsidence or active sand boils were noted.

3.4 Ground-based LiDAR data collection at Kaskaskia

3.4.1 Introduction and method

A terrestrial-based laser scanner or LiDAR was used to collect precise terrain and position data for accurate location of features and subsurface modeling of data collected. LiDAR is a highly accurate remote sensing technology used to obtain very high-resolution topographic survey X, Y, Z data points.

The LiDAR used for this data collection was Trimble's FX 3-D Laser Scanner. This instrument has a field of view (FOV) that is 3600 × 2700, and uses a single return, "line of site" 685 nm (red) laser.

Figure 25. Close-up view of CPT locations at the sand boil area.

Figure 26. Close-up view of CPT sounding locations in slump (depression) area.

Figure 27. CPT sounding locations in Control Area.

The instrument was mounted on a tripod (station), and small white reflective spheres were placed in and around the scanners FOV. These registration spheres were used later to join the scans together once all of the scans were completed (Figure 28).

Figure 28. The LiDAR station on the edge of a sand boil; Figure 28b shows the registration spheres distributed along the site.

The laser was initialized and a small mirror within the instrument began to spin, which in turn pulsed the laser beam as far as it can "see," capturing up to 200,000 data points per second. The collection was complete for that station once the instrument had completed the full 360 deg rotation. A data gap or shadow occurred underneath the instrument. The location of the next scan station was chosen to be close enough to fill in the shadow from this station and have enough common registration targets in order to stitch the scans together.

ERDC survey personnel used a pair of Trimble model R8 RTK GPS receivers and a modified roll-a tape instrument (S-Tracker) to conduct a 6-hr continuous topo on a 400-m by 600-m section of the Kaskaskia Levee and berm on the landside of the levee.

One GPS receiver served as the Base Station and was mounted on a stationary tripod on the top of the levee near a gate (Figure 29). This GPS unit was storing raw GPS signals while, at the same time, transmitting pseudo-corrected positional data to the mobile GPS mounted on the S-Tracker. The stored raw signals were later submitted to the National Geodetic Survey (NGS) via the Online Positioning User Service (OPUS) to obtain accurate positions for the entire survey. After the accurate position of the stationary GPS unit was established by NGS OPUS, the pseudo-corrected mobile GPS positions were adjusted to determine the final X, Y, and Z of every topo point collected.

Figure 29. GPS Base Station near the levee gate at Kaskaskia.

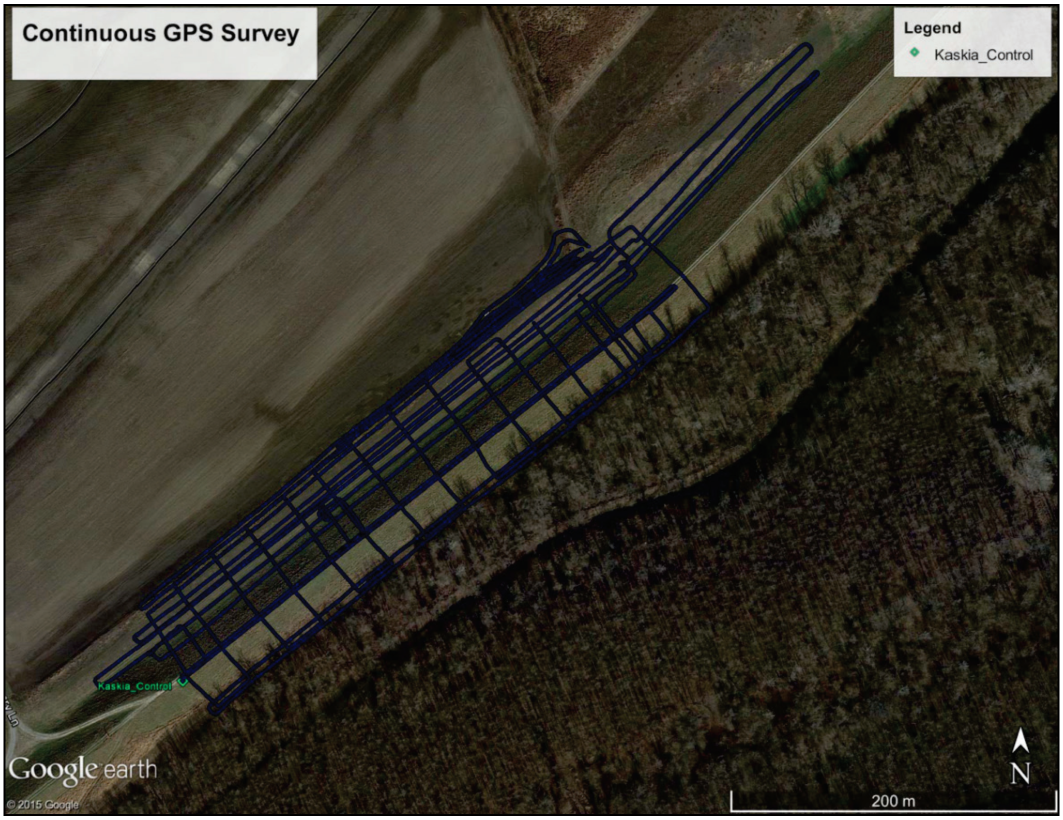
3.4.2 S-Tracker survey

The mobile GPS on the S-Tracker (Figure 30) was configured to store the pseudo-corrected positions at 1-m intervals along a line. Profile lines were visually established approximately 25 m apart along the levee and berm. A portion of these profiles coincided with an area where High Accuracy/ High Resolution LiDAR measurements were collected.

Figure 30. Mobile GPS unit mounted on the S-Tracker.

Another set of profiles lines were collected perpendicular to the levee profiles along the riverside and landside toe of the levee, along both lanes of the road on top of the levee, and on the berm adjacent to the levee. On the berm, the survey lines were spaced either 1 m or 5 m apart (Figure 31).

Figure 31. Image showing the GPS Base Station on the levee (green) and the Mobile GPS points collected with the S-Tracker (blue).



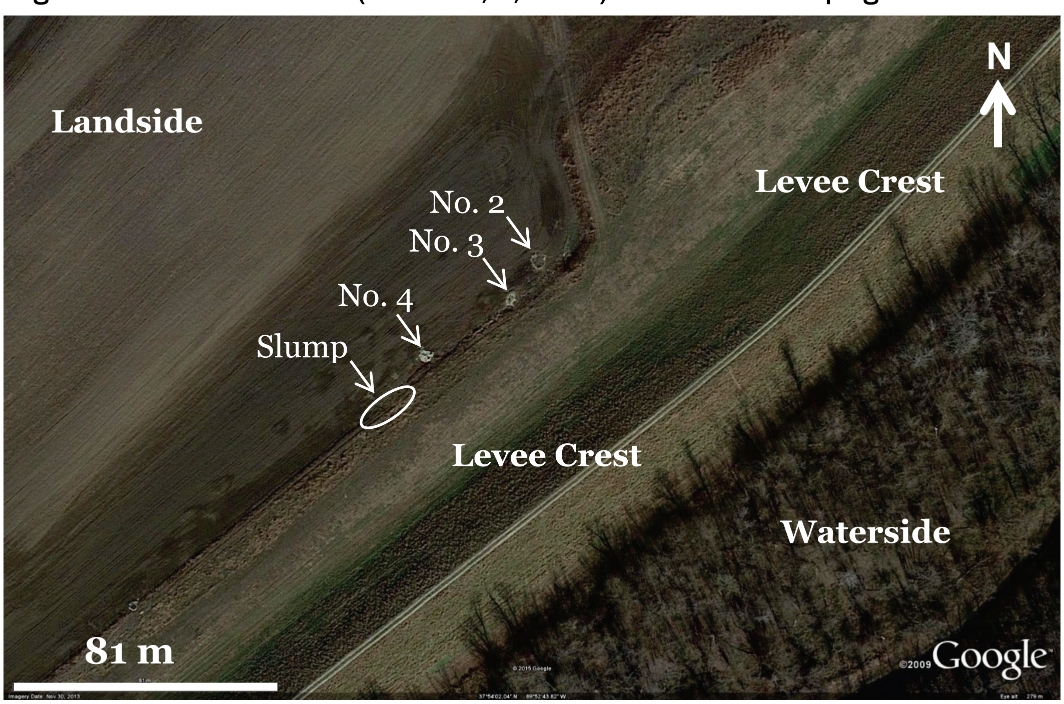
4 Geophysical Surveys

4.1 Method and survey chronology

Geophysical surveys were performed between 22 and 29 July 2014 to image the subsurface conditions at each location. The purpose for the surveys was to determine basic stratigraphic properties of the site, identify any anomalous geophysical signatures that may exist, and characterize the stratigraphy and soils comprising selected large sand boils. Electrical Resistivity Tomography (ERT) surveys measure the resistance to electrical current flow through the earth, which is a function of the electrical properties of the underlying soils and stratigraphy. The primary objectives for these surveys were to provide a two-dimensional view of the underlying stratigraphy at each boil site and to investigate which zones were directly impacted by sand movement in the subsurface.

ERT surveys were made in conjunction with CPT borings. Minor site disturbance resulted from vehicles and foot traffic where wet soils were present. Figure 32 presents a close-up image of the site with the primary features of interest identified.

Figure 32. Three sand boils (labeled 2, 3, and 4) and area of slumping at Kaskaskia.



4.2 Equipment and type of surveys

A total of 14 ERT surveys were conducted at the Kaskaskia Island site. All surveys were collected using a SuperSting R8 electrical resistivity imaging system manufactured by American Geosciences Inc. Equipment used is shown in Figures 33 and 34. All 14 surveys were performed using a dipole-dipole array, using 84 electrodes (Figure 35). These eletrodes were spaced at one of three electrode spacings (0.25 m, 0.3 m, or 0.5 m, or approximately 10 in., 12 in., and 20 in.)

Figure 33. AGI SuperSting in operation over Sand Boil No. 2 at Kaskaskia, looking southwest.

The 14 ERT surveys were conducted in three groupings (Figures 36 and 37) within a larger area (approximately 125 × 30 m, or approximately 410 × 100 ft) that had most recently experienced sand boil activity during the summer of 2013. All ERT surveys were collected on the landside of the Kaskaskia levees.

ERT groupings

ERT surveys were conducted in three groups (Figures 36 and 37).

Figure 34. AGI SuperSting command box, switch box, and power source.

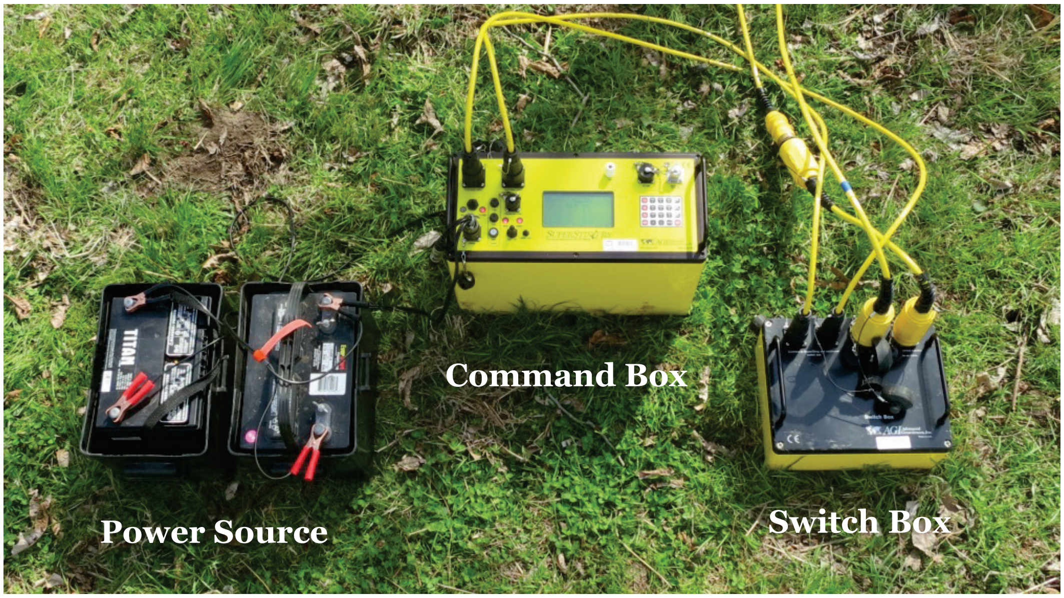
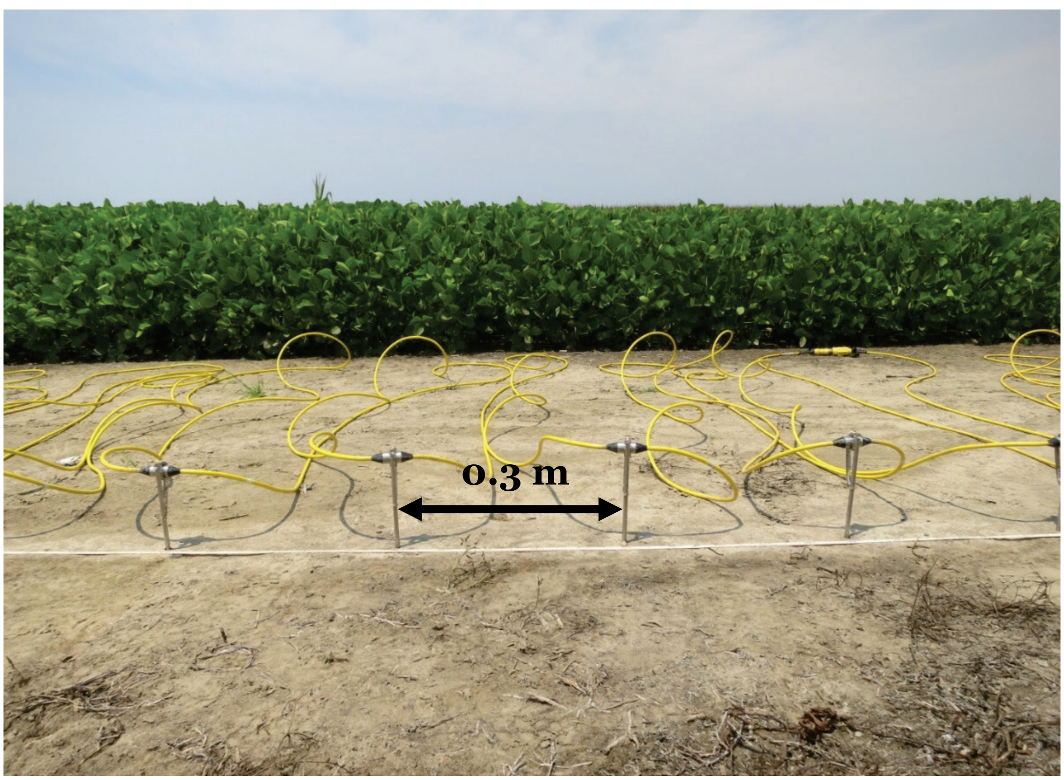


Figure 35. Close-up of SuperSting electrodes in use with 0.3-m (12-in.) spacing at Kaskaskia.



Each group was focused on different features, i.e., two different sand boils and the slump area. For purposes of this geophysical chapter, the two sand boils are referred to as Sand Boil No. 2 and Sand Boil No. 3 (see Figure 32).

A third boil in the immediate vicinity (Sand Boil No. 4) was not studied with ERT.

Figure 36. Location of the 14 ERT surveys conducted at Kaskaskia, July 2014. Surveys are grouped based on the features being studied.

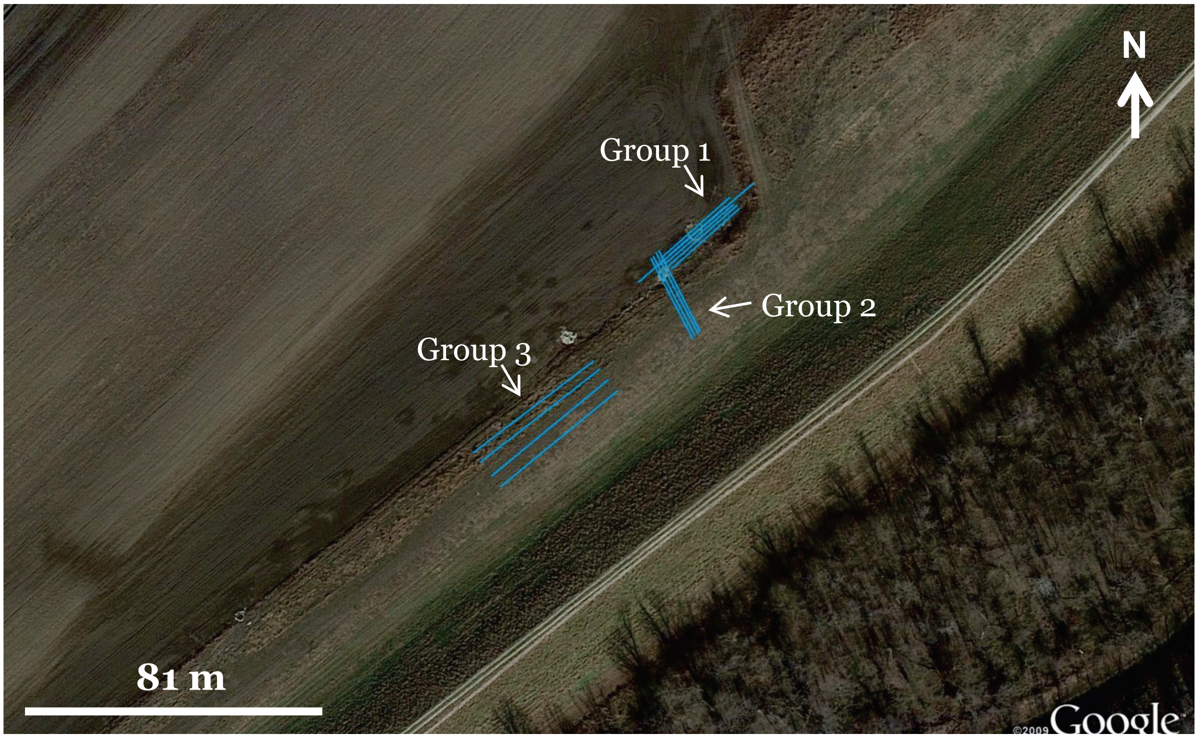
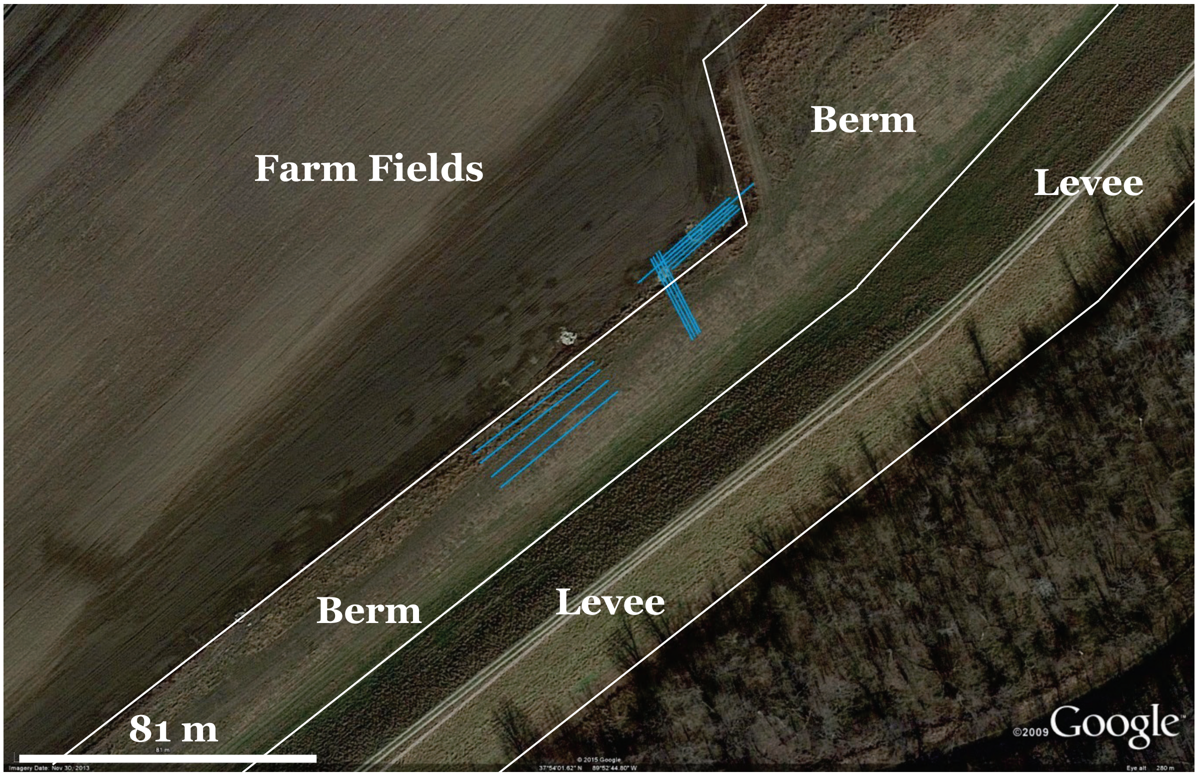


Figure 37. Location of ERT surveys relative to the levee, berm, and farm fields.



ERT Group 1: Six surveys were conducted over Sand Boil No. 2 (Figures 36 and 37). One survey was collected using an electrode spacing of 0.5 m; the northeast end of this survey (electrodes 1 to 8) was located on the edge of the seepage berm to the east (Figure 37). The remaining five surveys were conducted entirely landside of the berm. One of these five surveys was conducted using an electrode spacing of 0.25 m (10 in.), and the other four ERT surveys were conducted using an electrode spacing of 0.3 m (12 in.) All six surveys were collected parallel to the levee orientation.

ERT Group 2: Four ERT surveys were conducted on Sand Boil No. 3 (Figures 36 and 37). All four surveys were conducted using an electrode spacing of 0.3 m (12 in.), and all four surveys were oriented perpendicular to the levee orientation. Approximately two-thirds of each survey line was located on the seepage berm (Figures 36 and 37). The remaining one-third of each survey line was located landside of the berm.

ERT Group 3: Four ERT surveys were conducted over the area experiencing subsidence (Figures 36 through 39). Close-up views of the subsidence area are shown in Figures 38 and 39. All four surveys were conducted using an electrode spacing of 0.5 m (20 in.), and all four surveys were collected on the seepage berm and parallel to the levee.

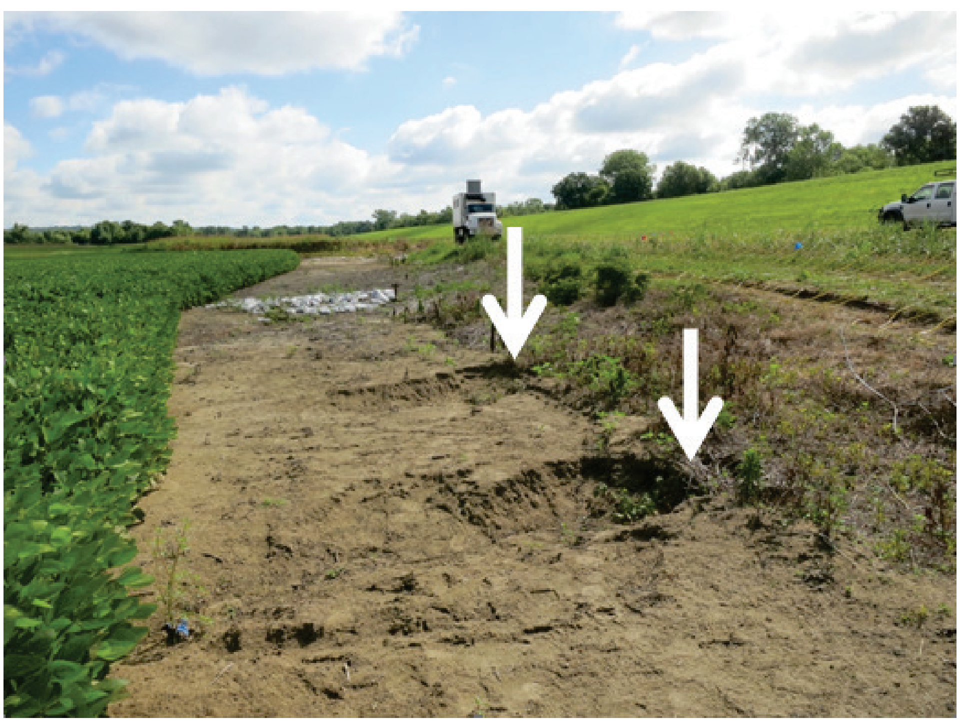
4.3 Inversion process and resistivity sections

RES2DINV inverse modeling software package by GEOTOMO was used to process all resistivity data collected at Kaskaskia to create resistivity sections. The process that develops a resistivity model from the data collected is known as an inversion. An inversion is a non-unique mathematical model or solution to the resistivity measurements that were collected. The model attempts to estimate the limits of the underlying electrical current flow, which is related to inherent properties of the soil, mainly texture, mineralogy, and moisture in the pore spaces.

Electrical current flow in soils involves movement of electrons by direct contact (conduction) and ionic charges (ionic conduction) in the aqueous fluids. The resulting inversion process produces a resistivity model that divides the earth into a discrete number of cells by a gridding process in the software with the possibility of more cells than actual (unique) data values being measured.

Figure 38. A dip in topography along the edge of the berm. ERT survey line K1407291 is shown. This is the ERT survey line closest to the edge of the berm. The other three slump area ERT lines were located progressively closer to the levee in the background (note pin flags in the background).

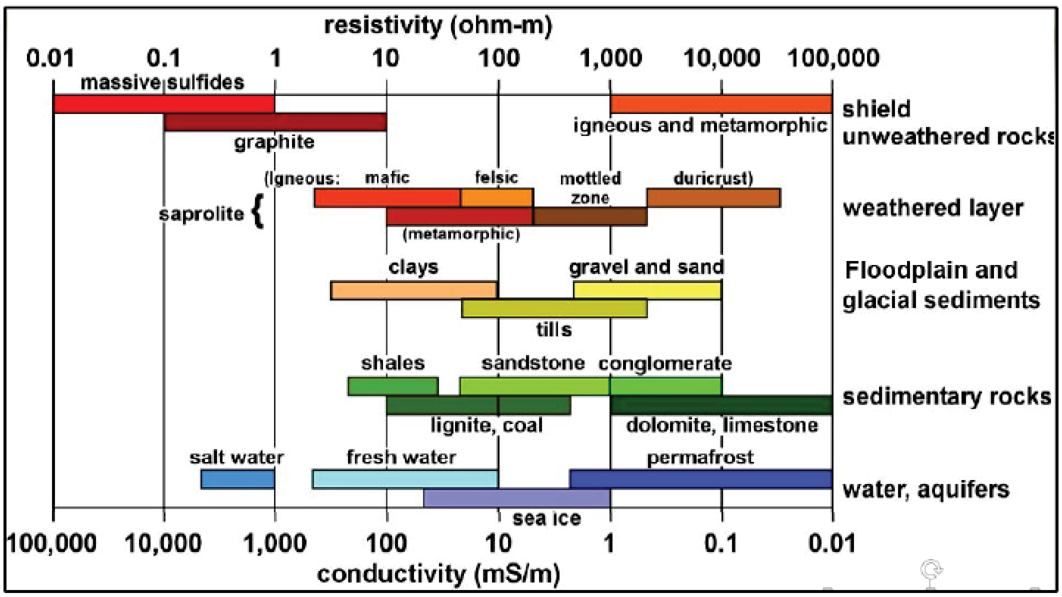
Figure 39. Two areas of slumping and erosion.



Hence, the profile that is produced is described as being an inverse model resistivity section, and the resulting solution represents a best estimate, mathematic model to the half-space measurements collected during the survey.

The inverse model resistivity section (from here on referred to simply as a resistivity section) is often viewed as being an approximation of a stratigraphic or geologic model for the resistance to current flow in the underlying earth. This model generally relates to the soil type, layering, and the stratigraphy present. Resistivity values commonly measured for rock and floodplain soils are presented in Figure 40.

Figure 40. Resistivity values as a function of earth materials (Palacky 1988).



4.4 Resolution

High resolution ERT imaging requires closely spaced electrodes and closely spaced inter-line surveys to characterize subsurface features in any detail. Survey lines collected at Kaskaskia Island involved different electrode spacings (primarily 30 and 50 cm, or 12 and 20 in.) and closely spaced survey lines. The purpose for closely spaced survey lines and electrodes was to observe the subtle changes that occur between the different survey lines and between the individual electrodes themselves. An important concept for geophysical data sets involves target resolution and the number of measurements points needed to discriminate a target of interest from the background media. Ideally, multiple measurement points are needed to image the target in order to separate it from the background media.

An important limitation of high resolution surveys is their shallow depth of penetration due to their closely spaced electrode configurations. To overcome this limitation, wider electrode spacings are used to image deeper into the subsurface (known as long line surveys). Only short line surveys were performed at the Kaskaskia Island site. The primary focus for this study was the shallow near surface and impacts from sand movement through the blanket. Thus, the surveys performed were classified as being short-line surveys.

An analogous concept in resolution occurs in image processing and the idea of pixel resolution involving imagery to resolve features of interest. Ideally, multiple measurements of the target of interest are required from the measurement field to discriminate features and subtle characteristics about the target. For imaging sand boils, being able to discriminate the size, shape, direction, and orientation of the underlying stratigraphy are important parameters of interest to this study.

4.5 Discussion Sand Boil No. 2

Six ERT surveys were made at Sand Boil No. 2 (Figure 41). ERT Survey KA140722 was collected using an electrode spacing of 0.5 m (~20 in.) and has an approximate depth of investigation of 10 m (~33 ft). This survey identifies three major stratigraphic layers beneath Sand Boil No. 2 as identified by Figure 42.

The topmost layer has the lowest resistivity and extends from the surface to a depth of 2.5 m. The second layer extends to 6.25 m depth. The third layer extends to the maximum depth of investigation and has a slightly lower resistivity than layer 2 but a higher resistivity than layer 1. In terms of layering of the point bar deposits being surveyed, the resistivity section identifies a well-defined, low conductivity, top stratum (layer 1), underlain by less conductive substratum sands and gravels (see geological cross section in Figure 14). The substratum, or aquifer sand, is composed of two measurably distinct layers in terms of their resistivity values. This difference may be due in part to river stage and groundwater elevation as it affects the saturation level of the sediments in the aquifer. As previously noted, electrolytic conduction is an important part of current flow and can directly impact measure values.

Figure 41. Close-up of the six ERT surveys conducted in the vicinity of Sand Boil No. 2 with survey file names identified.

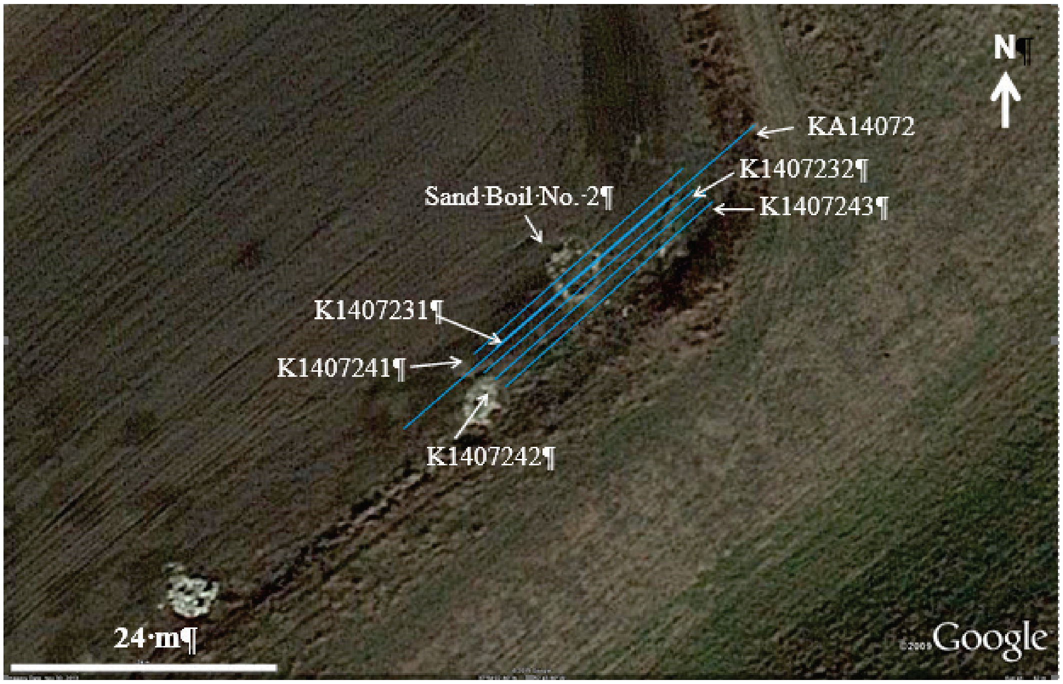
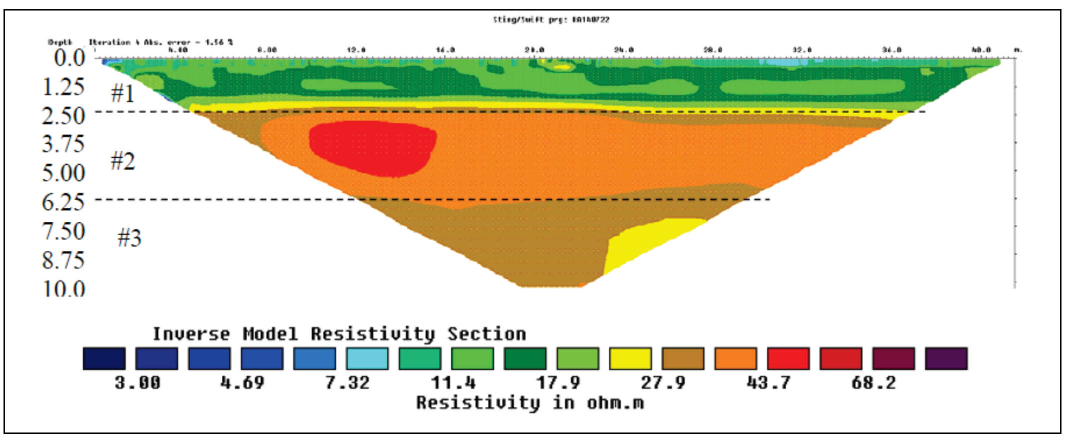
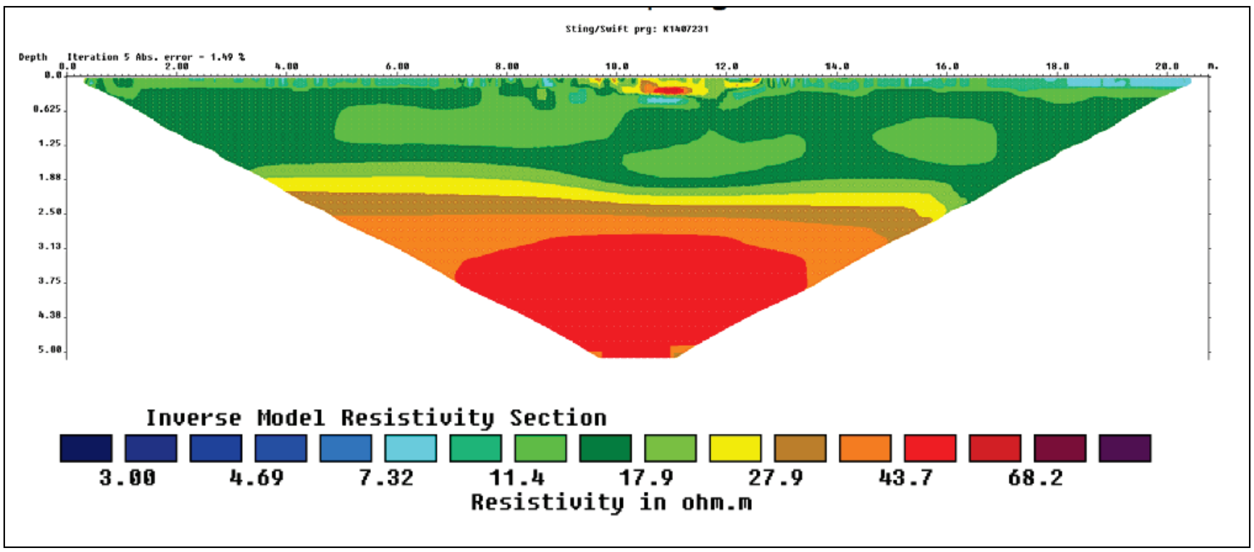


Figure 42. ERT File KA140722. Representative ERT inversion results for Sand Boil No. 2 identifying three major stratigraphic layers. Electrode spacing 0.5 m.



For the remaining five surveys in the vicinity of Boil No. 2, each used a shorter electrode spacing. Four of these surveys used an electrode spacing of 0.3 m, and the fifth survey used an electrode spacing of 0.25 m. The smaller electrode spacings have a shallower depth of investigation, at 6 and 5 m, for the 0.3 m and 0.25 m spacings, respectively. Thus, these shorter surveys measure only the upper two layers. The third or deeper layer does not appear due to the shallower depth of investigation; however, the shorter electrode spacing has a much higher spatial resolution and identifies the upper most layer as being composed of two measurably distinct layers in terms of their resistivity values, designated as 1a and 1b for discussion purposes (see Figures 43 and 44). Figures 43 and 44 correspond to the same resistivity section except for the color table presented. The different color tables aid in layer and feature identification. Layer 1a extends to a depth of 0.2 m and has a resistivity of ~7.5 Ohm-m. Layer 1b is located below, between 0.2 m and 2.5 m depth, and has a resistivity of 12.9 to 17 Ohm-m.

Figure 43. ERT File K1407231. Representative ERT inversion results for Sand Boil No. 2. Electrode Spacing 0.3 m.

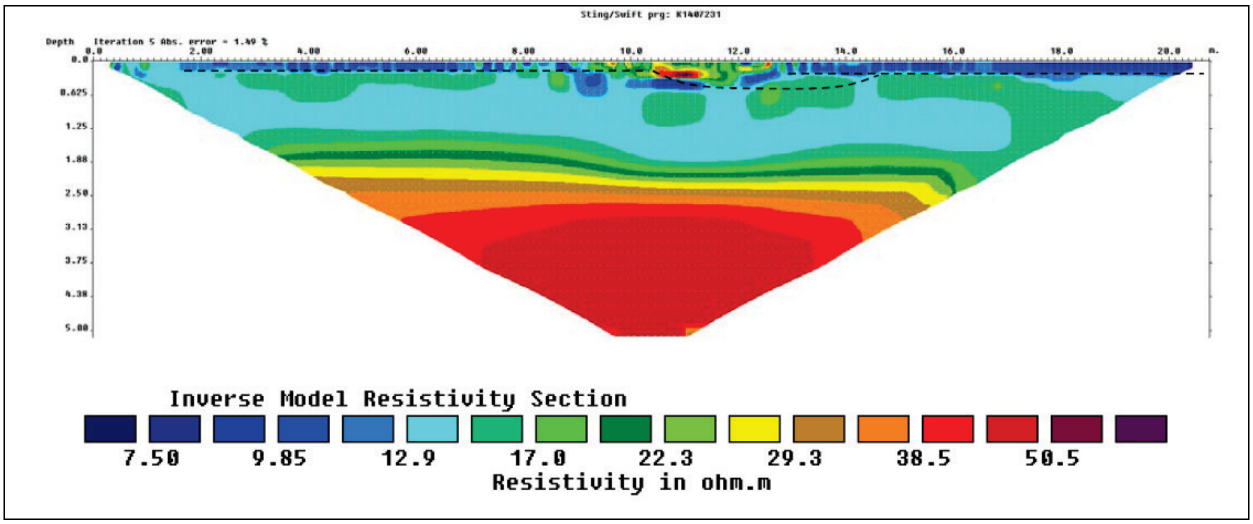


Both of the resistivity sections shown in Figures 42 and 43 identify an area of higher resistivity at the location of the sand boil to a depth of ~0.6 m. Survey K1407231 depicted in Figures 43 and 44 used an electrode spacing of 0.25 m. The measured values clearly show much higher resistivity (27 to 50 Ohm-m) below the boil area than the surrounding top stratum not immediately affected by the sand boil.

Layer 1a identified in Figure 43 dips beneath the sand boil as evidence by the layering between position 10 to 12 (see top of inversion section for stationing). The model results obtained from the inversion process also show the possible presence of a “feeder pipe” beneath electrode position 12. Resistivity values obtained from within the sand boil area match the sandy nature of the ejecta soils, confirmed by the ejecta samples obtained from this boil and others nearby (Table 1). Silt and silty sand samples were obtained from the throat of this sand boil.

The presence of a feeder pipe through the top stratum is not clearly defined with depth.

Figure 44. ERT File K1407231. Representative ERT inversion results for Sand Boil No. 2. Electrode Spacing 0.3 m. Alternate color scale presented here showing low resistivity layer (~7.5 Ohm-m) extending from the surface to a depth of ~0.2 m on both sides of the boil. Base of Layer 1a corresponds to dashed line. Same resistivity section as Figure 43 except for different color table. At the boil location, there are low-resistivity values that dip below the highly resistive sand boil ejecta (~50 Ohm-m).

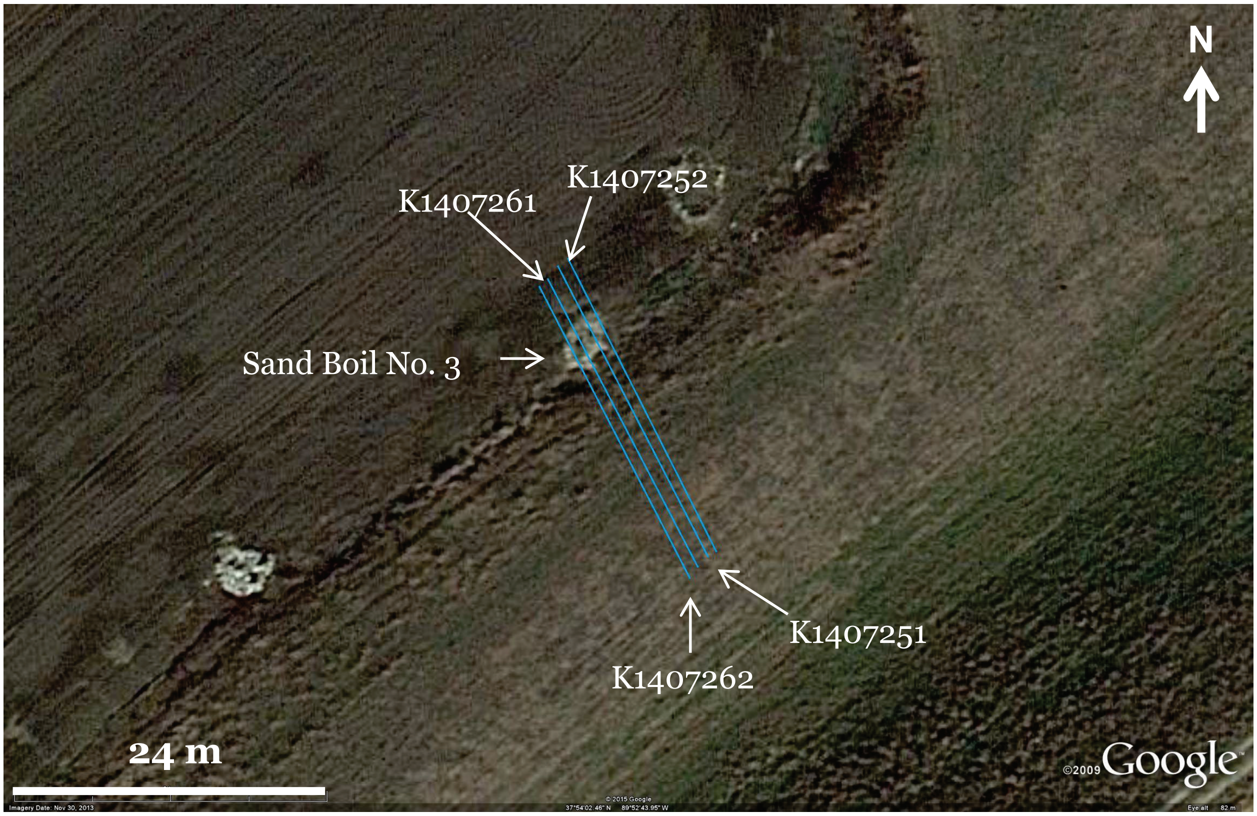


This lack of detail with increasing depth is possibly due to the spatial resolution of the target in terms of the volume of the top stratum being measured and the limited size and extent of the feeder pipe itself with depth. Another contributing factor is the orientation of the feeder pipe with orientation of the survey section. It is often assumed that the pipe is vertical but may in fact follow horizontal bedding planes and/or other defects that are inclined from the vertical and even follow horizontal flow paths for short distances. This pipe orientation would be masked with depth in terms of resolution, especially as the pipe distance increases from the plane of the survey.

4.6 Discussion Sand Boil No. 3

Four ERT surveys were made in the vicinity of Sand Boil No. 3 as shown by Figure 45. All four surveys were conducted using an electrode spacing of 0.3 m (12 in.), and all four surveys were oriented perpendicular to the levee orientation. The surveys extend from the natural floodplain surface to the 150-ft-wide seepage berm. Farming extends only to the seepage berm toe (Figure 37).

Figure 45. Close-up of the four ERT surveys made in the vicinity of Sand Boil No. 3 and survey file names.

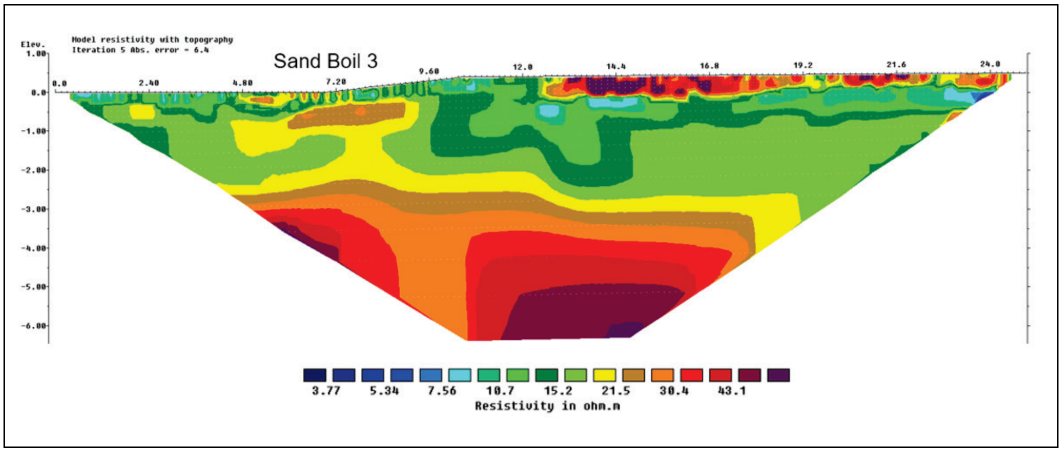


A representative resistivity section from these four surveys is presented in Figure 46 (profile K1407262). Inversion results show noticeable disturbance of the top stratum directly below the boil area, which is ~5 m wide and 2 m deep. The area affected by the sand boil has a much higher resistivity signal than the surrounding top stratum soil, corresponding to the green-colored layer, with resistivity values of 8 to 10 Ohm-m in Figure 46.

The top stratum is fairly thin at this location, approximately 2 m (7 ft) thick, which is one of the primary reasons for the poor performance at this location. Boil ejecta corresponds to sand and silt (Table 1) with resistivity values in the yellow and brown color range (20 to 30 Ohm-m) in Figure 46. The resistivity section in Figure 46 is a representative geological model of the existing conditions, a resistive vertical pipe that pierces the top stratum and extends to the surface.

A thin top stratum and shallow substratum sands are present at this location as evidenced by the existing boring data (Figure 14) and CPT obtained during this study that are described and presented in the next chapter.

Figure 46. ERT File K1407262. Representative ERT inversion results for Sand Boil No. 3.



The resistivity profile in Figure 46 extends onto the seepage berm and is interesting because of the presence of a resistive (>30 Ohm-m) layer at the surface. The levee designers intended for the berm to be pervious as evidenced by the nearly 1 m (3 ft) of resistive soils (sands) overlying the top stratum (or blanket) foundation beneath the levee. A common practice to control underseepage at the landside levee toe was the addition of a pervious seepage berm (USACE 1956a, 1956b; Moore 1972).

4.7 Discussion slump area

Four ERT surveys were made at the slump area (Figure 47). Two of the resistivity sections are presented as Figures 48 and 49 (K1407292 and K1407291, respectively). These sections are from the center of the surveys and at the edge of the levee berm as shown by their location in Figure 47. The first ERT section in Figure 48 (K1407292) identifies a fairly resistive thin layer 0.5-m (1.5-ft) thick overlying a thin top stratum (dark green layer is base of top stratum in Figure 48). The resistive layer corresponds to the pervious seepage berm overlying the natural floodplain soils.

Closer to the edge of the berm, the ERT section in Figure 49 shows that the resistive layer is much thicker at 1.25-m (4-ft) thick. The survey extends onto the natural floodplain surface at the center of the section and again images through the pervious seepage berm at the western edge of this section.

Figure 47. Close-up of the four ERT surveys conducted in the vicinity of the slump area with survey names identified. Note the previous sand boil activity as reflected by wet areas to the northwest of the bagged boils shown.

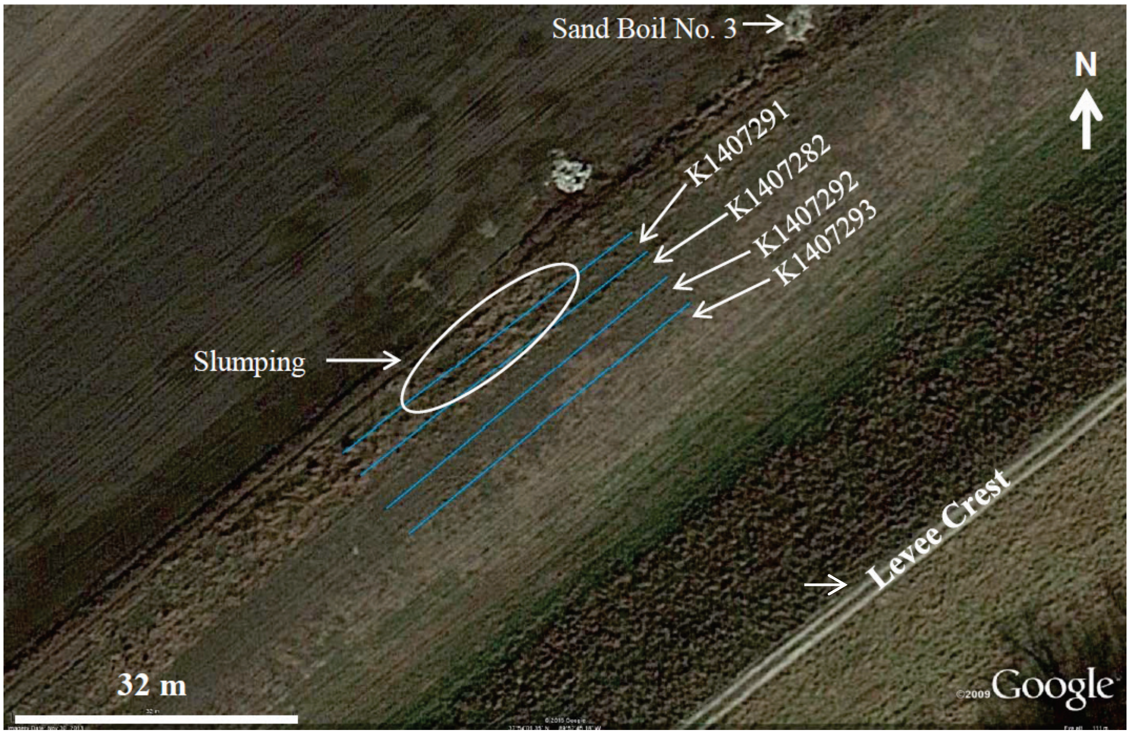
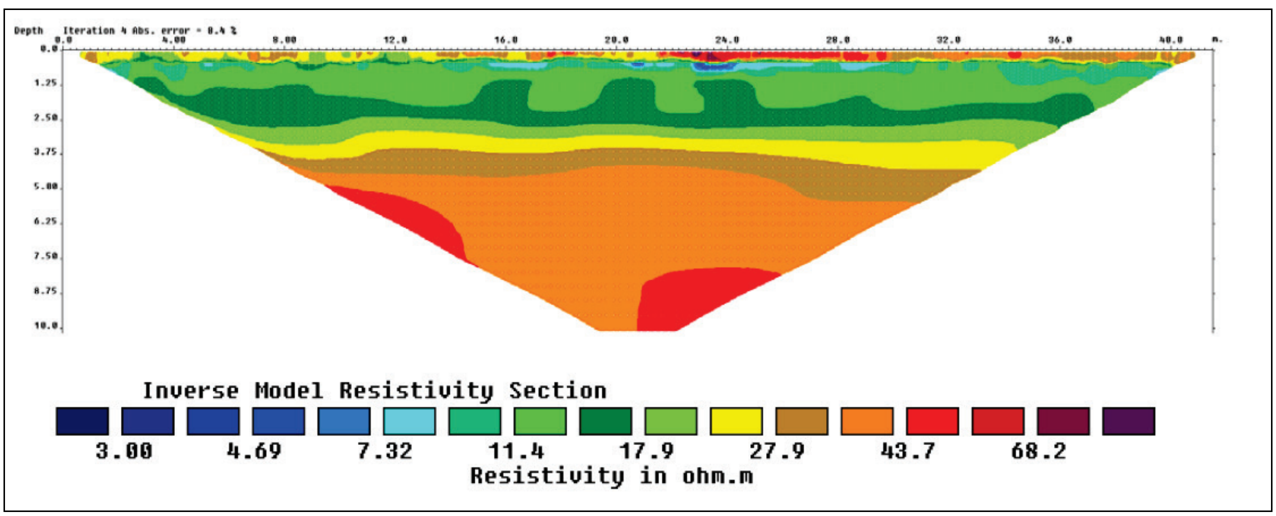


Figure 48. ERT File K1407292 ERT survey along berm near slump area.



Figures 38 and 39 previously referenced are views of the landside toe of the seepage berm with prominent elevation and erosion features identified. The view in Figure 39 is looking toward the east behind the levee and shows minor depressions and erosion due to seepage exiting from the previous seepage layer onto the floodplain surface. A fairly common sight along this reach is the presence of minor rills that extend from the edge of the berm (Figure 50).

Figure 49. ERT File K1407291. ERT inversion for survey closest to berm edge and crossing slump. The location of the topographic dip is noted in Figure 6.

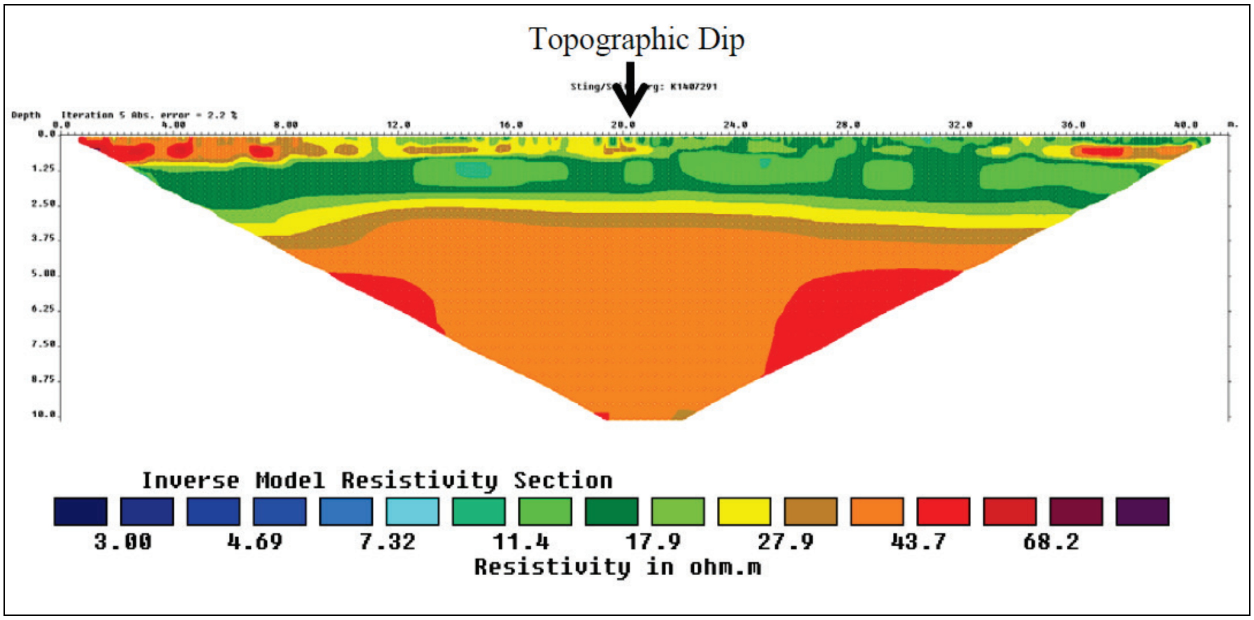


Figure 50. Almost evenly spaced drainage rills at edge of seepage berm. Photograph during January 2016 Flood.

4.8 ERT conclusions

ERT results identify anomalous high resistivity values directly below sand boil features at Kaskaskia Island to a maximum depth of approximately 3 m. Imaging of selected sand boils identifies vertical pipes and noticeable disturbances in the stratigraphy through the top stratum where sand boils are present. ERT results identify a thin top stratum (blanket) in this reach between 2 to 2.5 m (6.5 to 8 ft) thick. Ejecta samples obtained from sand boils indicate the soil texture is composed of silt to silty sand. This soil texture is confirmed by visual observation and laboratory soil testing.

The source of the ejecta based on ERT results, visual observation, and laboratory classification of ejecta samples obtained during the preliminary reconnaissance survey (Table 1) is identified as an upper point bar. This finding is consistent with the idealized sand boil model shown in Figure 16 and accurately portrays a point bar depositional model representing a fining-upward soil texture sequence. The orange layer in Figure 16 corresponds to silt and sand that is deposited by the meandering river and forms a diagnostic ridge and swale topography (Figure 15). Hydraulic fracturing of the thin blanket occurs during moderate to major flood events and results in upward mobilization of the silt and fine sand, where it is transported to the surface by artesian pressure that are built up beneath the blanket.

ERT surveys performed on the berm at the landside toe of the levee reveal the pervious nature of the berm itself, which was likely designed to relieve seepage pressure to safeguard the levee toe against internal erosion. Pervious seepage berms are a common design feature for protecting the levee against internal erosion. Seepage from this pervious berm has formed evenly spaced rills at the edge of the berm where seepage is exiting onto the landside, which is a farming area. This condition is further enhanced by the presence of a swale (low spot) that occurs at the toe of the levee.

5 CPT Results

5.1 Introduction

CPT data were collected between 28 April and 2 May 2015 at three areas and at a control site at Kaskaskia Island to characterize the soils and stratigraphy beneath these targeted locations (Figure 19). A total of 71 CPTs were pushed at Kaskaskia Island as part of this study. CPT soundings ranged from less than 10 ft (3 m) up to 70 ft (21.3 m) in depth. CPT logs obtained from Kaskaskia Island are presented in Appendix B. Soil types identified on each log in Appendix B are based on empirical relationships developed by Robertson et al. (1986) for cone-tip resistance and sleeve friction. CPT technology has been extensively used for delineation of soils and stratigraphy for engineering purposes.

The following discussion of the CPT data is described in the order of their drilling and is presented in Appendix B in this order. Targeted studies were performed in three main study areas at Kaskaskia Island. The vast majority of CPTs were pushed in area No. 3 as multiple large sand boils were present within this reach, and it was determined that this area contained multiple features of interest to evaluate. A summary of drilling activities in each area is described.

5.2 Study Area No. 1

Three CPTs (KAS-01-14C through KAS-03-14C, Appendix B) were pushed landside of the levee and adjacent to the 1993 levee breach area to determine the general nature of the top stratum or blanket thickness and the character of the lithology within this reach (Figures 21 and 22). Remediation of the levee breach after the 1993 Flood was accomplished by hydraulic dredge fill.

CPTs were pushed to 50 ft below the ground surface. Blanket thickness adjacent to the levee breach area ranges from 5 to 18 ft. The top stratum is underlain by substratum or aquifer sands. The blanket is composed primarily of stratified clay and silty clay. Substratum sands are composed of mixed silty sand and sand. CPT data obtained from this area are consistent with the geologic cross section presented in Figure 14; however, CPT data were used to identify localized thin zones in the blanket thickness as compared to the generalized section in Figure 14 incorporating 1956a-era boring data.

5.3 Study Area No. 2

Four CPTs (KAS-04-14C through KAS-07-C, Appendix B) were pushed at the landside toe of the levee along the reach where Sand Boil No. 1 was located (Figure 23). Additionally, CPT KAS-20-14C was pushed adjacent to the Sand Boil No. 1 to determine specific conditions beneath this boil. All of the CPTs in study area No. 2 were pushed 50-ft deep.

The blanket beneath the large sand boil shown in Figure 18 was 10-ft thick and was composed of fairly uniform clay based on CPT results. Throughout this reach, the blanket ranges from 5 to 15 ft as determined from the four nearby CPTs in the No. 2 study area. Silty sand and sand form the aquifer beneath this reach to a minimum depth of 50 ft. The boil is located between borings 348 and 202 in the geologic cross section in Figure 14, which identifies a thicker blanket than measured by the CPTs pushed for this study.

5.4 Study Area No. 3

Fifty-eight CPTs were pushed in area No. 3. These CPTs were pushed at two different locations in this study reach. Twenty-eight CPTs were pushed in the reach where two large active sand boils were present in 2013 (Figure 25). The remaining 29 CPTs were pushed in the slump area (Figure 26). CPTs pushed in the sand boil area are labeled with a “B” proceeding the CPT No. in Appendix B while CPTs that were pushed in the slump area are labeled with a “G” proceeding the CPT No. in Appendix B.

In both areas, CPTs were pushed both on the floodplain and the berm surfaces. No CPTs were pushed through the levee centerline. Blanket thickness (including the berm) in the vicinity of the large diameter sand boils varies from 9 to 13 ft (2.7 to 4.0 m). CPT data from the sand boil and slump areas are individually and collectively described further following presentation of CPT data in the control area.

5.5 Control area

Four CPTs were pushed at a location where no sand boil activity was witnessed, which was designated as the control area (Figure 27) for reference purposes. CPTs in the control area are designated with a “C” proceeding the CPT No in Appendix B. CPTs C3, C7, C10, and C16 are located approximately 1,500 ft southwest of the slump area as shown by Figure 27. CPT C3 is located at the edge of the berm on the floodplain surface and was used to identify a fairly thick blanket despite two relatively shallow sand layers near the surface (see CPT C3 in Appendix B). The top of the substratum sands is fairly deep at this location, with depth to the aquifer sands being nearly 20 ft below the ground surface. The thickness of the top stratum in the control area is related to the underlying depositional environment, which is further described.

5.6 Blanket thickness and top stratum elevation

A digital elevation model (DEM) through the control area and the sand boil area (sand boils No. 2 and 3) is presented in Figure 51 showing a color-coded relief model representative of this area. CPT C3 is located on the floodplain surface, along the edge of a large swale that is nearly parallel with the axis of the levee. The thickness of the blanket at CPT C3 is more than 20 ft. The depth to substratum deposits is influenced by the presence of the prominent swale landside of this CPT.

The swale represents a low-lying area situated between adjacent sandy ridges formed by the migration of the old river channel across its valley. The ridges are easily recognized in the DEM in Figure 51 by their light-green to green color. A generalized cross section in Figure 52 shows the variable nature of the landside top stratum thickness in profile. The control area is in the center part of the cross section corresponding to CPT C3. Northeast of this location is the slump area and the two prominent sand boils, which are the focus of this study. The blanket is relatively thin beneath the slump and sand boil areas.

A generalized contour map of the top stratum is presented in Figure 52. Values shown in Figure 52 include the berm thickness. Sand boil and slump areas generally have a blanket that is 11 ft or less in thickness extending away from the edge of the berm as shown by Figure 53.

A contour map showing the elevation of top of the substratum or alluvial aquifer beneath the slump and sand boil areas is presented in Figure 54. The elevation map identifies the “ridge-like” topography of the aquifer sands beneath the top stratum in this reach. This expression is characteristic of the point bar environment with the ridge and swale topography.

Figure 51. DEM of area No. 3 showing general relief behind the levee alignment (yellow to red), point bar ridge (light green) and swale (dark blue), and relic channels (dark blue). Cross section A-A′ extends from southwest to northeast (Figure 52).

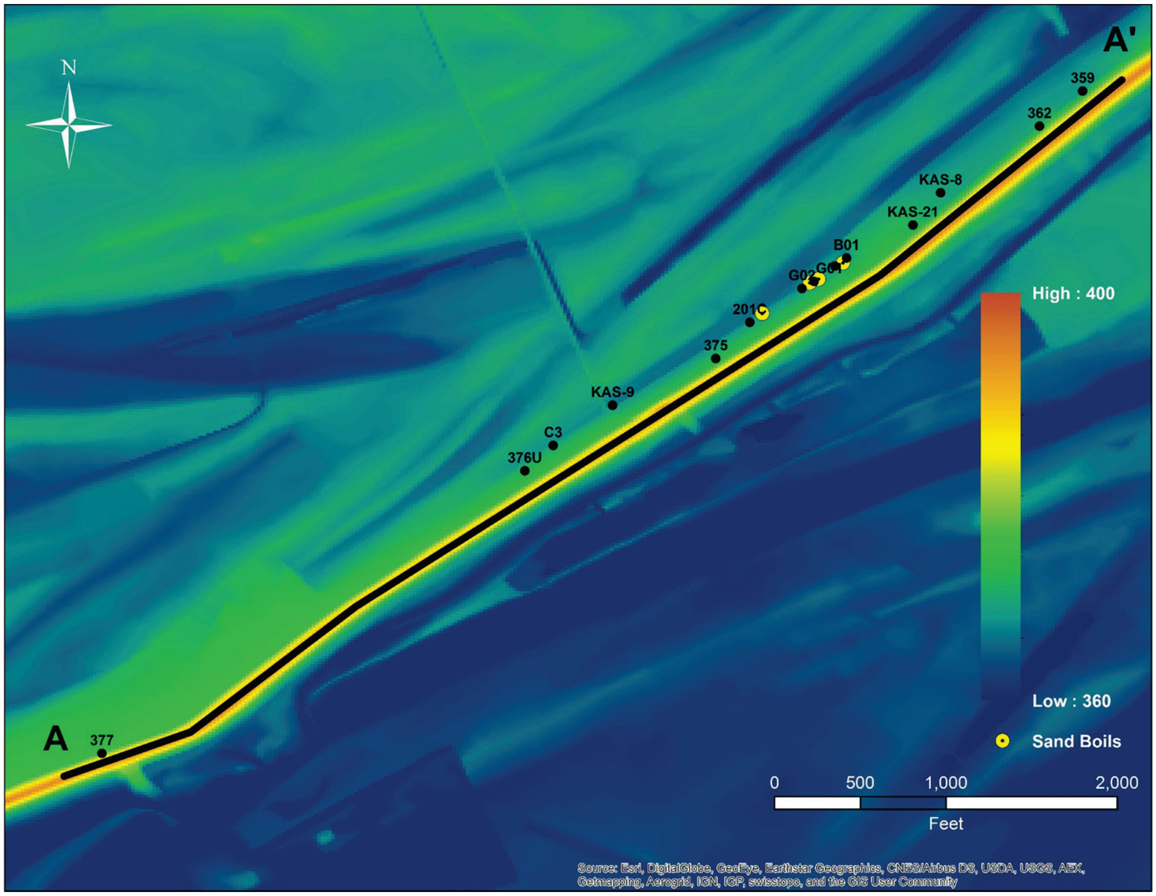
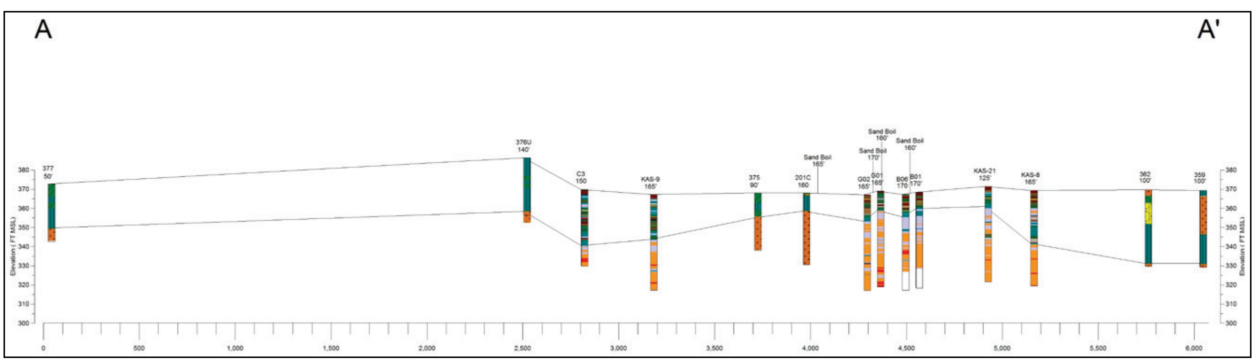
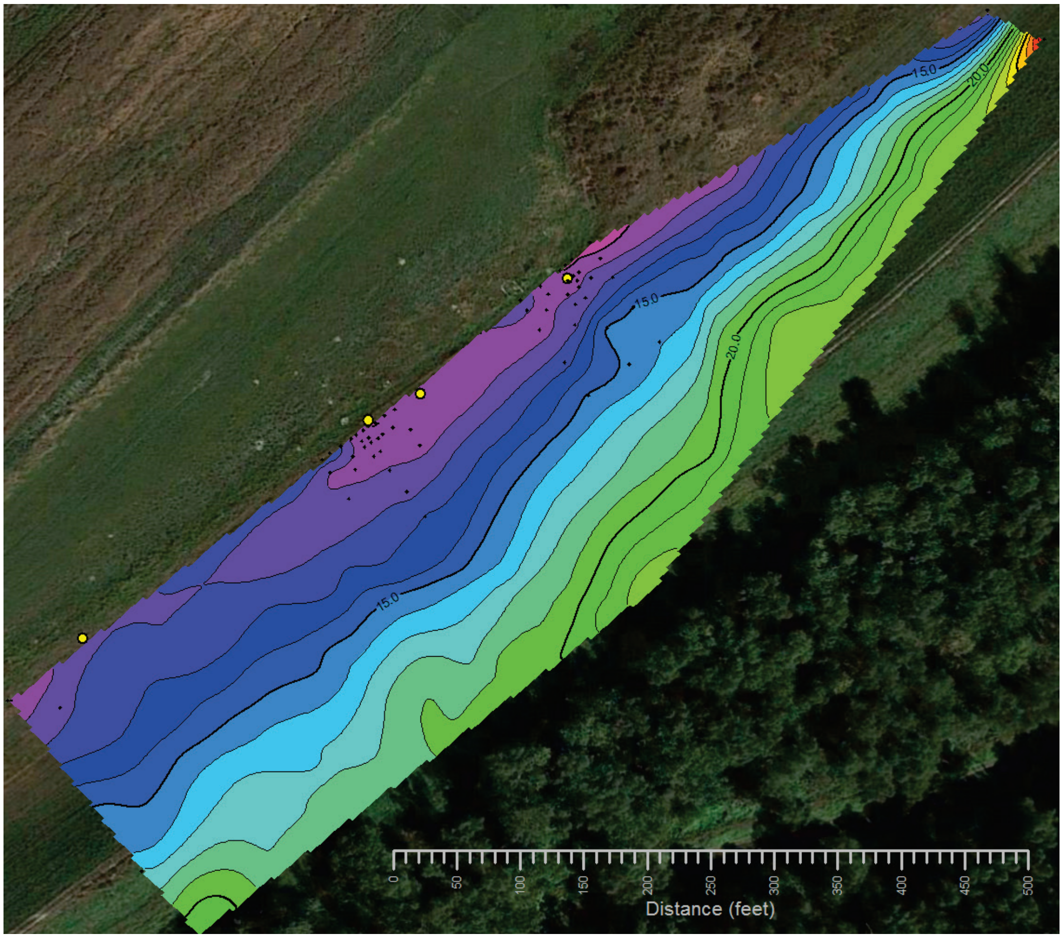


Figure 52. Cross section A-A′ along study area No. 3 and CPT C-3.



Again, this topography is easily recognized by the color-shaded DEM in Figure 51 where the ridges intersect the surface as shown by the light green color.

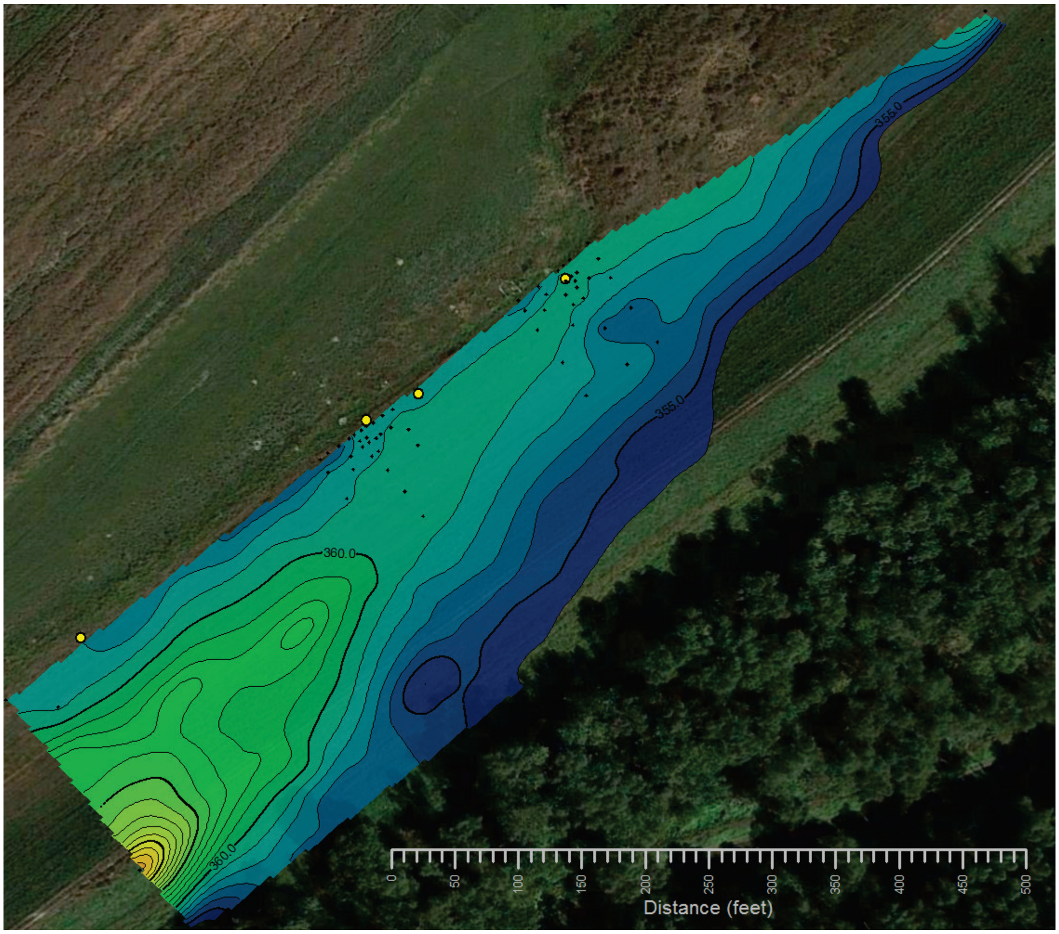
Figure 53. Thickness map of the top stratum (blanket) from CPT and existing boring data at 1-ft contour interval. Values shown include the berm thickness; however, thickness of the levee embankment is not included as no CPTs were pushed through the body of the levee.



5.7 Slump area close-up

A close-up examination of the soils and stratigraphy present in the slump area is described based on closely spaced CPTs and soil profiles derived from these soundings. Included with the thickness map of the blanket using only the CPTs from this site are the locations of the cross sections referenced in this discussion (Figure 55). The thickness of the top stratum along the natural floodplain, i.e., no berm or levee, surface is 10 ft or less. Closely spaced CPT-derived soil stratigraphy sections are presented in Figures 56 through 59 corresponding to sections B-B′, C-C′, D-D′, and E-E′, respectively, which show the top stratum and aquifer profile at these different locations.

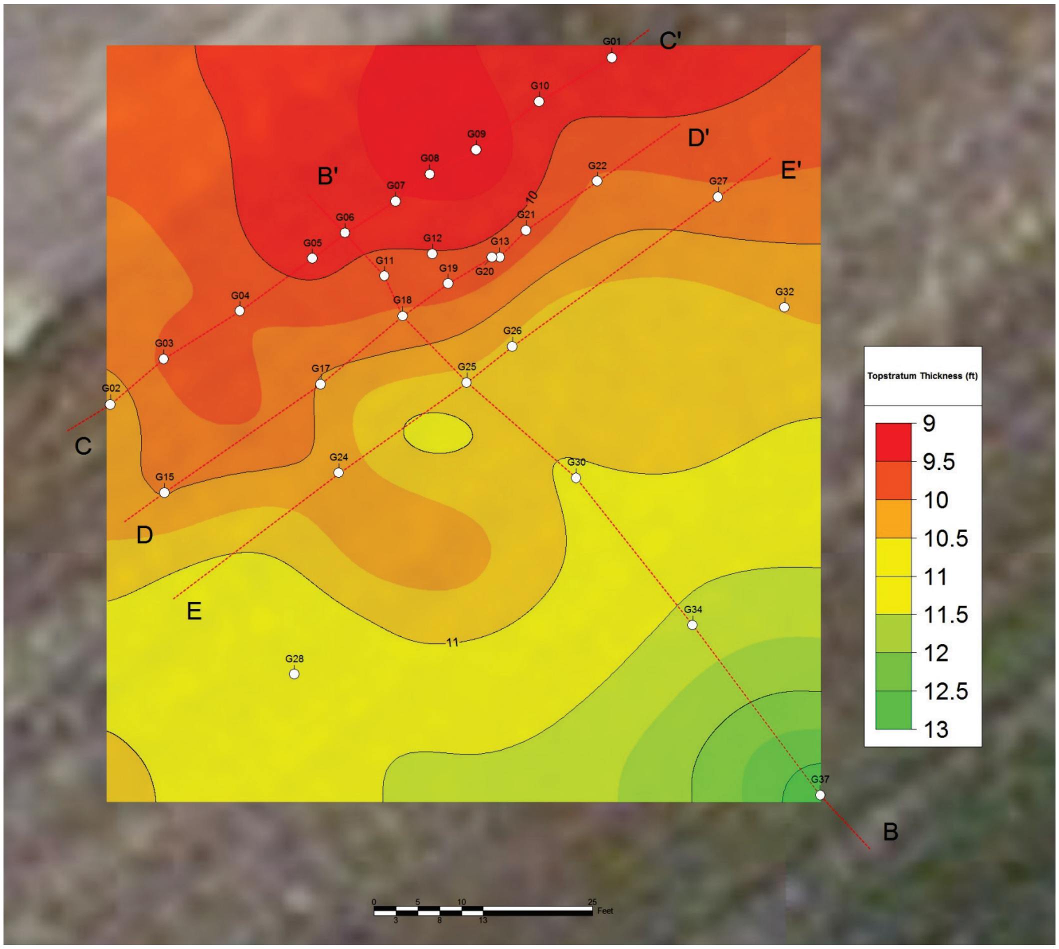
Figure 54. Elevation of the top of the substratum (alluvial aquifer) at 1-ft contour interval.



These different cross sections are informative by showing variations in the soils and the stratigraphy in this reach. Section B-B′ (Figure 56) extends perpendicular to the orientation of levee and shows the distribution of soil type horizontally based on CPT values involving sleeve friction and tip resistance of the pushed cone using the classification of Robertson et al. (1986).

The B-B′ profile identifies a sensitive fine-grained zone that occurs at the edge of the berm and beneath the top stratum, corresponding to the light-gray color soil type in the section. This soil is fairly pronounced in section C-C′ (Figure 57), which is located at the edge of the berm, on the natural floodplain surface, and parallel with the levee orientation; however, this soil type becomes less noticeable on section D-D′ (Figure 58), which is on edge of the berm but still relatively close to the floodplain. This soil type is present in only two CPTs (G19 and G21) in this section.

Figure 55. Locations of closely spaced CPT sections and thickness map of top stratum in feet.



5.8 Sensitive fine-grained soil type

Examination of the CPT data in Appendix B identifies a sensitive fine-grained soil type to be fairly common in the majority of CPTs that were pushed on the natural floodplain surface. This soil type is less common in the CPTs located on the edge of the berm and disappears completely closer to levee.

The distribution of the sensitive fine-grained soils is especially telling in the B series CPTs that were pushed in the vicinity of the sand boil areas in Figure 60. These CPTs showing this soil type are favorably orientated to Sand Boils No. 2 and 3 as shown by the cyan-colored locations in Figure 60.

A similar distribution is observed in the G series CPTs from the slump area in Figure 61.

Figure 56. CPT section B-B′ perpendicular to levee orientation.

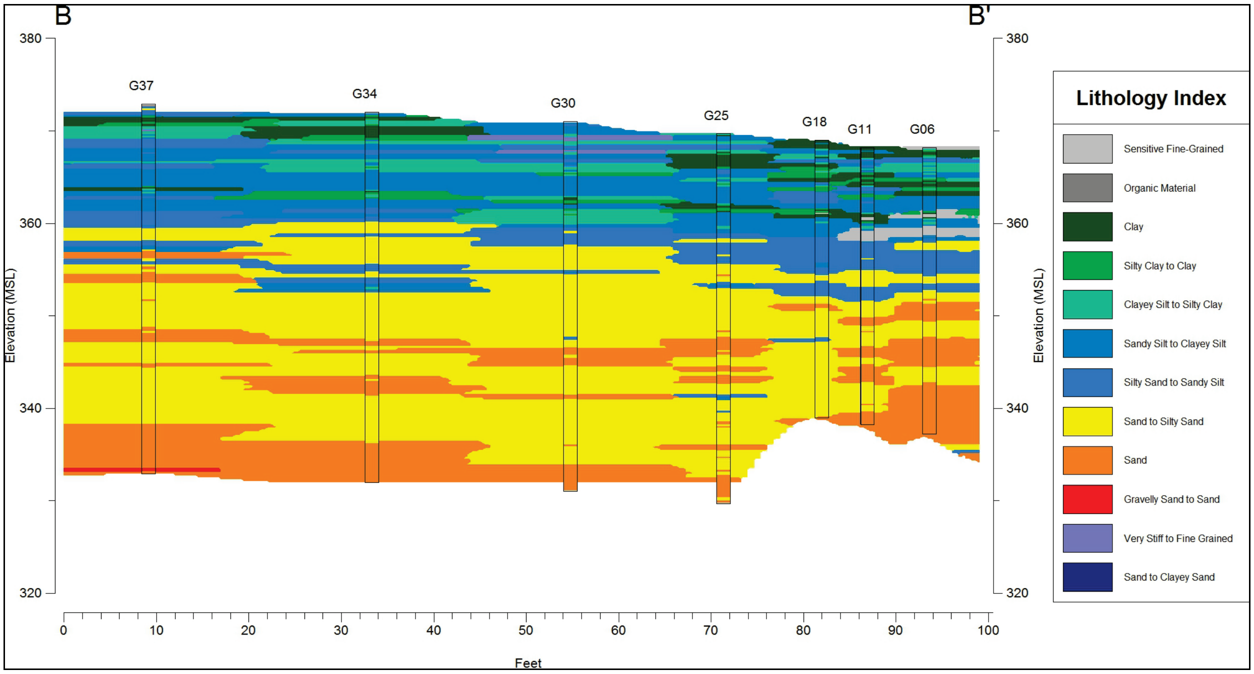


Figure 57. CPT section C-C′ parallel to levee orientation at the edge of the berm.

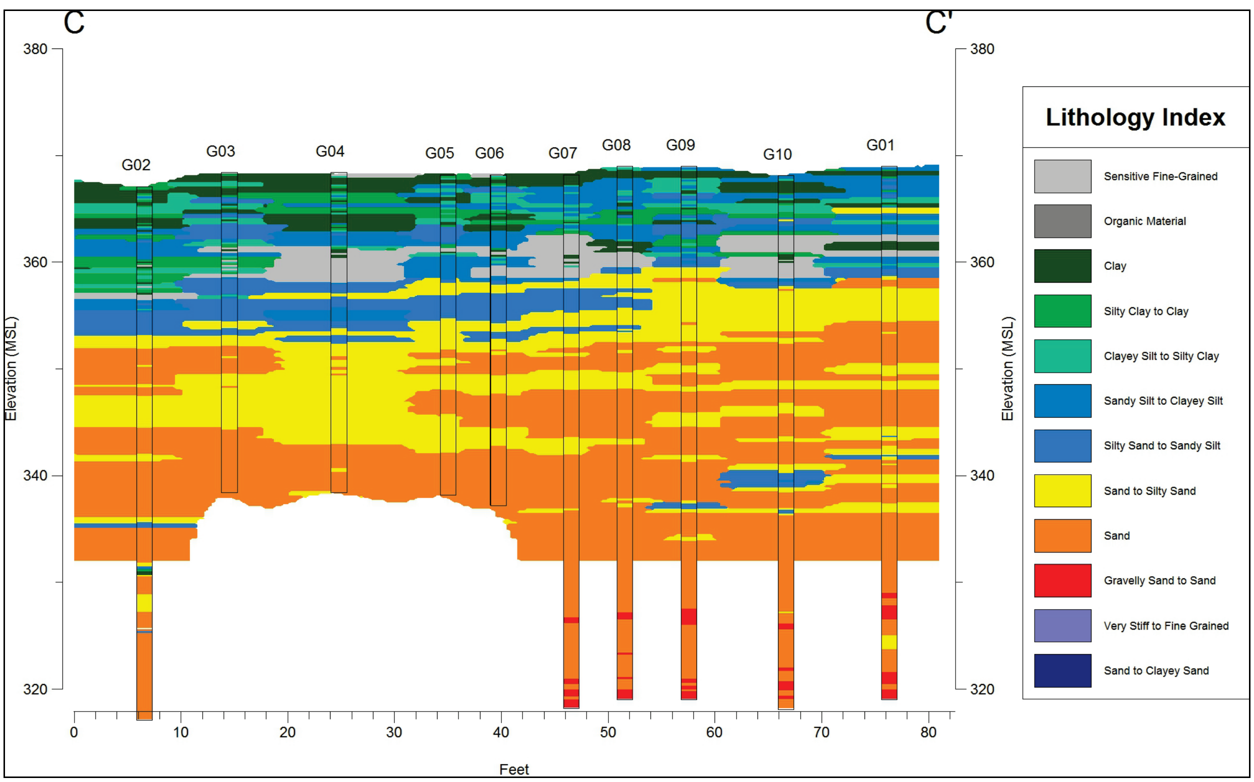
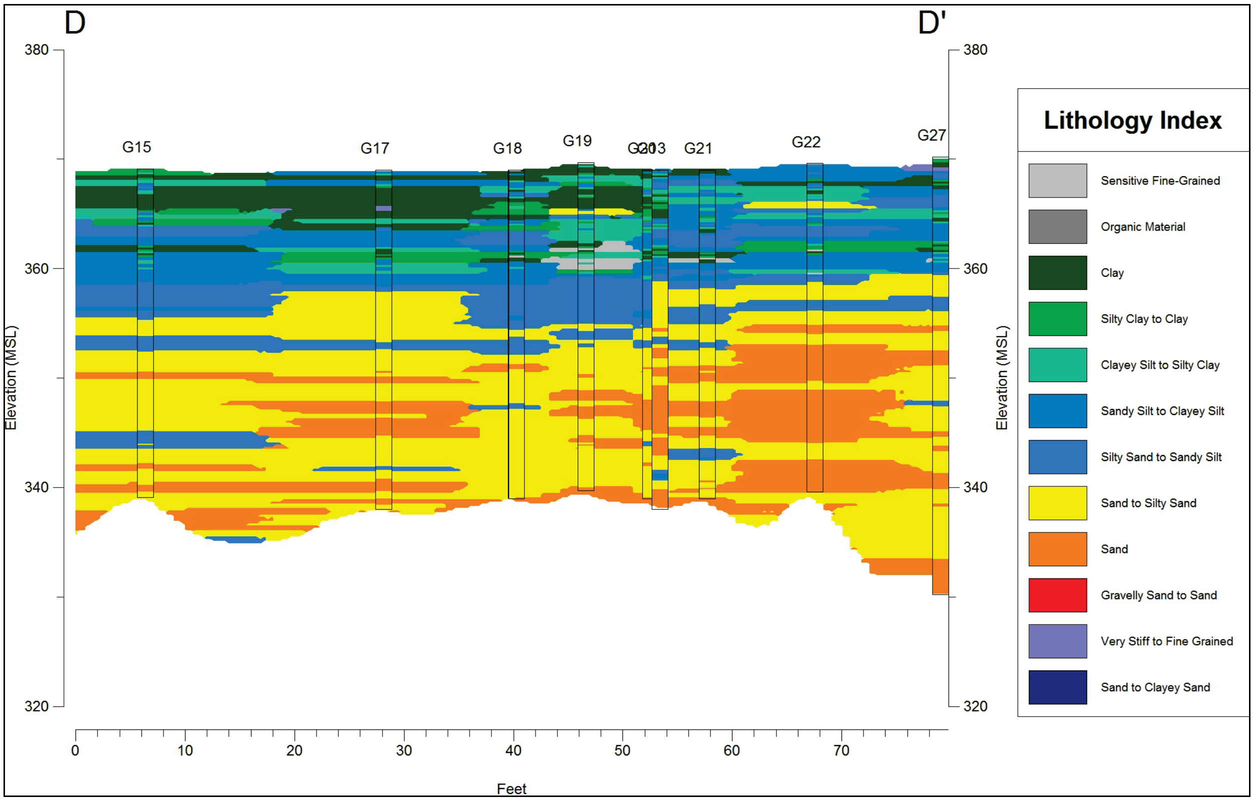


Figure 58. CPT section D-D′ parallel to levee orientation on the berm.



These CPTs are almost exclusively located at the edge of the berm with the exception of G19, 21, and 26. These CPTs only contained a trace interval where this soil type was present.

The thickness of this layer is variable in both the B and G series CPTs where present. The maximum thickness in the G series CPTs was almost 5 ft in CPTs G7 and G10. In the B series CPTs, the maximum thickness was observed at B8 at almost 3 ft. The typical range in thickness in the B and G series CPTs varies between 0.5 to 2 ft.

The depth where this layer was encountered was not uniform in the CPTs that measured its presence. The depth was variable between 5 and 9 ft where first detected.

5.9 Significance of sensitive layer

The significance of this soil type requires a brief review of the CPT technology used to identify soil type. A sensitive soil occurs where low values of sleeve friction and tip resistance on the instrumented cone are obtained.

These locations are identified in Figures 60 and 61 by their highlighted CPT locations.

Figure 59. CPT section E-E′ parallel to levee orientation on the berm.

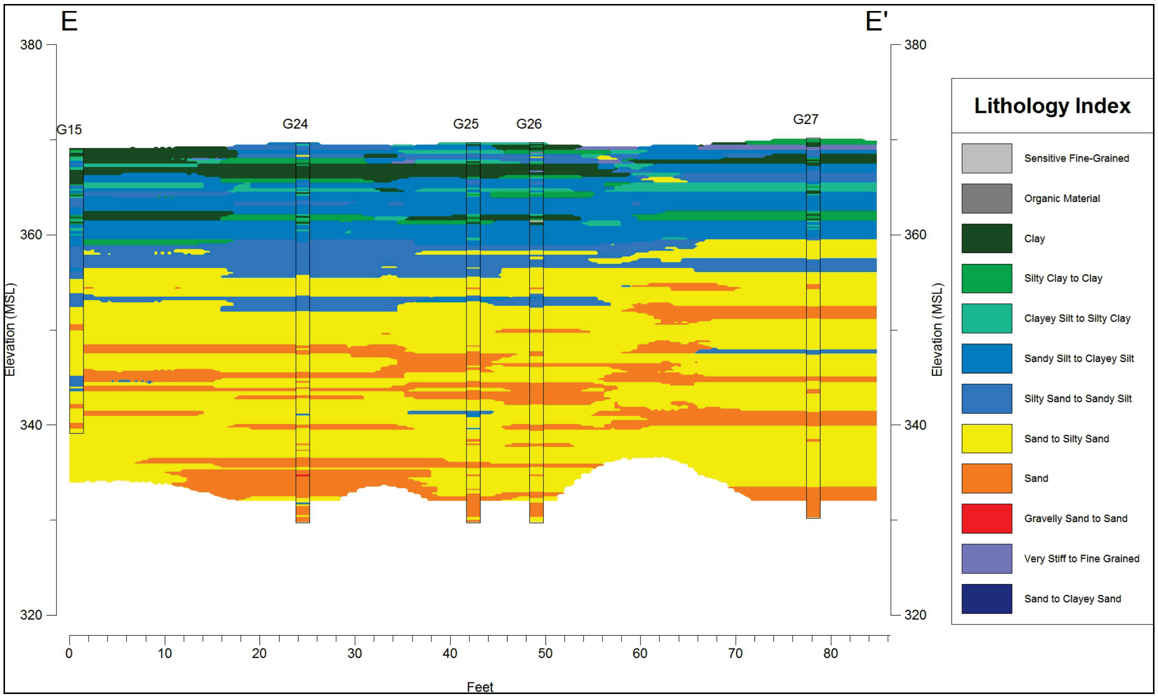


Figure 60. B series CPTs containing sensitive fine-grained layer (cyan highlighted).

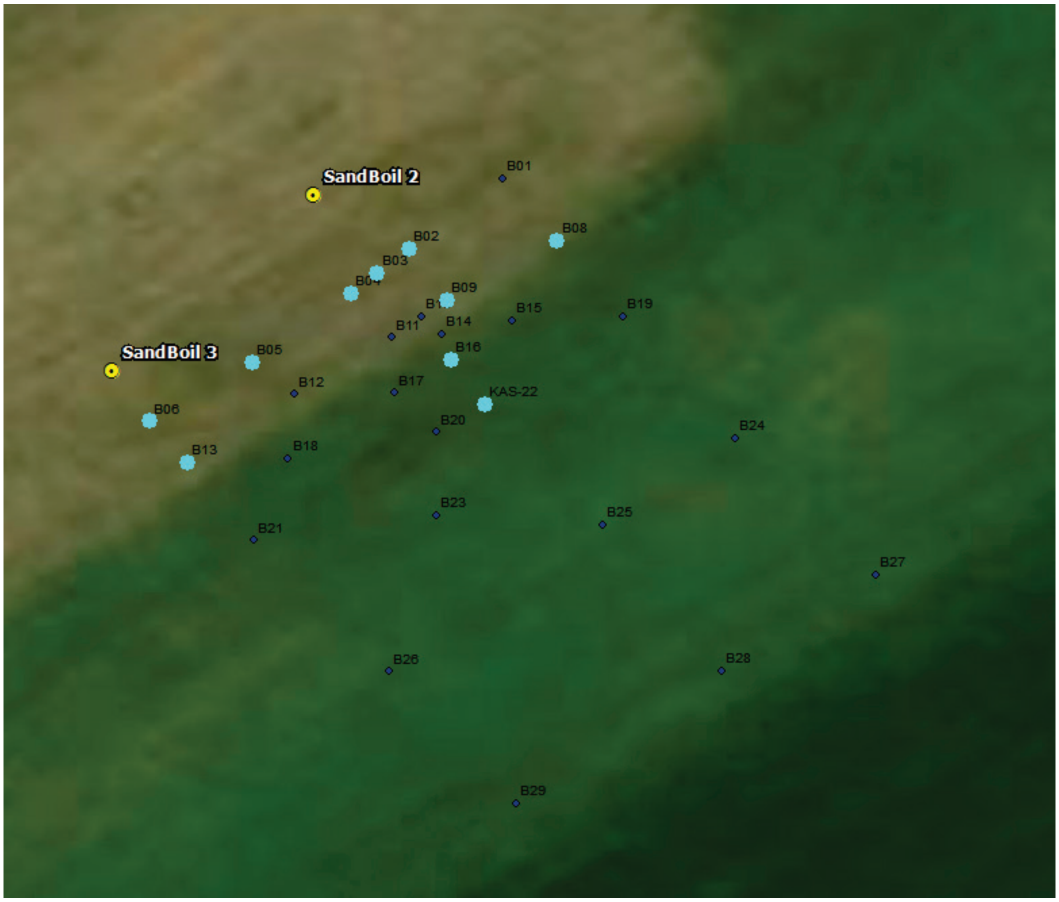
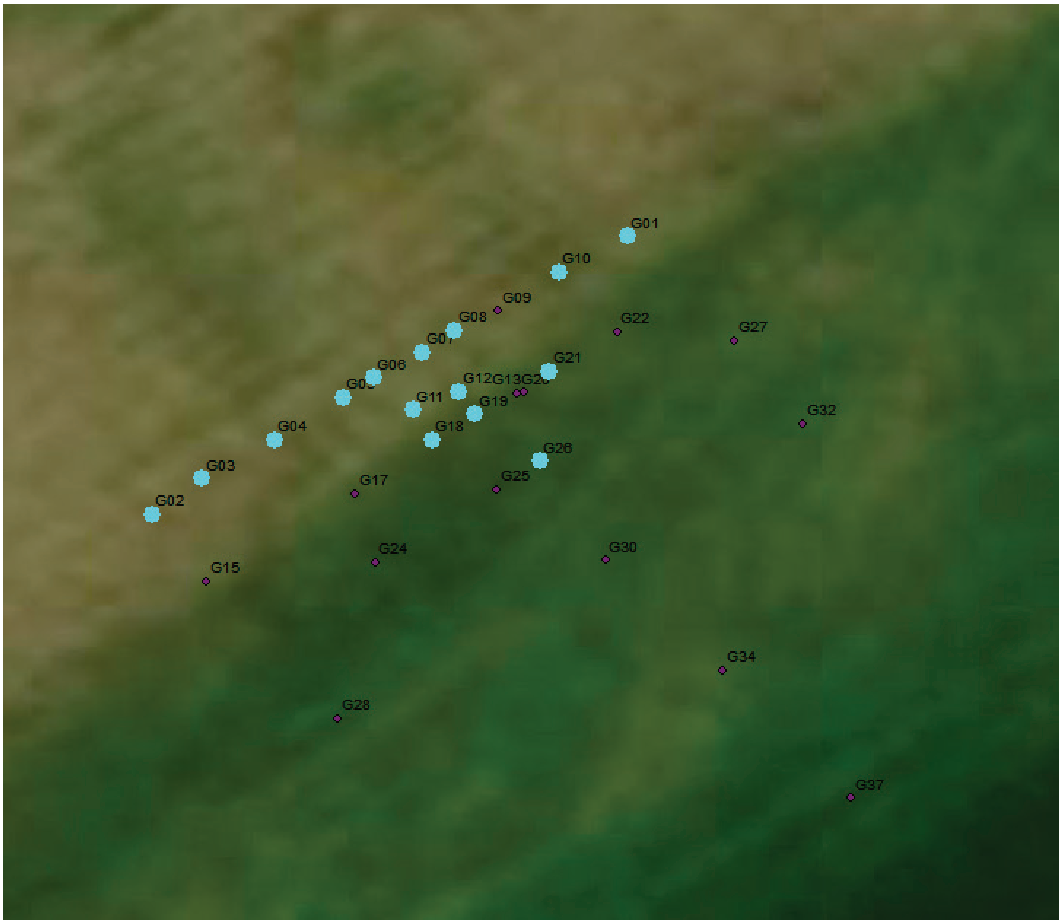


Figure 61. G series CPTs containg sensitive fine-grained layer (cyan highlighted).



Low measured values of sleeve friction and tip resistance are assigned to zone 1 of the Robertson et al. (1986) soil classification. Thus, these sediments are characterized as being low density, relatively soft, and easily deformed.

Because of their horizontal and vertical proximity to the underlying alluvial aquifer, floodplain surface, their variable depth, and spatial relationship to known sand boil areas, it is highly likely these low-density zones correspond to transport pathways for underseepage and mobilized substratum ejecta through the top stratum.

The specific mechanism envisioned for this transport is further described. During major flood events, as the alluvial aquifer becomes fully saturated and pressurized, it causes hydraulic fracturing of the blanket to occur in areas that are thin and/or contain any defects or weak spots in the blanket. These defects are typically local in nature and are due to thin zones, boundary changes in depositional environments, penetration by woody vegetation, actions of burrowing animals, man-made features, and/or at topographic low-lying areas.

Classification of a defect involving low-lying areas requires further discussion as it relates to the slump area. The term “slump area” implies a condition or process whereby the surface expression has negatively changed due to loss of foundation material and/or natural settlement has occurred here because of soft soils in a low-lying area containing relic drainage features. Thus, the underlying question becomes whether the appreciable change in elevation observed in Figure 38 is due to natural causes or caused by chronic seepage and piping in this reach and loss of foundation soils leading to settlement.

An explanation favoring relic drainage is easily evaluated by examination of historic maps identifying drainage features at this location. The 1914 levee map in Figure 5 does not show any drainage features at this location. Thus, it is judged that the dip in elevation is likely related to the loss of foundation material at some point in time. Close examination of Figure 47 identifies evidence of past sand boil activity in this reach as reflected by the numerous wet spots that are present here, which identifies a chronic seepage mechanism occurring at this location. Past farming-related activities at this location have muted these features, making long-term chronology difficult to establish.

5.10 Comparison of CPT and resistivity data

Results obtained from the CPT data described above corroborate the earlier findings obtained from resistivity surveys in both the sand boil and slump areas. Resistivity surveys at these locations (see Figures 42, 43, 44, 48, and 49) show movement of sediment occurring as evidenced by imaging of resistive pipes and disruption of the blanket stratigraphy. Sediment is being transported from the alluvial aquifer through the top stratum and is being deposited as sand boil ejecta at the ground surface.

6 CPT Soil Sampling and Laboratory Test Results

6.1 Introduction

Soil sampling was performed on two separate occasions during this study. The first effort was conducted as part of the initial field reconnaissance at Kaskaskia Island as previously described in Chapter 3. Activities and results of this sampling effort are not described here. Laboratory test results from the ejecta sampling from selected sand boils are presented in Table 1.

A second soil sampling program was performed as part of the CPT data collection effort and is the major focus of this chapter. Sampling was performed at the larger boils studied and selected soil samples were obtained from the top stratum and substratum column at these locations using a split-spoon sampler tailored to work with the CPT truck (Figure 20). Soil cores were obtained at three locations identified in Figure 62 (core locations identified in green).

The targeted sampling program at the larger sand boil sites involved closely spaced CPTs to determine both the horizontal and vertical variability of the stratigraphy at these sites. The primary purpose for this second soil sampling effort was to target specific soil horizons in the soil column, namely, to determine the source for the ejecta and to identify the characteristics of a sensitive zone from beneath and within the blanket. The sensitive zone was found to be present in several closely spaced CPTs and was interpreted as a low density zone that corresponds to a seepage pipe and pathway that had formed at the landside toe of the levee. CPT sampling results from this effort are further described herein to support the basis for this interpretation.

6.2 CPT logs and laboratory test results

Laboratory test results from CPT samples are presented in Table 2 and are classified according to the USCS. Included in Table 2 is a description of the primary feature and/or the underlying depositional environment that was sampled.

Figure 62. Locations of targeted soil sampling sites using the CPT.

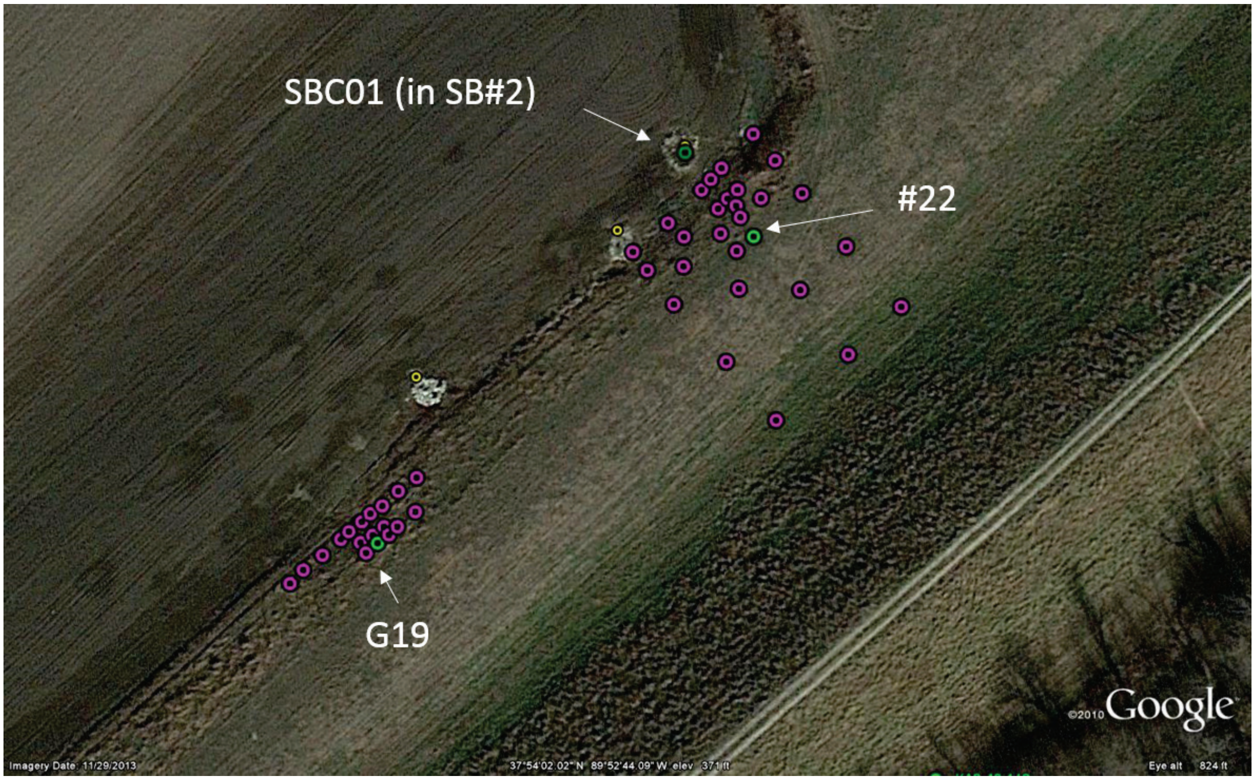


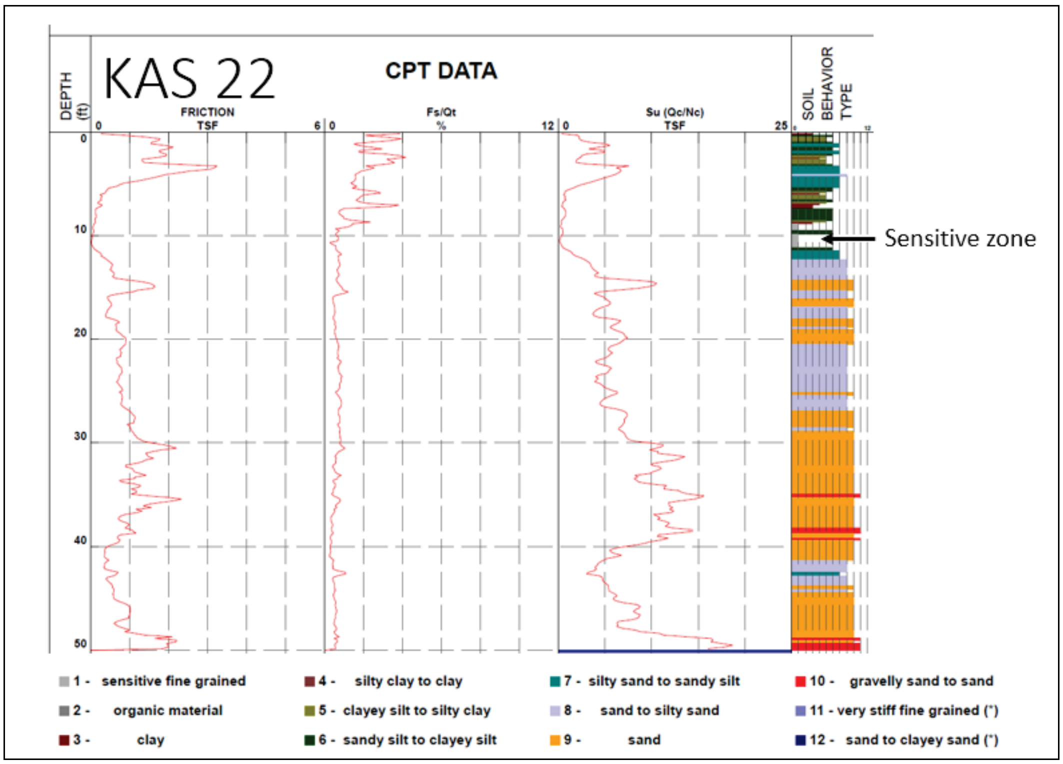
Table 2. USCS laboratory soil classification of CPT split-spoon samples and associated feature/environment.

CPT	Depth	USCS	USCS	Feature / Environment
KAS-22	1.5 - 2.0	ML	Silt	Berm
	2.0 - 3.0	CL	Clay	Berm
	3.0 - 4.5	ML	Silt with sand	Berm and Blanket
	4.5 -6.0	ML	Silt	Blanket
	6.0 - 7.5	CL	Clay	Blanket
	7.5 - 9.0	ML	Silt	Blanket
	9.0 - 10.5	ML	Silt	Sensitive zone
	10.5 - 12.0	ML	Silt	Sensitive zone
	12.0 - 13.5	SM	Silty Sand	Substratum aquifer
	13.5 - 15.0	SM	Silty Sand	Substratum aquifer
G-19	7.0 - 8.5	ML	Silt	Blanket
	8.5 - 10.0	ML	Silt	Sensitive zone
	10.0 - 11.5	SM	Silty Sand	Substratum aquifer
SB-C01	1.0 - 2.5	CL	Clay	Blanket
	2.5 - 4.0	CL	Clay	Blanket
	4.0 - 5.5	CL	Clay	Blanket
	5.5 - 7.0	ML	Silt	Blanket
	7.0 - 8.5	ML	Silt	Sensitive zone
	8.5 - 10.0	SM	Silty Sand	Sensitive zone and Substratum aquifer
	10.0 - 11.5	SM	Silty Sand	Substratum aquifer
	11.5 - 13.0	SM	Silty Sand	Substratum aquifer

Primary features identified are the berm, blanket, sensitive zone, and substratum (aquifer) sands. Grain-size curves for these CPT samples are included in Appendix D.

CPT logs for KAS 22, G 19, and SB C01 are presented in Figures 63 through 65, respectively. Identified on these CPT logs is the location of the sensitive layer that was targeted for sampling to determine USCS soil texture and associated engineering properties. Noteworthy on these three logs are the depth and location of the sensitive zone in the soil column, which occurs at the boundary between the blanket and the substratum alluvial aquifer.

Figure 63. CPT log KAS 22.



KAS-22 was continuously sampled from the surface of the berm to 3 ft into the top of the alluvial aquifer. The berm and blanket were composed of silt and clay with sand (Table 2), which is consistent with the CPT log in Figure 63. A sensitive zone composed of wet, soft, silt (ML) is present at the top stratum and substratum interface.

Three soil samples were obtained from CPT G19 at the interface between the top stratum and substratum as shown by Figure 64.

Figure 64. CPT log G 19.

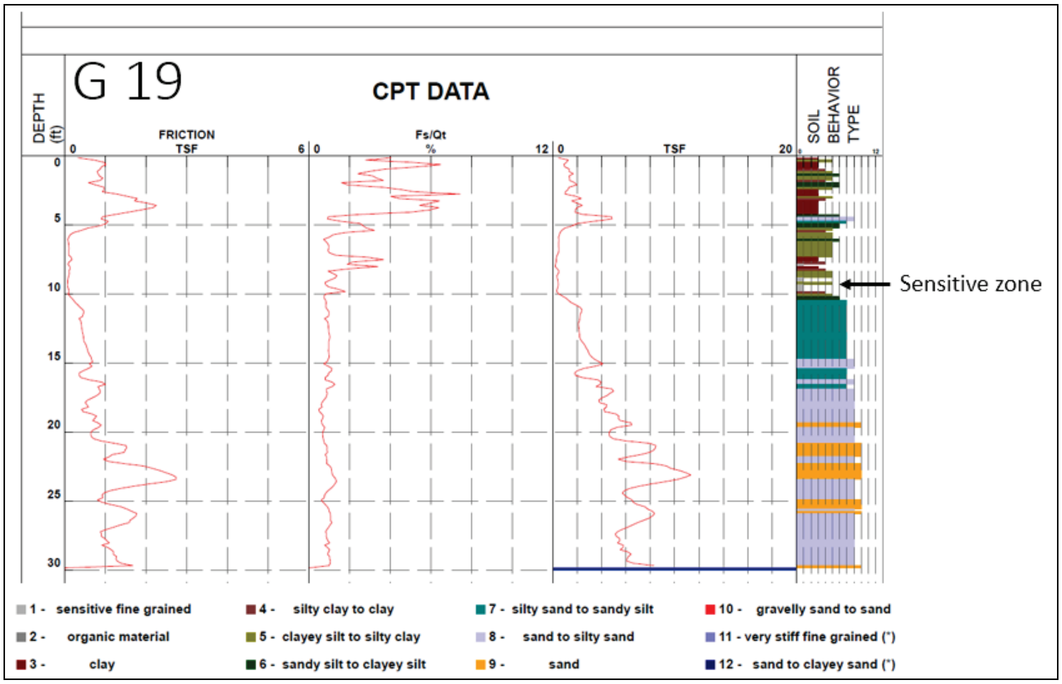
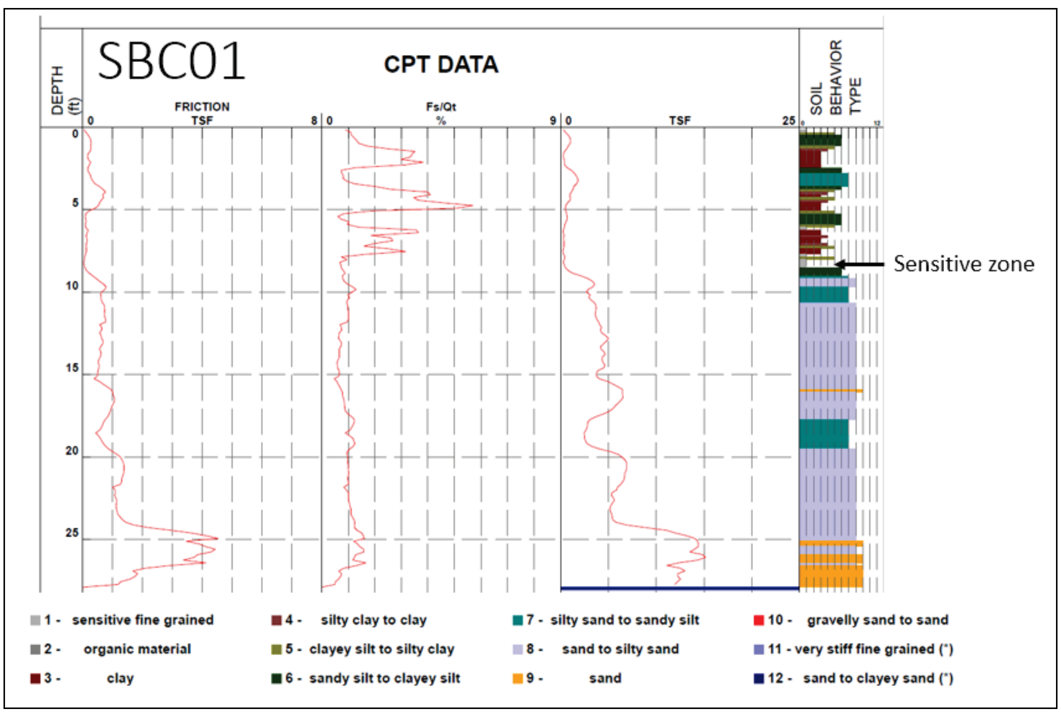


Figure 65. CPT log SB Co1.



The sensitive zone was sampled between 8.5 and 10 ft and was composed of wet, soft, silt (ML). A cross section presented previously as Figure 57 identifies this zone in profile and relationship to the underlying aquifer sands and the blanket.

A third soil sampling site involved the large Sand Boil No. 2 (Figure 61) from the ground surface to the upper part of the alluvial aquifer (Table 2 and Figure 64). The sensitive zone at this location was composed of wet, soft silt (ML).

6.3 Soil mineralogy

Mineralogy of the ejecta samples was analyzed using X-ray diffraction (XRD) techniques to determine the different minerals present in the Kaskaskia ejecta samples. XRD analysis of soil samples from Kaskaskia Island was conducted by ERDC's Concrete and Materials Branch. A total of 18 samples were evaluated using XRD methods. A description of XRD methods in geologic studies is presented at the U.S. Geological Survey (USGS) site https://pubs.usgs.gov/info/diffraction/html/.

Examination of samples through hand lens indicated that the ejecta was dominated by quartz silt and fine-sand particle sizes. Quartz comprised approximately 95 percent of the sample by volume. The remaining 5 percent was composed of other minerals, e.g., feldspars (albite, orthoclase, and microcline), clays (kaolinite and montmorillonite), calcite, dolomite, and mica (mostly muscovite with minor biotite). The presence of feldspar and mica minerals in these samples indicated their relatively young age as weathering will alter the feldspar minerals to stable clay minerals (kaolinite, illite, and montmorillonite) with time. The source for these other minerals is mechanical weathering of rocks in volcanic terrains.

6.4 Summary

Results of the laboratory testing of CPT-derived samples identify the sensitive zone at the boundary between the top stratum and substratum as being comprised of a wet, soft, silt with little to no cohesion. This condition is consistent with the behavior of the CPT data described above and observed at the sites sampled. The engineering significance of this finding verifies current ideas on internal erosion models involving backward erosion piping. The sensitive zone was measured in multiple CPTs and was found to occur at the base of the blanket (top stratum), acting as a roof for the low density zone to progress toward the river.

7 January 2016 Flood

7.1 Introduction

A field investigation of flood conditions and levee performance along the lower reach of the Middle Mississippi River was conducted by an ERDC inspection team during the January 2016 Flood. This flood event was a moderate flood and was nearly comparable to the design flood event the levee was built to protect. The January 2016 examination of levee performance during this flood resulted in a third site visit to Kaskaskia Island by ERDC personnel.

The field inspection of Kaskaskia Island during this flood was part of a larger inspection of the levee system to observe system performance between Prairie du Roucher and Cape Girardeau, MO. The inspection was conducted for the St. Louis Engineer District, Geotechnical Branch. Results of the Kaskaskia Island inspection during January 2016 are further described here as these observations have important bearing on the research activities conducted at the locations described by this study. Observations made during this third visit are the focus of this chapter.

7.2 Background on 2013 and 2016 Floods

The June 2013 Flood was estimated to be a 15- to 20-yr flood event and was the first official reporting of the large sand boils witnessed at the Kaskaskia Island locations described herein and the focus of this study. The 2013 high water was well below the design flood or the project maximum flood the levee was designed to protect.

For comparison purposes, the January 2016 Flood corresponds to a 75- to 100-yr event at Kaskaskia Island. This flood was informative in terms of levee performance involving a major high-water event. The 2016 Flood produced numerous new sand boils, and the levee had several minor levee slides, which occurred during high-water conditions. This chapter describes conditions that were observed during the January 2016 Flood.

7.3 Site access conditions

The road to Kaskaskia Island and the river road north leading out of St. Mary, MO, were impassable for most of the site visit because of backwater flooding during the 2016 Flood (see Figures 66 to 67). The water level over the road had receded sufficiently to permit travel onto the island by the last day of the planned site visit on 5 January 2016.

Figure 66. View of flooded access road in St. Mary, MO, leading to Kaskaskia Island.

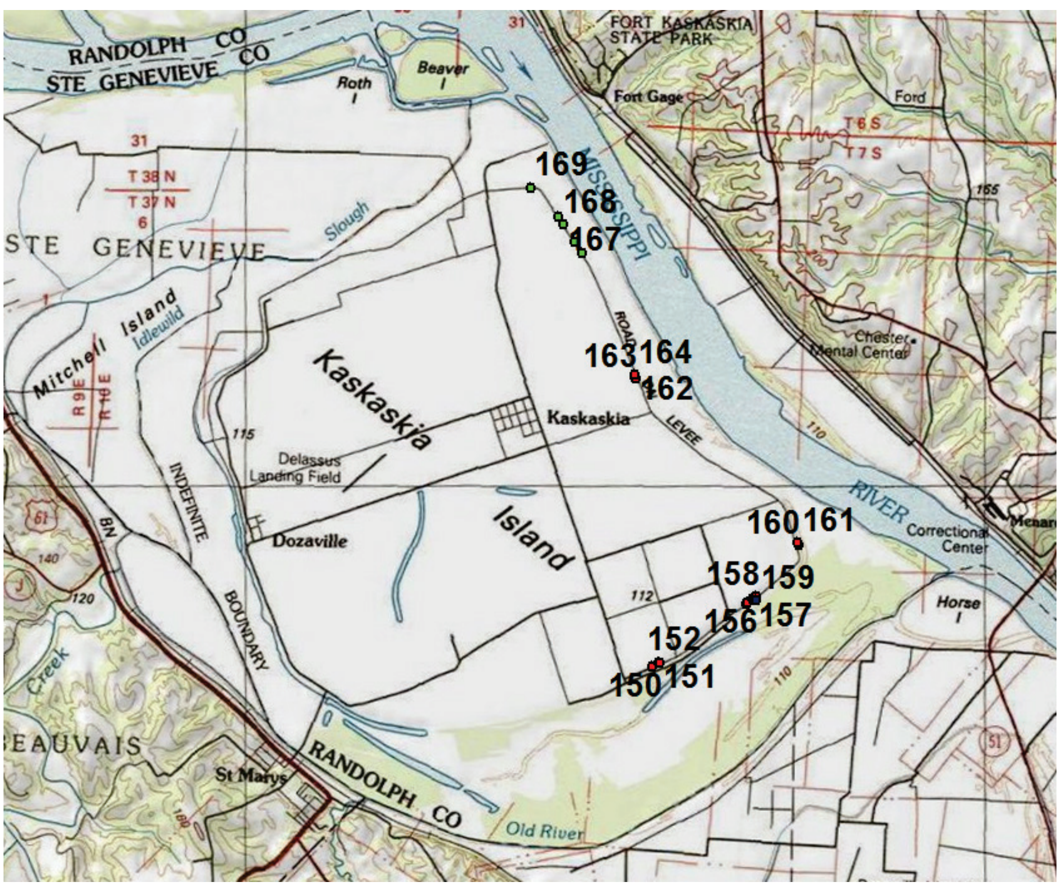
7.4 2016 levee performance site map

New sand boils were observed behind the levee during this visit, as well as at the earlier locations, which are the primary focus of this study. Additionally, several small, shallow slides involving the levee crown occurred near the northern part of the ring levee system encircling Kaskaskia Island as shown by the topographic location map of recorded incident types in Figure 68. These slides likely involved a combination of underseepage and through seepage as evidenced by the saturation of the levee soils where the slides had occurred. These slides are further described in more detail in this chapter.

The ring levee that protects the island has been in existence for 100 yr (Figure 5) and follows the bank of an abandoned Mississippi River oxbow channel. The levee system reduces the risk of flooding of the interior of the oxbow.

Figure 67. Flooded U.S. Highway 61 North in St. Mary, MO.

Figure 68. Sand boil locations (red) and levee slides (green) that were present during the January 2016 Flood. Piezometer (blue) described in the text is located in the cluster of sand boils 153 through 159 in southeast corner of the island. This area corresponds to field activities described by this study.



The old channel has subsequently been filled with sediment since its separation from the active channel (Figures 3 and 4) but still maintains a hydraulic connection to the Mississippi River during flood stages. The access road to the island crosses the old oxbow channel at St. Mary (Figure 66). The roadway was impassable during the high river stages, which was estimated at a 75- to 100-yr flood event (Figure 66).

7.5 Major purposes for site visit

The flood inspection during the January 2016 Flood was an opportunity to observe levee conditions during a large magnitude flood, which was near the design flood event. Thus, a central focus for this site visit was to observe the existing sand boils and any new boils that may have formed behind the ring levee (Figure 68). This information will help to better understand both the geologic and hydraulic conditions that are responsible for these occurrences.

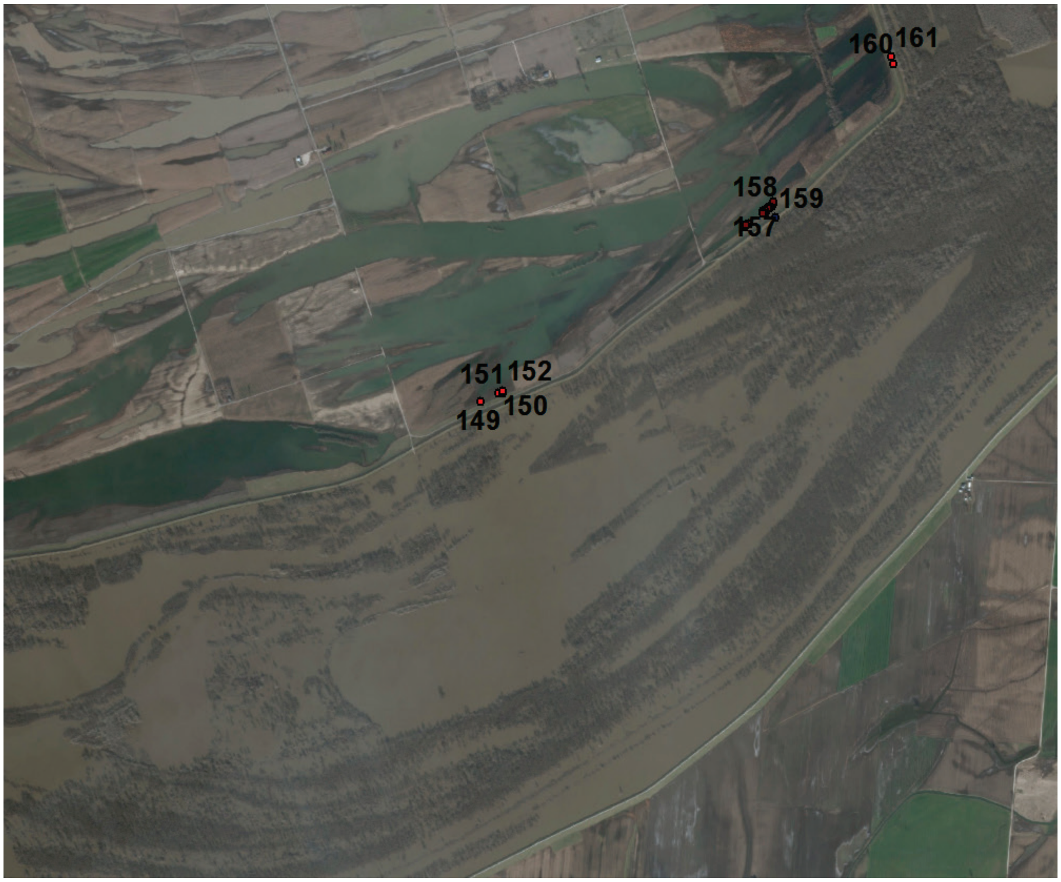
7.6 Seepage conditions

A common sight across most of the island is the seepage that collects behind the levee system in the low-lying point bar swales (Figure 69). Seepage beneath the levee and through the alluvial aquifer rises to the surface at the boundary between the sandy point bar ridges and the neighboring lower-lying swales due to the artesian pressure created by high-water flooding by the Mississippi River (Figure 16).

Contributing to seepage conditions are the drainage gullies at the edge of the levee berm shown in Figure 50. Seepage exits from beneath the berm at this location. This seepage drains to and collects in the low-lying swales adjacent to the ring levee that surrounds Kaskaskia Island. A Digital Globe image of the southern part of Kaskaskia Island in Figure 69 shows high-water conditions at the peak of flooding. This image shows the extent of flooding in the old oxbow channel and in the interior parts of the island. Photographs of seepage conditions on the ground are presented in Figures 70 and 71. These photographs are looking west and were taken on the same day as the Digital Globe image shown in Figure 69.

Several new sand boils are shown by the image in Figure 70. Yellow-colored sand bags were used to flood fight the new boils during the 2016 Flood, while white-colored sand bags were used in previous year flood-fight activities.

Figure 69. Digital Globe image of sand boil locations 149 to 161 taken during the 2016 Flood on 5 January 2016. Note extensive flooding in the old river channel and large seepage extent behind the levee.



The different-colored sand bags permit easy identification of any new sand boils from those that had occurred in previous years.

Figure 70 is a view of the large water-filled swale west of sand boil locations 149 to 152. Figure 71 is a westerly view near sand boil locations 149 to 152. Piezometer (marked by blue circle) described in text is located in the cluster of sand boils numbered 157 to 159 at the southeast corner of the island.

Close-up views of sand boil 151 (see Figures 68 and 69 for location) are shown in Figure 71 and 72. This boil has a 4.3-ft-diam fine sand cone with a 12-in.-diam throat. A dried foam crust is present on the boil surface. The boil was no longer actively flowing at the time as the river stage had dropped below a critical threshold.

Figure 70. View looking west from levee crest toward town of St. Mary. Photograph taken on the morning of 5 January 2016 as flood waters were receding. Interior seepage has collected in the large swale on the right side of the photograph forming extensive lakes across much of the island.

Figure 71. View looking due west from base of berm in vicinity of boil No. 151. Several sacked sand boils visible in background. Note the dry brown foam crust present on the surface of the sand boil.

Figure 72. Close-up view of the 4.3-ft-diam sand boil cone at sand boil No. 151, with nearly a 12-in.-diam throat. Boil was no longer active as the river fell below a critical threshold on 5 Jan 2016 visit.

This location did not display sand boil activity during the 2013 Flood as evidenced by the record of sand boil locations recorded by the District (field notes from Curtis Moore and Caroline Williams.) Additionally, the boil was sacked with yellow-colored sand bags, another indication of new boil activity.

7.7 Current study area during 2016 Flood

Figures 70 through 76 correspond to different views of sand boil activity in the vicinity of the 2013 sand boils that are the focus of this study. This series of photographs is fairly informative of the current flood conditions near the maximum river stage and the number of new sand boils present at this location.

It is noteworthy that sand boil activity is concentrated at the western edge of the wider (~300 ft) seepage berm that was built after the 1993 Flood (see Figure 75). Boil activity occurs at the transition between the post-1993 berm that was constructed to remediate the 1978 levee section where only a 100-ft-wide seepage berm was present. Likely, this area had experience sand boil activity prior to and during the 1993 Flood.

Figure 73. View looking due east at new sacked sand boils (locations 154 to 158) near edge of the enlarged seepage berm in background of photograph. Landside piezometer is visible in center of photograph, where bollards are present to protect the piezometer from vehicle damage. These boils occur at the edge of the 150-wide landside berm and 50 to 75 ft past the edge of the berm. Note the extensive seepage volume that has collected in the large swale, which is nearly parallel to the levee orientation.

7.8 East side of Kaskaskia Island during 2016 Flood

Closer to the Mississippi River, sand boil activity was observed at locations 160 through 164 (see location map in Figure 67). Figures 77 and 78 show sand boils at the toe of the levee near the turn in the ring levee. These boils are located in a reach containing a 100-ft-wide seepage berm. The berm was added as part of the 1978 levee improvements. Figure 78 is closer to study area 2 where Sand Boil No. 1 (Figure 18) is visible in the background in the center part of the image.

7.9 Slides during 2016 Flood

Three shallow levee slides were present in the northeast corner of the Kaskaskia Island levee (see location map in Figure 67). These slides extended from the crown to the landside toe (locations 167 to 169). A view of the middle slide (location 168) is shown in Figure 79. The shallow slide of location 168 is shown in Figure 80.

Figure 74. Close-up view of the sacked sand boils (locations 154 to 158) near the landside toe piezometer. Note the different colored bags and the small sand cone that was not sacked in center of image. This location corresponds approximately to the site of the 2013 sand boils (white sand bags were used to ring these boils). This area is the focus of this study. Note extensive seepage at this location.

The slide was approximately 100 × 100 ft in extent and had a scarp height of 18 to 20 in. Seepage was present at the toe of the slide area, and soils were saturated in the disturbed area.

Soils used to build this section of the levee are likely highly plastic in nature. The presence of three slides in this reach indicated a different borrow source for construction of this reach as compared to other reaches observed. Possible levee through seepage may be occurring at this location because of the shrink-swell nature of these soils. Internal levee cracking from moisture loss and desiccation during dry weather permits seepage pathways to form through cracks, and later high-water conditions use these conduits. It is very probable that complete closure of these cracks does not occur because of outside sediment entering these cracks during maximum desiccation.

Figure 75. Close-up Digital Globe aerial image of flood conditions and sacked sand boils in Figures 72 through 76. Boils are concentrated at the western end of the wide berm extension (northwest corner) following the 1993 Flood. Image was taken 5 January 2016 at time of the ERDC site visit to Kaskaskia Island. Standing water is near its maximum height.

7.10 Summary

The 2016 Flood permitted inspection of the levee system during a major flood event to observe seepage extent and new sand boil activity behind the ring levee system protecting Kaskaskia Island. New sand boils were present in the three study areas that are the focus of this investigation. Widespread seepage and flooding were fairly extensive in the vicinity of sand boils No. 2 and 3 as shown by Figures 72 through 76. In addition, several large, new sand boils were present at these locations.

Figure 76. View of landside seepage at piezometer KI-375C15 on 5 Jan 2016. View is looking northeast with large sand boils in background of image and underwater. View shows location of 2013 sand boils.

Figure 77. Extent of sand boil range near edge of the seepage berm constructed following 1993 Flood (right edge of photo).

Figure 78. Small bagged boil (number 160) near turn in levee.
Note seepage behind levee.

Figure 79. Two moderate-sized bagged sand boils (number 163 and 164) visible in the seepage lake (swale filled with seepage). View is in vicinity of study area 2 corresponding to location of sand boil 1 in Figure 18, which is visible in center of image.

Figure 80. Shallow slide (location 168) developing on the landside slope. Slide incorporates the crown and toe of the levee at the northeast corner of the island. Note the seepage that has collected and the wet area at the toe. Probable levee through seepage occurring at this location. Several slides are present in this reach with very plastic soils used to build this section of the ring levee contributing to slide conditions.

8 Seepage Control

8.1 Introduction

This chapter reviews levee remediation at Kaskaskia Island and historic changes in flood control policy. Important to this discussion is the evolution of underseepage control for levees. Section 1.4 contains a brief historic summary of the levee system at Kaskaskia Island. The original design of the Kaskaskia Island levee system predates standards established after 1952 following publication of USACE (1952, 1956a, 1956b) and current day standards (USACE 2000); however, flood control measures on the island have generally kept pace with the design standards that were adopted (USACE 1978, 2000). During the 1973 Flood, a section of the Kaskaskia Island levee was breached at Pujol, IL, resulting in a levee enlargement with seepage berms incorporated into the design of the levee system along with pump stations (USACE St. Louis District 1979a). This breach was on the west side of the island.

8.2 Seepage control research

The Kaskaskia Island levee system was federalized by the Flood Control Act of 28 June 1938. The original project provided funding for raising and enlarging the 14.8 miles of the ring levee surrounding the flood control district (Figure 5). Work was completed in August 1942. Federal involvement and construction of the Kaskaskia Island levee system included the concept of a standard levee section where the geometry and construction practice were based on local experience with controlling floods in the respective geographic area. Additionally, the Kaskaskia Island levee system was not part of the Alton to Gale project, which received Congressional approval in 1944. This project studied seepage control measures for the reach between St. Louis and Cairo and eventually raised the levee system to the guidance standards outlined in USACE 1956a.

The time period between 1938 and 1942, when the Kaskaskia Island levee system was being designed and built, was a period of active and focused research into complete understanding and effective control of underseepage by the USACE (U.S. Department of the Army 1939, 1941; USACE 1939, 1941a, 1941b, 1941c). This early research effort would eventually culminate in the mid-1950s with current-day analytical methods to analyze and control underseepage behind levees using principally seepage berms and relief wells. This early research would advance and result in detailed engineering guidance (Turnbull and Mansur 1957, 1961; USACE1941a, 1947, 1952, 1955, 1956a, 1956b, 1978, 1992, 2000, 2018a, 2018b). The solution for effective seepage control in levee design would require detailed understanding of the site geology, alluvial soils, the stratigraphy in the levee reach, hydraulic conditions of the site, and the concept of exit gradient behind the levee reach. Detailed study of the geology and seepage control measures would be incorporated into the Kaskaskia levee design by USACE St. Louis District (1979a, 1979b).

8.3 Exit gradient

Seepage control policy for USACE levees has historically been based on the concept of exit gradient (i_o) to determine whether countermeasures (e.g., berms, relief wells, cutoff walls) were needed at the landside toe of the levee (USACE 1947, 1956a, 1956b, 1978, 2000). The exit gradient is derived from definition of the foundation geology and the hydraulic properties at the location being evaluated. The exit gradient corresponds to the ratio of h_o/z (Figure 81), where h_o is the excess hydraulic head above the ground surface that would be measured by a piezometer at the location of interest, and z is the blanket or top stratum thickness at that location (USACE 1956a, 1956b). Where piezometer data were unavailable, analytical solutions were developed by USACE (1956a, 1956b) to calculate the exit gradient for various geologic cases that were determined to exist and which were common in the Lower Mississippi River Valley.

8.4 Exit gradient and sand boil activity

Empirical study of seepage and sand boil activity was performed by USACE at study sites in the LMV during the 1940s and 1950s to fully understand the geologic conditions responsible for seepage and sand boil occurrence (USACE 1941a, 1956a). These field studies provided empirical relationships to relate the exit gradient at the various sites studied to severity of seepage and occurrence of sand boil activity (Figure 82). Sand boil activity was observed to occur at exit gradients above 0.5, and dangerous boils were typically encountered at exit gradients as low as 0.7 (USACE 1947).

Figure 81. Primary variables for exit gradient calculations.

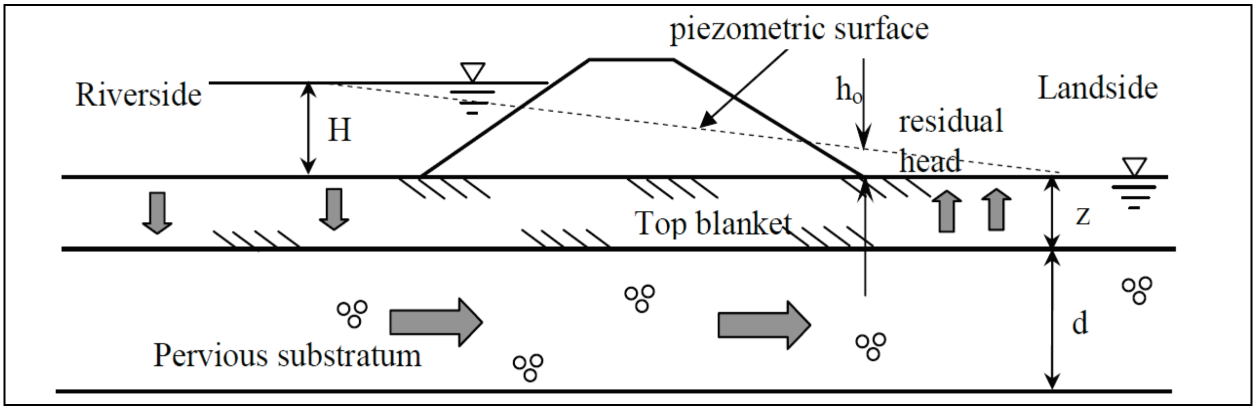
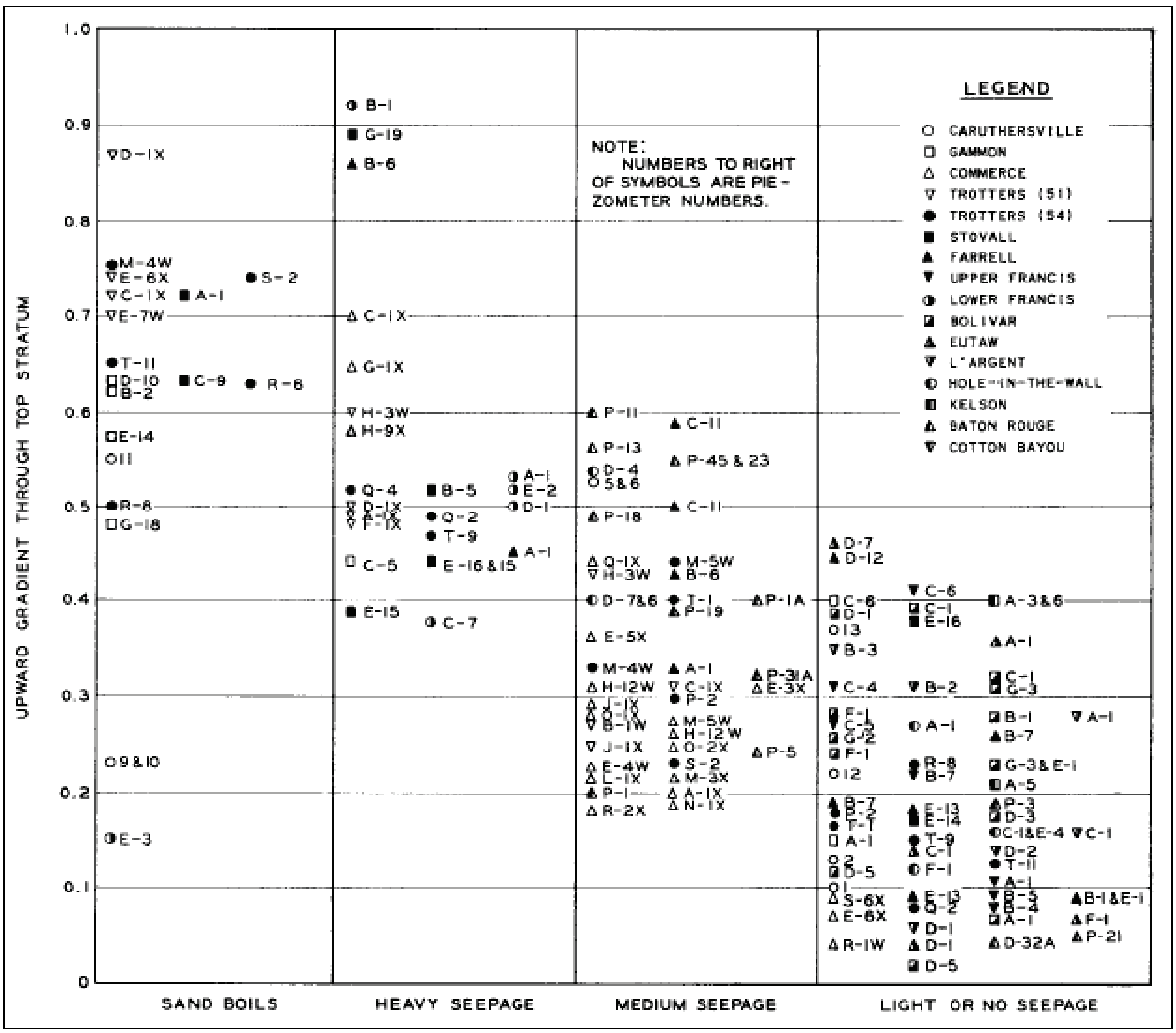


Figure 82. Relationship between exit gradient and severity of seepage and occurrence of sand boils (USACE 1956a).



In addition to the hydraulic gradient and the blanket thickness, material properties of the blanket itself have a direct bearing on seepage and sand boil potential. The gradient required to cause heaving and possible fracturing of the top stratum is defined as the *critical gradient* and corresponds to the ratio of the submerged unit weight of the soil comprising the top stratum and the unit weight of water (Turnbull and Mansur 1961).

For cohesive soils, the critical gradient is at 0.8 for soils with unit weights of between 112 to 115 lb/ft^3, which is typical of top stratum (blanket) deposits within the alluvial valley. The buoyant weight for silts and sands is often attained at this critical gradient, resulting in a quick condition for these soils and upward flotation of the silt and sand grains to the surface as a sand boil (USACE 1941a). Thus, local defects in the uniformity of the top stratum and blocked exit conditions (see Figure 16) can adversely contribute to sand movement from the foundation to the ground surface and may result in much lower gradients for sand transport to occur.

Examples where lower gradients caused sand boil conditions were found to occur at Caruthersville and Lower Francis (Figure 82). At these locations, exit gradients were calculated at between 0.15 and 0.25. Lower gradients at these sites were probably caused by a chronic seepage problem at these locations where past floods had enlarged and worsened conditions at these sites, resulting in sand boil activity below the 0.5 threshold. This condition is envisioned with sand boil activity reported in 2013 at the study site.

8.5 USACE seepage criteria

Current USACE (2000) policy for seepage control has evolved since the Kaskaskia levees were first federalized in 1942. Current seepage criteria recommend a minimum seepage berm width of 150 ft for exit gradients between 0.5 to 0.79 and 300-ft-wide berms for gradients above 0.8. Relief wells at these locations can reduce berm widths or even eliminate them altogether as a means to effectively control underseepage; however, their use requires landside drainage control and long-term maintenance to ensure well efficiency. Relief well guidance is described by USACE (1992, 1993, 2018b).

Seepage berm guidance has evolved since 1962 following the MRC internal staff study review of berm design in the LMV. This review subsequently standardized seepage berm design across LMV districts (USACE 1956b, 1962). This internal review by the MRC would later be incorporated into the Engineer Manual (EM) for levee design and construction, first published in 1978, updated in 2000, and currently undergoing its third revision (USACE 1978, 2000, 2018a).

8.6 Estimated hydraulic conditions at the Kaskaskia Island study area in 2013

Hydraulic conditions responsible for sand boil activity during the 2013 Flood at the Kaskaskia Island study area are estimated based on historic river stages and groundwater elevations from nearby piezometers installed in the study reach. Flood stage data for the 2013 Flood are reviewed first followed by the measured groundwater response in piezometers installed in the reach under study.

A record of the flood stage on the Mississippi River at both the Chester and Cape Girardeau gages is presented in Figure 83. An estimate of the water surface elevation at Kaskaskia Island for the 2013 Flood is derived from the Chester gage and a longitudinal profile between river miles 148 to 94 above the Ohio River showing the water surface profile of past floods through this reach (Figure 84). The Kaskaskia Island study area is located between river mile 111.6 and 115.5, and the Chester gage is located at river mile 109.9 in Figure 84. The Chester gage is 1.7 miles downstream of the southern-most extent of the Kaskaskia Island study area.

Figure 83. 2013 Flood gage data at Chester and Cape Girardeau (data from Dr. Mike Navin, St. Louis District).

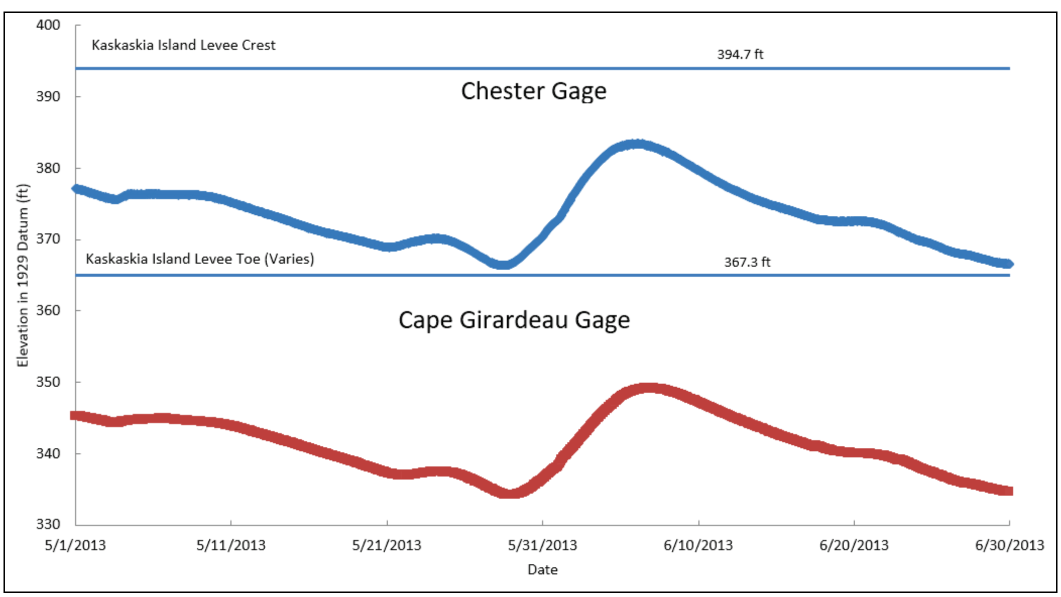
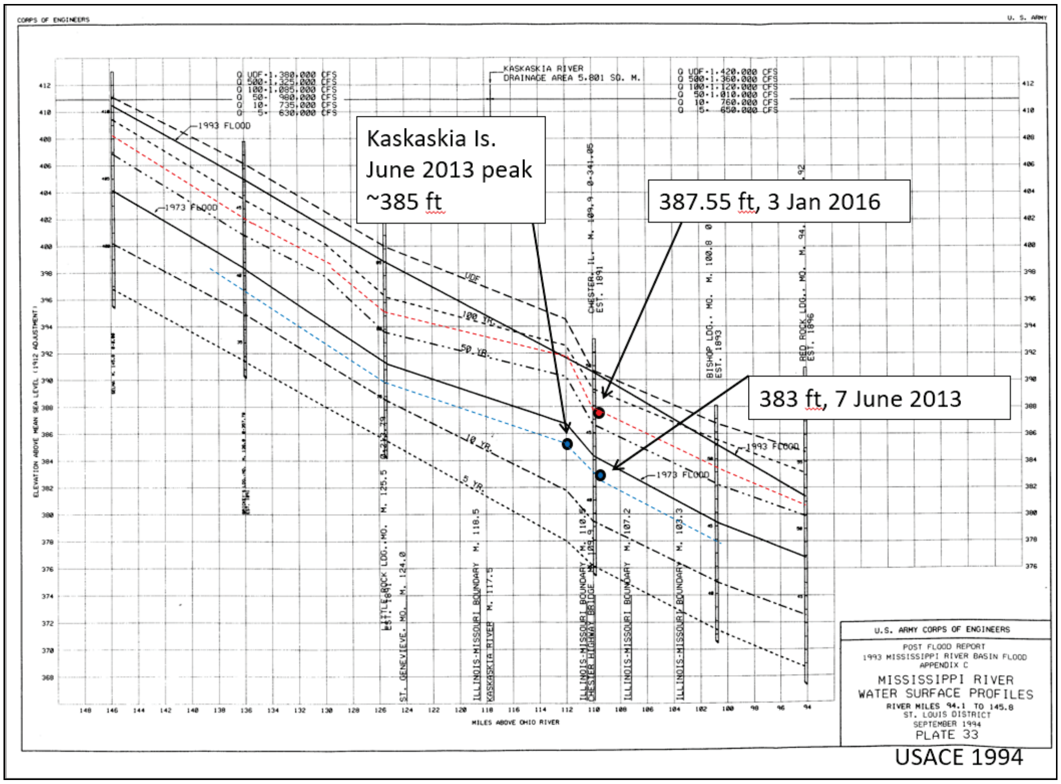


Figure 84. Water surface profile for different historic floods.



The Chester gage on the Mississippi River in 2013 was at flood stage (gage above 27 ft) for 28 days, beginning on 29 May and ending on 26 June 2013 (Figure 83). The 2013 crest occurred on 6 June 2013 with a gage reading of 42.41 ft (elevation 383.46 ft NGVD29). Accounting for the longitudinal river slope in Figure 84, the estimated water surface profile at Kaskaskia Island was approximately at 385 ft at a distance of 2.1 river miles upstream of the gage.

For comparison purposes, the peak of the 1 January 2016 Flood on the Chester gage was at 387.03 ft, for a net difference of 3.57 ft between the 2013 and 2016 floods. The August 1993 Flood of record on the Chester gage was at 390.75 ft, for a net difference of 7.29 ft in river stage between the 1993 and 2013 floods. Thus, the variation in river height between a 15- to 20-yr flood event versus a 75- and a 100-yr flood event corresponds to a difference of about 3.57 and 7.29 ft, respectively, at the Chester gage.

The authorized design for the Kaskaskia Island levee system provides a reduced risk for a flood corresponding to once in 50 yr with a stage of 46.6 ft (elevation 387.65) at Chester, IL (USACE St. Louis District 1979b). The recommended design was verified using steady flow water surface profiles on the Mississippi River Basin Model at Clinton, MS. Appropriate freeboard was added to the 50-yr water surface profile (USACE St. Louis District 1979b). For the Kaskaskia Island study area, a design flood event occurs at elevation ~390 ft (Figure 84), which incorporates 3 ft of levee freeboard as determined from the levee crest elevation from a DEM of the island. For comparison purposes, the water surface elevation in Figures 66 and 67 over the access road onto the island is ~385 ft.

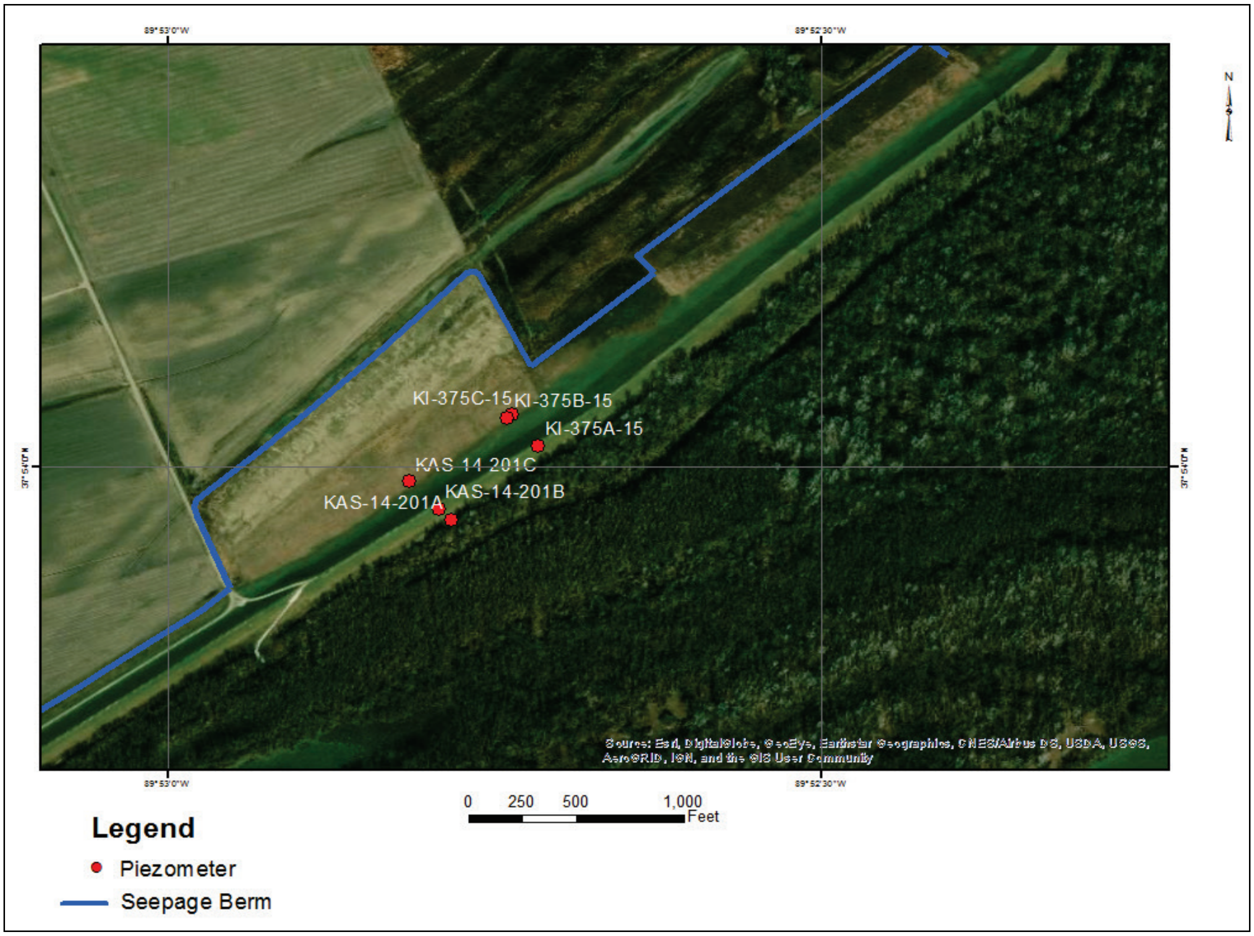
8.7 Exit gradient during the 2013 Flood

Piezometer data from the sand boil study area are used as a proxy to estimate the hydraulic conditions responsible for sand boil formation in 2013. The underlying assumption here, for purposes of this discussion, is the large sand boils formed when the river stage was at its maximum. At this point, the alluvial aquifer would have been fully saturated and capable of producing artesian pressures needed for fine-grained silt and sand to mobilize and to form sand boils. This assumption is not reasonably valid but is considered initially here for discussion purposes.

Piezometer locations in the sand boil study area are shown on the Google image in Figure 85. Views of the landside piezometer (KI-375C15) during the peak of the January 2016 Flood are shown in Figure 86 for reference of seepage conditions during a major flood event. These piezometers were installed by the St. Louis District in 2015 for monitoring aquifer conditions at this location but were not automated for daily measuring until the summer of 2016. Fortunately, nearby piezometers KI-201A, 201B, and 201C were installed in 2014 after the 2013 sand boils were first discovered and are used to evaluate and estimate groundwater conditions responsible for the 2013 sand boil activity (Figure 11). The riverside well (KI-201A) is not considered here for purposes of discussion as this well overtops during flooding in a high-water event. Only the 201B and 201C wells are considered, and these wells are 171 ft apart.

The 201 series piezometers were installed at the levee crest (B), riverside (A), and landside (C) levee toes. These piezometers were instrumented to obtain a continuous record of daily groundwater elevation with time. Records of groundwater elevations in these three piezometers are presented in Figure 86 for the 2014 through 2018 time period (data from Jeremy Eck, St. Louis District). The groundwater record for each well parallels the river stage cycle as would be expected for a shallow alluvial aquifer.

Figure 85. Location of referenced piezometers and seepage berm limits in 2017.



The record of daily groundwater elevation in the landside toe well (KAS-14-201C) easily permits the exit gradient at this location to be estimated for the 2013 Flood conditions by inference from a flood of similar stage comparable to that occurring in 2013.

The exit gradient corresponds to the ratio of h_o/z (Figure 81), where h_o is the excess hydraulic head above the ground surface that would be measured by a piezometer at the location of interest (KAS-14-201C), and z is the blanket or top stratum thickness at that location. The landside ground surface elevation where the 2013 sand boils were first observed is ~367 ft at the edge of the berm.

Figure 86. View of the KI-375-15 series (A, B, and C) piezometers.

The KAS-14-201C piezometer at the levee toe is used here as a proxy to estimate the landside head and the value for h_o by the above equation using the peak stage value at the Chester gage for 2013 and the corresponding groundwater elevation in the 201 series wells during the 2013 Flood peak. This approximation will ignore any potential time lag in groundwater response as a function of river stage, which would ordinarily occur.

Derivation of the maximum groundwater elevation responsible for sand boil formation at the landside toe well is further complicated because of the nature of the well construction at this location. The piezometer's top of riser pipe elevation is lower than the height needed to accurately measure the peak groundwater elevation during the flood. Automation of the groundwater measurements and a capped but vented system has limited the reliability of readings to only the top of the riser pipe elevation in well 201C at 371.78 ft. Thus, this value is an upper bound on the well's ability to accurately measure the change in water-table elevation at this location in response to the river's rise in elevation on the nearby Chester gage. Fortunately, it is possible to calculate the estimated value for well 201C using the corresponding change in water-level elevation in the 201B well on the levee crest because this well does not overtop.

The point at which the 201C well begins to overflow the top of the riser pipe (elevation 371.78 ft) is matched to the corresponding water elevation at the levee crest well (201B) for the time period of interest. This set of paired values is then used to calculate the net change in water-level elevation above these reference values. This procedure assumes the riser pipe at the levee toe extends above the corresponding elevation of interest. The point in time where the landside riser pipe begins to overflow matches to a value of 373.02 ft at the levee crest well 201B. A difference in head of 1.74 ft occurs at this time between the 201B and 201C wells. Water levels with this elevation pair were measured on 28 December 2015, with a Chester gage reading of 381.24.

However, the Chester gage during the 2013 Flood reached an elevation of 383 ft (Figure 83) and resulted in a groundwater elevation in the 201B piezometer at 375.94 ft, measured on 30 December 2015. Solving for the unknown groundwater elevation at the landside levee toe using a simple proportion for the known values in wells 201B and 201C (values: 375.94/373.02 = x/371.78) yields an approximate groundwater value of 374.69 ft in well 201C for a Chester gage elevation of 383 ft.

The net difference between the groundwater elevation (374.69 ft) and the ground surface elevation (~367) at the edge of the berm is approximately 7.7 ft for the value of h_o. The blanket thickness previously identified in Figure 54 is approximately 10 ft thick based on the nearby CPT data. Thus, the estimated exit gradient for this location during the peak of the 2013 Flood is approximately 0.77, which is at the upper range of sand boil activity in Figure 81; however, this value assumes there is no tail-water condition, which is highly unlikely as shown by standing water in Figure 86. Thus, a tail water of 1- to 2-ft depth would reduce the exit gradient to 0.67 to 0.57, respectively, which is still within the limit range for active sand boils identified in Figure 81.

Examination of the groundwater response curve in Figure 85 for well KAS-14-201C indicates the peak is of relatively short duration. It is far more likely that sand boil activity begins at a much lower elevation than at the flood peak. Thus, for a minimum exit gradient of 0.5, the corresponding groundwater value would be at approximately 372 ft and for a value of 0.6 would be at 373 ft for a blanket that is 10 ft thick (i.e., ground surface elevation plus 5 or 6 ft, respectively). These latter elevation values are considered more reasonable for boil activity to form in this reach because of the longer flood duration needed and due to the size and spacing of the boils shown in 2013 in Figure 11. These boils were considered to be small to moderate in size in terms of their throat diameter based on the flood notes from Curtis Moore and Caroline Williams (St. Louis District, Geotechnical Branch). Furthermore, their notes identify evidence of boils being present earlier in 2011 at this location.

Earlier sand boil activity would indicate a chronic seepage problem at this location. A chronic seepage condition may be responsible for even lower gradients capable of producing problem sand boils because of cumulative effects of foundation soils being lost in this reach. Also, any variations in blanket thickness below the 10-ft value used here for discussion in this reach would increase the value of the exit gradient above the 0.5 threshold in Figure 81. Thus, any type of defect to the blanket itself (cumulative effects of chronic seepage problems, woody vegetation, burrowing mammals, man-made activity, or a stratigraphic discontinuity) could locally increase the gradient value.

A possible contributing factor at this location might be the prominent swale that is present at the landside levee toe shown in Figure 11. This clay-filled depositional feature could locally increase artesian pressure beneath the blanket due to the presence of the clay-filled swale, which may act as a hydraulic barrier to horizontal groundwater flow during flooding.

Comparison of the response curves in Figures 87 and 88 for the two different piezometer locations in Figure 85 identifies a similar groundwater response pattern for the two locations; however, the two response curves are somewhat dissimilar because of differences in well placement, aquifer depth being measured, and their number identification scheme.

The 375 well series does not have a corresponding riverside well location. The levee crest well is the A well for the 375 series and would be comparable to the B well in the 201 series. Furthermore, there are two landside wells next to each other in the 375 well series (B and C) that have been screened at different aquifer depths. The 201C well is at the same levee position and approximate aquifer elevation as the 375B well. The 375C well is nearly 50 ft deeper in the aquifer than the paired 201C and 375B wells. Thus, a casual examination of the two response curves in Figures 87 and 88 requires careful consideration in terms of their well placement and numbering with respect to the levee profile for accurate understanding of groundwater elevation in this reach.

The 375 landside wells begin to overflow at about the same time as both tops of riser pipes are at a similar elevation, 371.74 (375B) and 371.75 (375C). Thus, for all practical purposes, both wells begin to overflow at nearly the same point in time based on their response to a rising river stage. Similarly, these wells are both capped and limited above their riser pipe elevations in terms of valid readings.

The 2017 Flood is the first flood cycle containing automated readings for the 375 well series and was nearly comparable to a 2013 Flood event based on readings obtained on the Chester gage. A flood crest on the Chester gage occurred on 6 May 2017 with a gage elevation of 385.71 ft, approximately 2.71 ft higher than the 2013 Flood. Times and piezometer readings of interest occurred 1 May 2017 with the landside 575B and 575C wells beginning to overflow near elevation 371.75. The corresponding groundwater elevation in the 575A well was at 372.87 ft. The differences in measured head between the 375A and the 375B and C wells were 1.48 and 1.21 ft. The Chester gage at this point was at elevation 377.67 ft. When the

Chester gage attained an elevation of 383 ft on 4 May 2017, the corresponding groundwater value recorded for the 575A well was 377.77 ft.

Figure 87. Piezometer data for KAS-14-201A, B, and C from Dec 2014 through March 2018 (from Jeremy Eck, St. Louis District 2018).

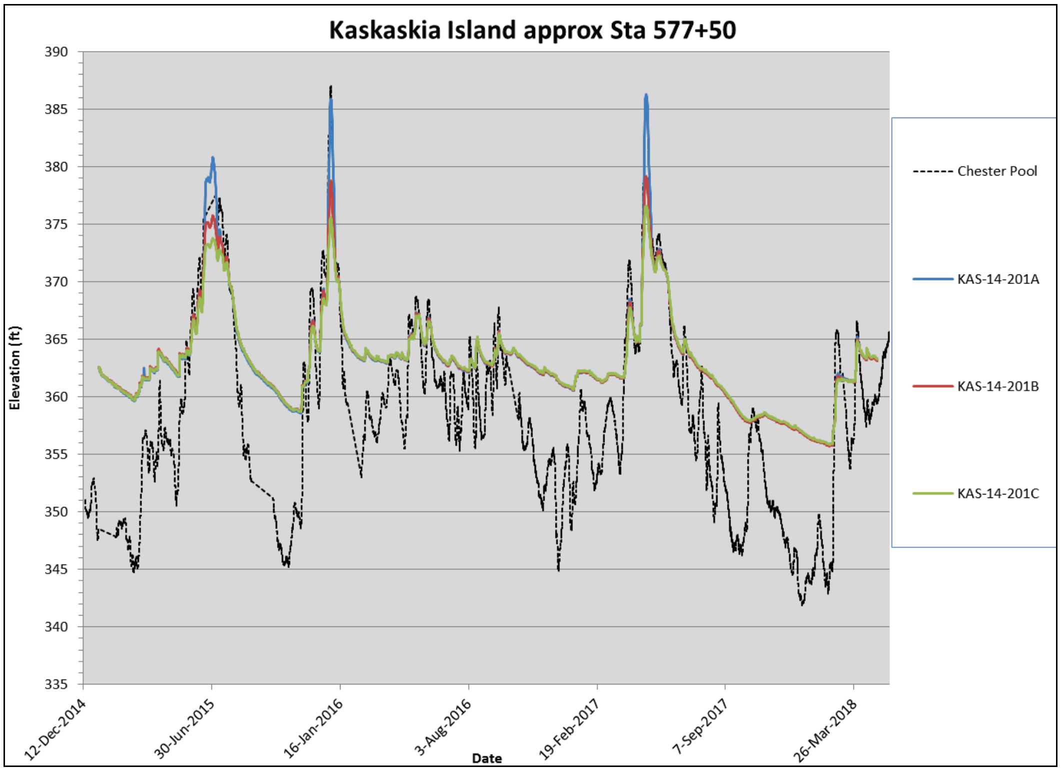
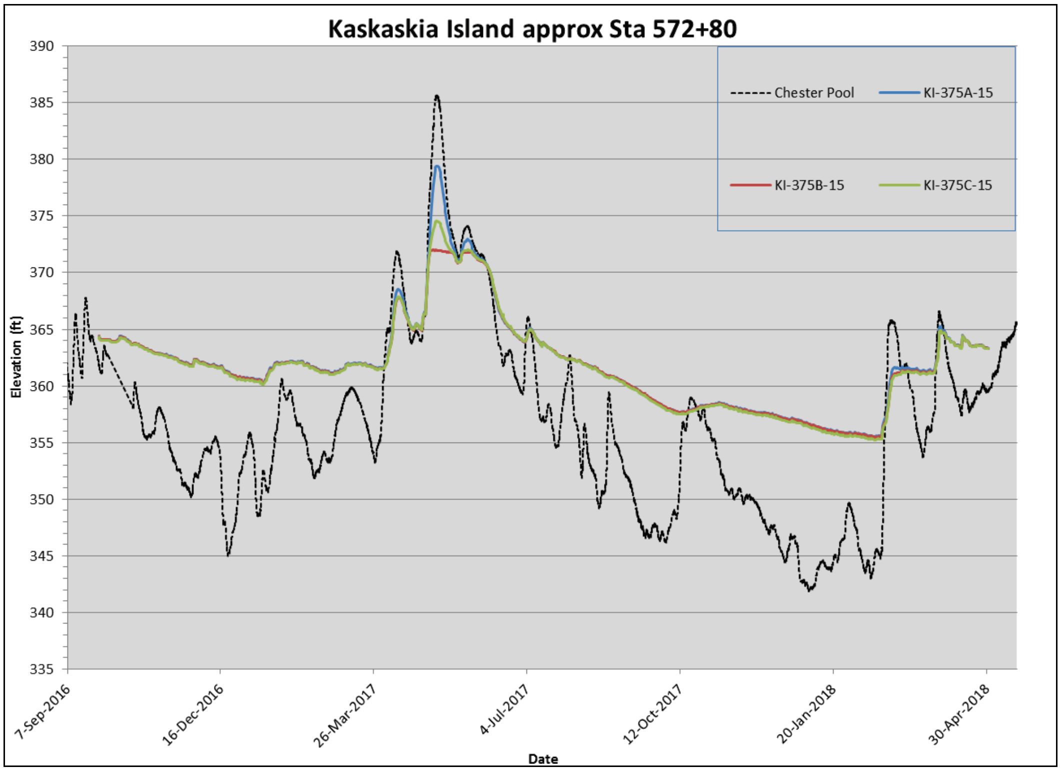


Figure 88. Piezometer data for KI-375A, B, and C from Sept 2016 through March 2018 (from Jeremy Eck, St. Louis District 2018).



For 575B and 575C wells, the calculated groundwater responses were at elevation 376.27 ft and 376.54 ft, respectively. These groundwater levels correspond to a value of h_o in a hypothetical standpipe of 7.38 and 7.81 ft above the ground surface at these well locations. The exit gradient for these locations with a 10-ft-thick blanket and no tail water was 0.738 and 0.781 for the 575B and 575C wells, respectively.

These latter values do not include a tail-water condition that occurs as shown by Figure 86. A 2-ft-deep tail-water condition in the swale reduced this value to 0.538 and 0.581 for locations 575B and 575C, respectively. These values are near the low end threshold for sand boil activity.

8.8 Design values for study reach

Design values for the study reach are compared to those measured and derived by the nearby piezometers. Seepage berm design by USACE St. Louis District (1979a, 1979b) at Kaskaskia Island was based on formulas in the Division Regulation (DIVR) 1110-1-400, Section 8, Part 6, Item 1, dated 12 December 1998. The berm width constructed during the 1979 enlargement between stations 572+00 to 587+00 (study area) was 100-ft wide. Formulas in the DIVR specified a berm thickness of 3 ft, which reduced the exit gradient at the levee toe to 0.3, and a berm length (100 ft), which results in the gradient at the berm toe being 0.8. The slope of the berm was 1 on 100 (USACE St. Louis District 1979b).

It is important to note that deviations in berm design (USACE 1978, 2000) were permitted following a joint meeting between LMVD and the St. Louis District on 14 August 1975 for exit gradients in the range between 0.5 and 0.55. These deviations were permitted based on the result of the long service record for underseepage controls in the Alton to Gale levees where underseepage controls were provided only at exit gradients greater than 0.85. Thus, where the computed exit gradient was between 0.55 and 0.8, a minimum length of 100 ft, rather than the required 150-ft-wide berm specified in current guidance, was used.

The exit gradient values obtained for the study reach using the piezometer data compare favorably to those specified in the design memorandum (USACE St. Louis District 1979b). These values were based on results of borings, geological cross sections, and blanket theory calculations described in USACE (1956a, 1956b, 2000) and the DIVR (USACE 1998).

Design values are further summarized below and were based on a flood height of 24 ft (elevation 390 ft) on the levee section with a freeboard of 3 ft. The blanket value used in the analysis was 11 ft thick (13 ft transformed thickness based on an average of the blanket soil permeability), a landside ground elevation of 367.5 ft, a tail water of 1.5 ft, a value for h_o of 7.9 ft, which yielded an exit gradient of 0.61. These values closely match those measured by the piezometer data from the study area used in estimating the 2013 conditions; however, these values occur at lower flood levels than a design flood.

Different flood stages observed on the Chester gage including the 2013, 2016, and 1993 Floods were summarized in section 8.6. The 2016 Flood on the Chester gage more closely corresponds to a 50-yr event with the Flood peak occurring on 1 January 2016 and a Chester gage at 387.03 ft. Sand boil activity was widespread in this reach, especially at the toe of the berm (Figures 70 through 76); however, the enlarged 1979 levee cross section allowed for an exit gradient at the toe of the berm at 0.8, which was below this value because of tail-water conditions landside of the berm described in section 8.7.

Performance data are unknown for the study area for the 1993 Flood, which resulted in a levee breach on the east side of the island at river mile 113, station 462+00. Because of the massive interior flooding to the island from this flood event, it is doubtful that any observations were noted at the study area for a 100-yr flood event because of the catastrophic levee breach. Earlier, the 1973 levee breach at Pujol (or Dozaville, IL), on the west side of the island at station 975+00, likely was responsible for the 1979 levee enlargement of the original 1944 levee section to meet USACE design standards for levee underseepage.

8.9 Remediation

The post-2016 Flood remediation involved construction of a 600-ft-wide seepage berm in this reach by the local levee district. This work was coordinated with the St. Louis District (Figure 85). The remediation maintained the existing berm slope and filled the prominent swale that was present at the levee toe as shown by the limits in Figure 85.

8.10 Summary

This chapter has reviewed the hydraulic factors that were responsible for sand boil formation in the study area in terms of the exit gradient producing sand boils during the 2013 Flood. Exit gradients were derived from nearby piezometer data installed in 2014 and 2015. Values for the exit gradient were compared to the design values calculated for the levee enlargement that was performed in 1979. This enlargement was responsible for the addition of a 100-ft-wide seepage berm at this location.

Flood conditions in January 2016 were similar to a design flood based on the Chester gage, but flood levels in the study area on the levee surface were slightly below the design flood height that was estimated. Values of exit gradient determined for the 2013 Flood at the edge of the berm were between 0.5 and 0.7, depending on the flood stage and the height of the tail-water conditions.

The design of the 100-ft-wide berm in 1979 allowed for an exit gradient at the toe of the berm at 0.8. Tail-water conditions present at the toe of the berm resulted in an exit gradient below this value. The use of a 100-ft-wide seepage berm that was incorporated into the design enlargement in 1979 was permitted by the LMVD following a meeting between St. Louis District and LMVD. Instead of the 150-ft-wide berm specified by USACE (2000) and

USACE St. Louis District (1979b), a 100-ft berm was approved because of successful experience with similar berms in the Alton to Gale levee system. The Kaskaskia Island levee system was not part of the Alton to Gale project.

Sand boil activity and severity observed in the study area matches values for exit gradient documented by USACE (1956a). Seepage conditions involving moderate to large floods are a common occurrence in the low-lying swales across much of the island, due to the nature of the point bar geology that exists. This geology has variable blanket or top stratum thickness beneath the levee right-of-way.

9 Summary and Conclusions

9.1 Summary

This report documents a case history of internal erosion and sand boil activity at a study site on Kaskaskia Island, IL. Conditions responsible for sand boil activity at this site during the 2013 Flood are inferred from the results of field studies performed and groundwater data measured from nearby piezometers during later flood events.

An important geologic unit for levee engineering and underseepage potential is the character and thickness of the top stratum deposits. The orientation of the levee system with the underlying geology are contributing factors for seepage potential. The presence of clay-filled swales and other site defects can increase the aquifer pressure and localize excessive underseepage potential and sand boil activity.

Field investigations were performed to determine the geology, site stratigraphy, sand boil characteristics, and groundwater conditions that caused the 2013 sand boils to occur at Kaskaskia Island. CPT characterization of the study site identified the top stratum or blanket thickness, associated soil types, and other important characteristics of the underlying stratigraphy. Closely spaced CPT data from active sand boils at the study site identified a zone of low density sands directly beneath the blanket that are part of the transport pathway to the surface.

Instead of an open pipe often used to characterize the seepage and piping mechanism, the conduit pathway instead involves an irregular-shaped low density zone beneath the blanket. The loss of foundation material in the low density zone has noticeably deformed the blanket surface in one area (slump zone) due to plastic deformation of the blanket layer.

Closely spaced resistivity surveys were able to successfully image through the top stratum and upper aquifer to determine characteristics of the stratigraphy, its thickness, and any disturbances caused by seepage pathways beneath sand boils studied. Resistivity surveys were able to successfully image the presence of resistive aquifer sands near the surface due to sand movement under artesian pressure.

Exit gradient data for the study site were derived from nearby piezometers and past matching flood and aquifer measurements to determine the hydraulic conditions that were responsible for sand boil activity during the 2013 Flood. These data were matched to design values for the levee enlargement that occurred in 1979 after the levee was upgraded following a breach on the island at Pujol, IL. Values from the 1979 levee enlargement design were compared to values calculated for the 2013 and 2016 floods, using the daily groundwater record from automated piezometer data at this site. These data were compared to empirical data gathered by USACE (1956a) to mitigate underseepage control behind levees.

9.2 Conclusions

Sand boil activity at the study site following the 2013 Flood was classified as being in the low-to-moderate range in terms of severity and throat diameter from the field notes recorded by flood fighting personnel at this location. Based on the results of the field studies that were performed, sand boil development at the Kaskaskia Island study site during the 2013 Flood occurs at exit gradients in the range of 0.5 to 0.7, depending on the tail-water depth that occurs at the toe of the berm. Sand boil activity is fairly common for exit gradients at this range (USACE 1956a).

The design of the 1979 levee enlargement at Kaskaskia Island allowed for an exit gradient of 0.8 at the toe of the 100-ft-wide seepage berm. A 100-ft-wide berm was common practice at Kaskaskia Island for the planned enlargement at gradients between 0.6 and 0.80 by USACE St. Louis District (1979a, 1979b). Long-term successful performance with the Alton to Gale levee project resulted in shorter berms being permitted at Kaskaskia Island by MVD, instead of the 150-ft-wide berms that are common practice behind levees today for gradients between 0.5 to 0.8 (USACE 2000).

The record of groundwater measurements from piezometers installed in 2014 and 2015 at the Kaskaskia Island study area was used as a proxy to estimate the exit gradients that led to sand boil formation at this location in 2013. Floods occurring after installation of these piezometers were equivalent in magnitude and duration according to the stage record from the Chester gage, which is 2.1 miles downstream from the area of interest.

An initial assumption was that the sand boil activity at Kaskaskia Island occurred during the peak flood when gradients were at their maximum; however, exit gradients above 0.5 can occur at flood stages well below the peak at the location studied because of geologic conditions that exist. The depth of tail-water seepage that collects in the low-lying swale immediately adjacent to the edge of the berm has a significant influence in terms of the landside head differential and ranges from 1 to 2 ft.

Performance data before the 2013 Flood at this location identify sand boil activity reported in 2011. Minor sand boil activity was described for this area. During the large 2016 Flood (a ~75-yr flood), this area experienced widespread sand boil activity in the study reach and extensive seepage conditions. Performance data are unknown for the study area for the 1993 Flood, which resulted in a levee breach on the east side of the island (river mile 113, station 462+00). Because of the massive interior flooding to the island from this 100-yr flood event, it is doubtful that any observations were noted at the study area because of the catastrophic levee breach.

It is highly likely that sand boil activity at this location was associated with a chronic seepage condition because of the underlying site geology, levee orientation with this geology (point bar ridge), a blocked exit condition (nearby deep swale), and the design of the short landside berm. Thus, activity at these locations tends to progress through time in terms of the severity and lower response threshold under medium to large flood events. This idea is further supported by the plastic deformation of the blanket at this location beneath a low density zone that is interpreted to be a preferred seepage pathway.

9.3 Recommendations

Resistivity surveys of large sand boil areas should be continued as part of any post-flood evaluation and analysis of the performance of the levee system. These surveys should be conducted with CPT soundings to maximize the quality of the information obtained from these surveys.

Direct observations of field conditions and water-level elevations are an important part of fully understanding system response and levee performance problems. The targeted use of unmanned aerial vehicles/systems (UAV/UAS) in chronic seepage areas would greatly facilitate better understanding of sand boil activity and local conditions that are responsible.

UAV/UAS imaging of sand boil and tail-water areas should be performed in chronic seepage areas to catalogue seepage conditions and permit direct observation of these areas for understanding of boil progression. An important addition would be the use of thermal imaging technology to discriminate temperature contrasts due to the welling of groundwater in tailwater areas and to identify and target potential seepage pipes or conduits for selective measurements.

Current UAV/UAS capabilities permit construction of elevation point clouds and elevation models at sand boils and levee sites. These data can be compared to high-resolution LiDAR data sets to determine subsidence of the levee due to loss of foundation support. Thus, it is recommended that these types of data should be routinely collected from large sand boil sites to determine any vertical changes that are occurring.

Seepage velocity is poorly documented at moderate to large sand boils and not well calibrated in terms of the exit gradient at these sand boil sites. Thus, both direct and indirect methods to measure velocity and other parameters of interest are needed in order to obtain specific measurements during active flooding.

Properties of sand boil ejecta are an important data point to determine the source in the stratigraphic column and indirect evidence of particle velocity. Samples should be collected and catalogued to provide a database of properties and characteristics.

Trenching of sand boil locations should be performed following medium to large floods to directly observe the seepage pathways and ejecta being transported. These soils should be sampled and further compared to ejecta samples from the surface.

After action flood maps showing the locations of sand boils, seepage conditions (low, moderate, and heavy), and adverse levee stability slides should be compiled to document levee performance following each flood. These maps should be evaluated, in terms of both spatial and temporal occurrences, to understand both short- and long-term trends, in terms of levee performance and characteristics of internal erosion. This information, in conjunction with field measurements from large sand boils, will provide a valuable data set to build on USACE (1956a and b) studies.

Enterprise geographic information system technology (EGIS) easily facilitates this transfer of information within USACE districts and

ERDC research laboratories. Toward this goal, it is recommended that USACE districts easily share access to this information across USACE commands. ERDC partnership with USACE districts is necessary to collect performance data from large flood events to develop better risk models of levee performance.

References

Bhowmik, N. G., S. A. Changonon, R. H. Dalton, A. Durgunoglu, M. Demissie, A. R. Juhl, H. V. Knapp, K. E. Kunkel, S. A. McConkey, R. W. Scott, K. P. Singh, T. D. Soong, R. E. Sparks, A. P. Visocky, D. R. Vonnahame, and W. M. Wendland. 1994. *The 1993 flood on the Mississippi River in Illinois*. Miscellaneous Publication 151. Champaign, IL: Illinois State Water Survey.

Chrzastowski, M. J., M. M. Killey, R. A. Bauer, P. B. DuMontelle, A. L. Erdmann, B. L. Herzog, J. M. Masters, and L. R. Smith. 1994. *The great flood of 1993, geologic perspectives on the flooding along the Mississippi River and its tributaries in Illinois*. Special Report 2. Champaign, IL: Illinois State Geological Survey.

Frankie, W. T., J. A. Devera, and M. Seid. 2008. *Horseshoe Lake State conservation area and surrounding area, Alexander County, Illinois, Illinois Department of Natural Resources*.Field Trip Guidebook 2008. Champaign, IL: Illinois State Geological Survey.

McDonough, J. L., and Co. 1883. *Combined history of Randolph, Monroe and Perry counties, Illinois*. Philadelphia: J. L. McDonough and Co.

Mississippi River Commission. 1914. *President's File # 547, map of Kaskaskia Island, Randolph County, Illinois*. Vicksburg, MS: Mississippi River Commission.

Moore, N. R. 1972. *Improvements of the Lower Mississippi River and Tributaries, 1931 – 1972*. Vicksburg, MS: Mississippi River Commission.

Palacky, G. J. 1988. Resistivity characteristics of geologic targets. In *Investigations in geophysics*. 52-129. Tulsa, OK: Society of Exploration Geophysicists.

Robertson, P. K., and K. L. Cabal (Robertson). 2010. *Guide to cone penetration testing for geotechnical engineering, 4th ed.* Signal Hill, CA: Gregg Drilling and Testing Inc.

Robertson, P., Campanella, R., Gillespie, D. and J. Greig. 1986. *Use of piezometer cone data*. Use of in-situ testing in geotechnical engineering, GSP6 Specialty Publication. Reston, VA: ASCE.

Seid, M. J. 2013. *Bedrock geology of Kaskaskia Quadrangle, Randolph County, Illinois, and Ste. Genevieve and Perry Counties, Missouri, Illinois*. Champaign, IL: State Geological Survey, Illinois Geologic Quadrangle.

Simons, D., S. Schumm, and M. Stevens. 1974. *Geomorphology of the middle Mississippi River*. Prepared for U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Turnbull, W. J., and C. I. Mansur. 1961. Investigation of underseepage-Mississippi River levees. *Transactions, ASCE* 126(1):1429-1485.

Turnbull, W. J., and C. I. Mansur. 1957. *Underseepage and its control Mississippi River levees*. Miscellaneous Paper no. 3-205. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

United States Department of the Army. 1939. *Proceedings of the soils and foundation conference of the U.S. Engineer Department, 17-21 June 1938*. Boston, MA: Corps of Engineers, U.S. Army.

United States Department of the Army. 1941. *Report of the chief of engineers, annual reports, war department, fiscal year ended June 30, 1941*. Washington, DC: War Department.

U.S. Army Corps of Engineers (USACE). 1939. *Mississippi River levees underseepage studies, Black Bayou Levee, East Bank in Mississippi, 440 M.B.C.* Vicksburg, MS: U.S. Army Corps of Engineers Vicksburg District.

_______. 1941a. *Mississippi River levee underseepage*. Vicksburg, MS: U.S. Army Corps of Engineers Vicksburg District.

_______. 1941b. *Seepage and foundation studies*. Map at 1:125,000 scale, E-MR-49. Vicksburg, MS: U.S. Army Corps of Engineers Vicksburg District.

_______. 1941c. *Studies completed or in progress at the Waterways Experiment Station, July 1, 1940 to June 30, 1941, studies of the soil mechanics division; chief of engineers annual report for U.S. Army Corps of Engineers (USACE)*. Conference on control of underseepage. Cincinnati, Ohio.

_______. 1947. *Code for utilization of soils data for levees*. Vicksburg, MS: Mississippi River Commission.

_______. 1952. *Soil mechanics design, seepage control*. EM-1110-2-1901. Washington, DC: U.S. Army Corps of Engineers.

_______. 1955. *Relief well design*. Civil Works Engineer Bulletin 55-11. Washington, DC: U.S. Army Corps of Engineers.

_______. 1956a. *Investigation of underseepage and its control, Lower Mississippi River levees*. Technical Memorandum No. 3-424, prepared for President, Mississippi River Commission. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

_______. 1956b. *Investigation of underseepage, Alton to Gale, IL*. Technical Memorandum No. 3-430, prepared for President, Mississippi River Commission. Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station.

_______. 1978. *Design and construction of levees*. EM-1110-2-1913 (First Publication). Washington, DC: Department of the Army.

_______. 1992. *Design, construction, and maintenance of relief wells*. EM 1110-2-1914. Washington, DC: U.S. Army Corps of Engineers.

_______. 1993. *Seepage analysis and control for dams*. EM-1110-2-1901. Washington, DC: U.S. Army Corps of Engineers.

_______. 1998. *Engineering and design soil mechanics data*. Division Regulation (DIVR) 1110-1-400 (Change 2). Washington, DC: Department of the Army.

_______. 2000. *Design and construction of levees*. EM-1110-2-1913 (Second Publication). Washington, DC: Department of the Army.

_______. 2018a. *Design and construction of levees*. EM-1110-2-1913. Washington, DC: Department of the Army.

_______. 2018b. *Corrections, revisions, and clarification of EM 1110-2-1914; design, construction, and maintenance of relief wells*. Engineering and Construction Bulletin. Washington, DC: U.S. Army Corps of Engineers.

USACE, St. Louis District. 1973. *Kaskaskia Island drainage and levee district, Illinois*. Design Memorandum No. 2, General Design Memorandum Phase II. St. Louis, MO: USACE St. Louis District.

_______. 1976. *Re-evaluation of underseepage controls Mississippi River levees, Alton to Gale, IL, Phase 1: Performance of underseepage controls during the 1973 flood*. St. Louis, MO: USACE St. Louis District.

_______. 1977a. *General design memorandum, Phase 1 plan formulation, Kaskaskia Island drainage and levee district, Illinois*. St. Louis, MO: USACE St. Louis District.

_______. 1977b. *Final environmental statement, Kaskaskia Island drainage and levee District, Illinois*. St. Louis, MO: USACE St. Louis District.

_______. 1979a. *General design memorandum phase II, part A*. St. Louis, MO: USACE St. Louis District.

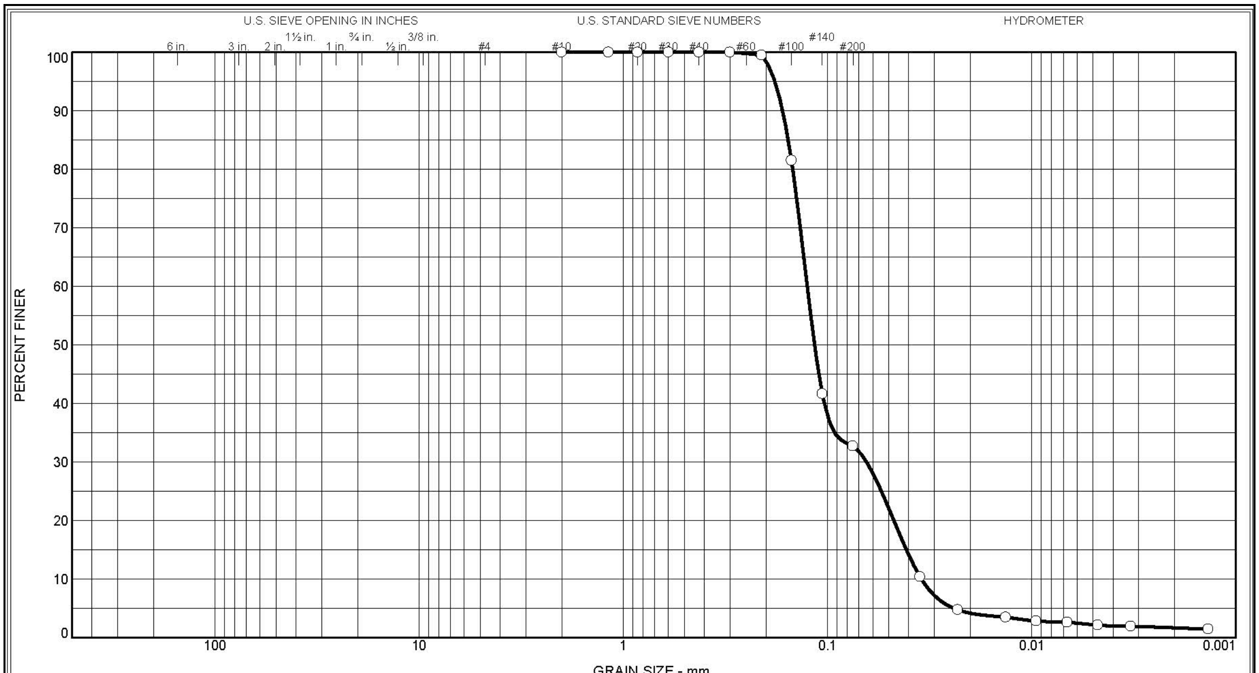
_______. 1979b. *General design memorandum phase II, part B – plates*. St. Louis, MO: USACE St. Louis District.

Warner and Beers. 1876. Map of Randolph County, Red Bud and Chester; Union County Atlas Co. www.davidrumsey.com.

Woerner, E. G., J. B. Dunbar, E. Villanueva, and L. M. Smith. 2003. *Geologic investigation of the middle Mississippi River*. ERDC/GSL TR-03-7. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Appendix A: Soil Curves from Ejecta Samples from Sand Boil Cones

MD1514KK-1 (0 - 12 in.):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	KK-1	0-12"	Silty Sand (SM), Gray			NP	

Project Cape Girardeau

Area

Boring No.

Particle Size Distribution Report

Date: 8/6/2014

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/LDD Checked By: JFB

GRAIN SIZE DISTRIBUTION TEST DATA

8/6/2014

Project: Cape Girardeau
Depth: 0-12" **Sample Number:** KK-1
Material Description: Silty Sand (SM), Gray
PL: NP
Tested by: AT/LDD **Checked by:** JFB

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
99.60	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.50	99.5
			#100	18.40	81.5
			#140	58.10	41.7
			#200	67.00	32.7

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =99.6
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.67 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 **-** 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.0	1.0112	1.0065	0.0136	10.7	13.5	0.0352	10.4
5.00	20.0	1.0077	1.0030	0.0136	7.2	14.4	0.0230	4.8
15.00	20.0	1.0069	1.0022	0.0136	6.4	14.6	0.0134	3.5
30.00	20.0	1.0065	1.0018	0.0136	6.0	14.7	0.0095	2.8
60.00	20.5	1.0063	1.0016	0.0135	5.8	14.8	0.0067	2.6
120.00	20.5	1.0060	1.0013	0.0135	5.5	14.8	0.0047	2.2
250.00	21.0	1.0058	1.0012	0.0134	5.3	14.9	0.0033	1.9
1440.00	21.0	1.0055	1.0009	0.0134	5.0	15.0	0.0014	1.5

CEERD-GS-E

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	67.3	67.3	30.5	2.2	32.7

D_{10}	D_{15}	D_{20}	D_{30}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
0.0346	0.0411	0.0473	0.0643	0.1156	0.1256	0.1478	0.1555	0.1657	0.1808

Fineness Modulus	C_u	C_c
0.18	3.63	0.95

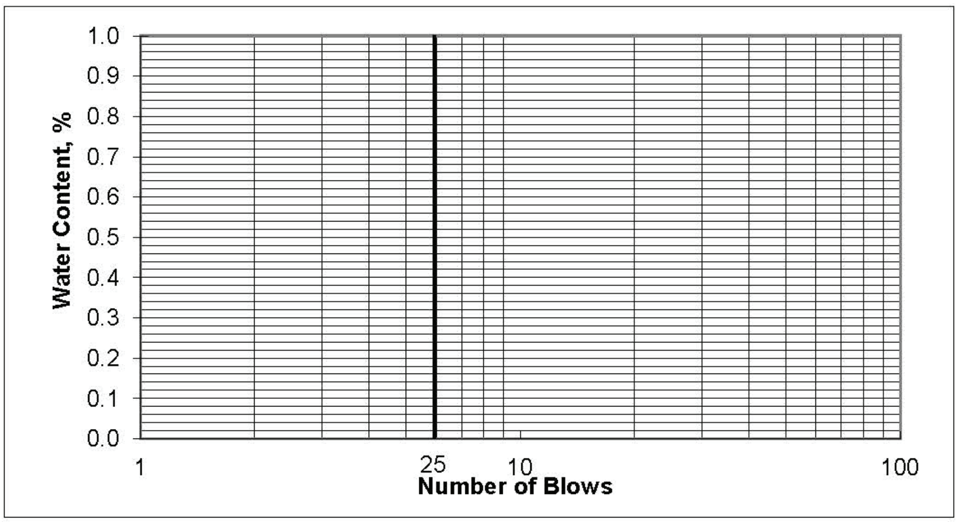
LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

WORK ORDER NO.	MD1514	DATE	7/25/2014
PROJECT	Cape Girardeau		
BORING NO.		SAMPLE NO.	KK-1 0-12"

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL
PL
PI

Symbol from plasticity chart

SM

Plastic LIMIT

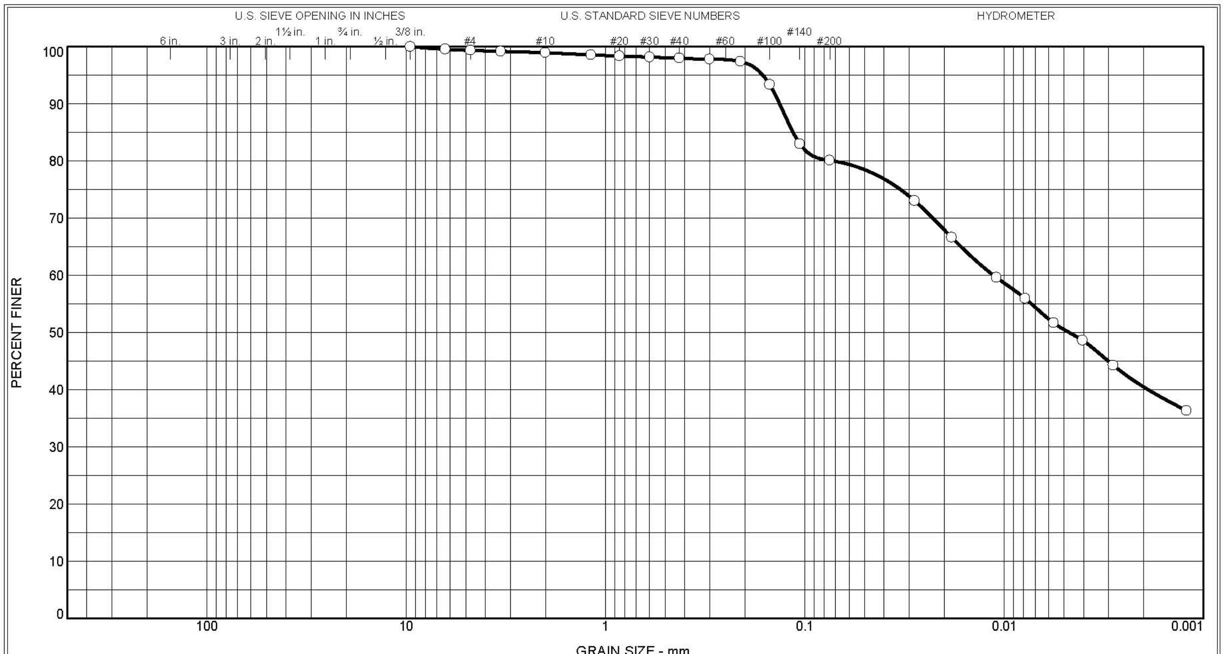
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silty Sand (SM), Gray

Technician AT Computed By AT Checked By JFB

Revised 5/21/09

MD1514KK-1 (1.5 - 2.5 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	KK-1	1.5-2.5′	Clay (CH) with Sand, Gray		62	21	41
		(Blanket)					

Project Cape Girardeau

Area

Boring No.

Particle Size Distribution Report

Date: 8/6/2014

Corps of Engineers

ENG FORM 1 MAY 63 **2087**

Tested By: AT/LDD **Checked By:** JFB

GRAIN SIZE DISTRIBUTION TEST DATA

8/6/2014

Project: Cape Girardeau
Depth: 1.5-2.5' (Blanket) **Sample Number:** KK-1
Material Description: Clay (CH) with Sand, Gray
PL: 21 **LL:** 62
PI: 41
Tested by: AT/LDD **Checked by:** JFB

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
565.00	0.00	0.00	3/8 IN	0.00	100.0
			1/4 IN	2.50	99.6
			#4	3.60	99.4
			#6	4.60	99.2
			#10	5.90	99.0
51.50	0.00	0.00	#16	0.20	98.6
			#20	0.30	98.4
			#30	0.40	98.2
			#40	0.50	98.0
			#50	0.60	97.8
			#70	0.80	97.4
			#100	2.90	93.4
			#140	8.30	83.0
			#200	9.80	80.1

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 99.0
Weight of hydrometer sample =51.5
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.70 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.5	1.0286	1.0239	0.0134	28.1	8.9	0.0281	73.1
5.00	20.5	1.0265	1.0218	0.0134	26.0	9.4	0.0183	66.6
15.00	20.5	1.0242	1.0195	0.0134	23.7	10.0	0.0109	59.6
30.00	20.5	1.0230	1.0183	0.0134	22.5	10.3	0.0078	56.0
60.00	20.5	1.0216	1.0169	0.0134	21.1	10.7	0.0056	51.7
120.00	20.5	1.0206	1.0159	0.0134	20.1	11.0	0.0040	48.6
250.00	21.0	1.0191	1.0145	0.0133	18.6	11.4	0.0028	44.3
1440.00	21.0	1.0165	1.0119	0.0133	16.0	12.1	0.0012	36.3

CEERD-GS-E

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.6	0.6	0.4	1.0	17.9	19.3	29.6	50.5	80.1

D_{10}	D_{15}	D_{20}	D_{30}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
				0.0047	0.0113	0.0713	0.1145	0.1337	0.1619

Fineness Modulus
0.14

CEERD-GS-E

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

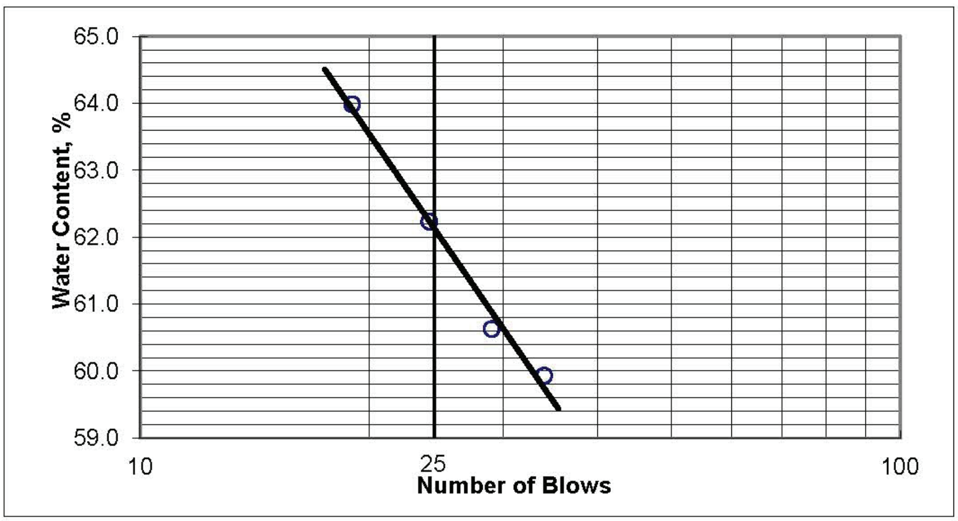
WORK ORDER NO. MD1514 DATE 8/1/2014

PROJECT Cape Girardeau

BORING NO. SAMPLE NO. KK-1 1.5-2.5'

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.	297	K51	A5	310			
Tare Plus Wet Soil, g	34.25	34.47	33.72	35.69			
Tare Plus Dry Soil, g	27.13	27.91	26.75	28.05			
Water, g	7.12	6.56	6.97	7.64			
Tare, g	15.25	17.09	15.55	16.11			
Dry Soil, g	11.88	10.82	11.20	11.94			
Water content, %	59.9	60.6	62.2	64.0			
Number of Blows	34	29	24	19			



LL	62
PL	21
PI	41

Symbol from plasticity chart

(CH)

Plastic LIMIT

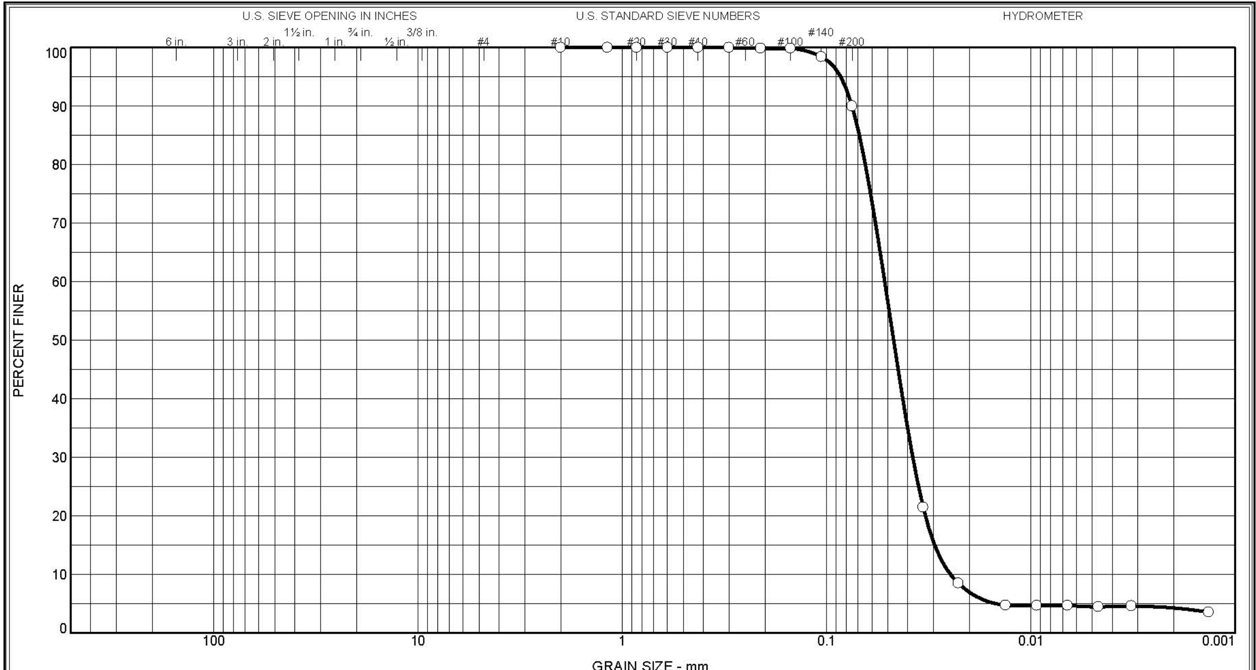
Run No.	1	2	3	4	5	6	7
Tare No.	A18	13					
Tare Plus Wet Soil, g	24.78	25.53					
Tare Plus Dry Soil, g	23.27	23.89					
Water, g	1.51	1.64					
Tare, g	15.94	16.03					
Dry Soil, g	7.33	7.86					
Water content, %	20.6	20.9					
Plastic Limit	20.7						

Remarks Clay (CH), Gray

Technician L.D.D. Computed By L.D.D. Checked By JFB

Revised 5/21/09

MD1514KK-2A:



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	KK-2A		Silt (ML), Gray			NP	

Project Cape Girardeau

Area

Boring No.

Particle Size Distribution Report

Date: 8/6/2014

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/LDD Checked By: JFB

GRAIN SIZE DISTRIBUTION TEST DATA

8/6/2014

Project: Cape Girardeau
Sample Number: KK-2A
Material Description: Silt (ML), Gray
PL: NP
Tested by: AT/LDD **Checked by:** JFB

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
76.10	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.10	99.9
			#100	0.10	99.9
			#140	1.20	98.4
			#200	7.60	90.0

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =76.1
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.69 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.0	1.0150	1.0103	0.0135	14.5	12.5	0.0337	21.5
5.00	20.0	1.0088	1.0041	0.0135	8.3	14.1	0.0226	8.5
15.00	20.0	1.0070	1.0023	0.0135	6.5	14.6	0.0133	4.8
30.00	20.5	1.0069	1.0022	0.0134	6.4	14.6	0.0093	4.7
60.00	20.5	1.0069	1.0022	0.0134	6.4	14.6	0.0066	4.7
120.00	20.5	1.0068	1.0021	0.0134	6.3	14.6	0.0047	4.5
250.00	21.0	1.0068	1.0022	0.0133	6.3	14.6	0.0032	4.6
1440.00	21.0	1.0063	1.0017	0.0133	5.8	14.8	0.0013	3.6

CEERD-GS-E

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	10.0	10.0	85.5	4.5	90.0

D_{10}	D_{15}	D_{20}	D_{30}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
0.0247	0.0295	0.0328	0.0378	0.0470	0.0519	0.0646	0.0691	0.0750	0.0852

Fineness Modulus	C_u	C_c
0.00	2.10	1.12

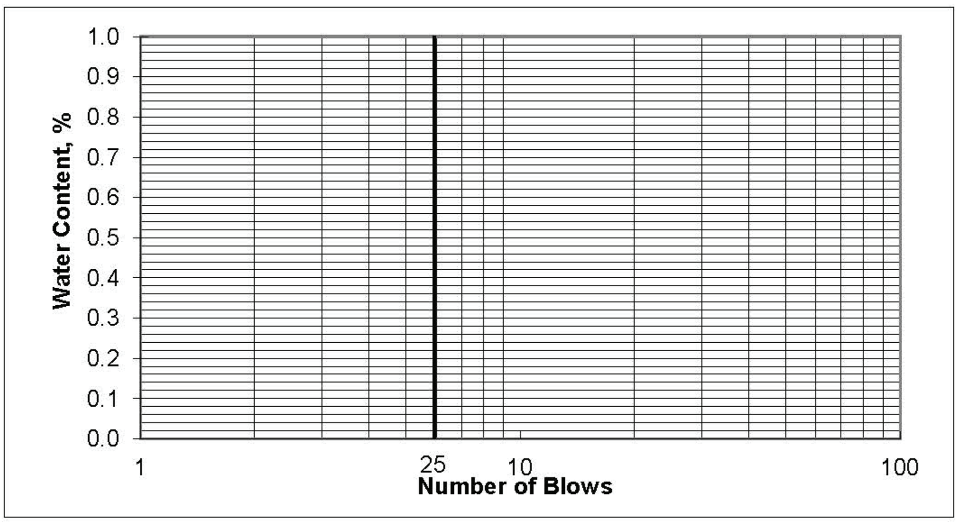
LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

WORK ORDER NO.	MD1514	DATE	7/25/2014
PROJECT	Cape Girardeau		
BORING NO.		SAMPLE NO.	KK-2A

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL	
PL	
PI	
Symbol from plasticity chart	SM

Plastic LIMIT

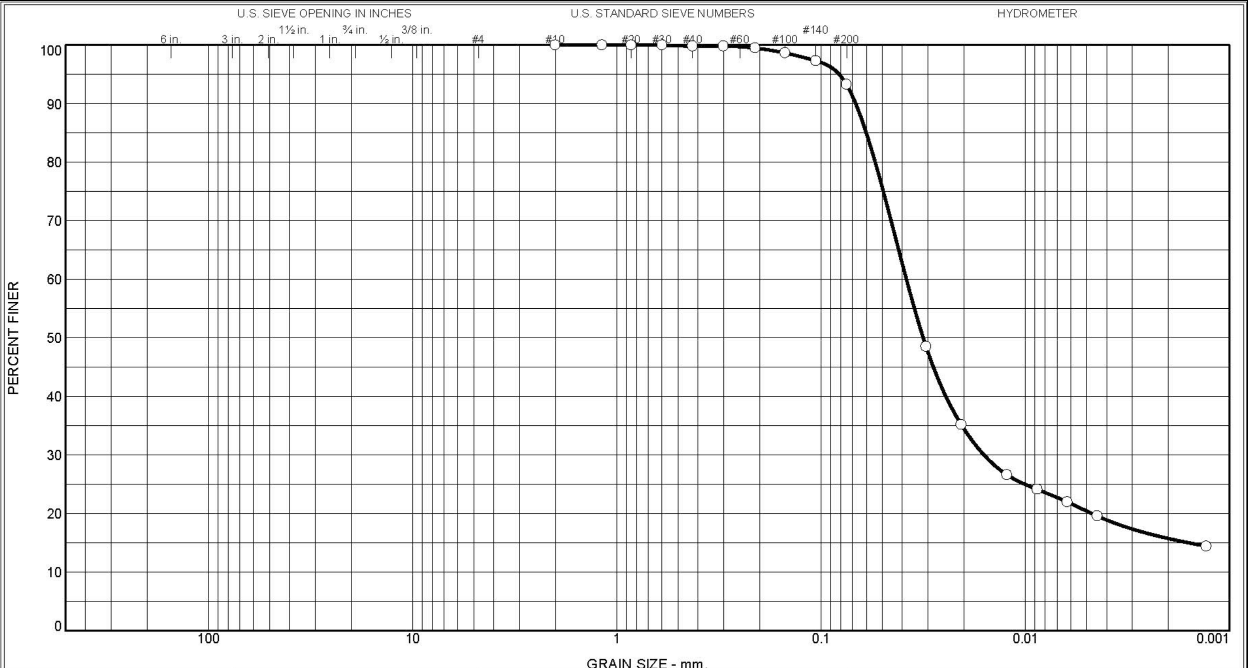
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks: Non-Plastic Silty Sand (SM), Gray

Technician	AT	Computed By	AT	Checked By	JFB

Revised 5/21/09

MD1514KK-2B:



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	KK-2B		Clay (CL), Gray		35	23	12

Project Cape Girardeau

Area

Boring No.

Particle Size Distribution Report

Date: 8/6/2014

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/LDD Checked By: JFB

GRAIN SIZE DISTRIBUTION TEST DATA

8/6/2014

Project: Cape Girardeau
Sample Number: KK-2B
Material Description: Clay (CL), Gray
PL: 23 **LL:** 35
PI: 12
Tested by: AT/LDD **Checked by:** JFB

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
59.50	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.10	99.8
			#50	0.10	99.8
			#70	0.30	99.5
			#100	0.80	98.7
			#140	1.60	97.3
			#200	4.00	93.3

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =59.5
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.70 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 **-** 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.0	1.0229	1.0182	0.0134	22.4	10.4	0.0306	48.5
5.00	20.0	1.0179	1.0132	0.0134	17.4	11.7	0.0206	35.2
15.00	20.0	1.0147	1.0100	0.0134	14.2	12.5	0.0123	26.6
30.00	20.5	1.0137	1.0090	0.0134	13.2	12.8	0.0087	24.1
60.00	20.5	1.0129	1.0082	0.0134	12.4	13.0	0.0062	22.0
120.00	20.5	1.0120	1.0073	0.0134	11.5	13.3	0.0044	19.6
1440.00	21.0	1.0100	1.0054	0.0133	9.5	13.8	0.0013	14.4

CEERD-GS-E

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.2	6.5	6.7	72.9	20.4	93.3

D_{10}	D_{15}	D_{20}	D_{30}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
	0.0016	0.0047	0.0159	0.0316	0.0382	0.0543	0.0600	0.0676	0.0814

Fineness Modulus
0.02

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

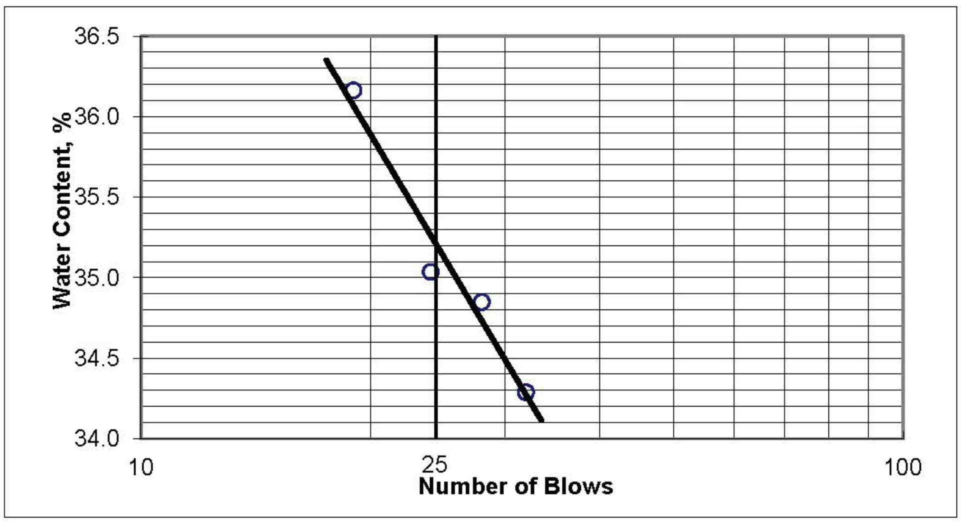
WORK ORDER NO. MD1514 DATE 1 Aug. 14

PROJECT Cape Girardeau

BORING NO. SAMPLE NO. KK-2B

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.	109	11	14	K15			
Tare Plus Wet Soil, g	32.46	33.77	34.70	40.67			
Tare Plus Dry Soil, g	28.15	29.17	29.83	34.45			
Water, g	4.31	4.60	4.87	6.22			
Tare, g	15.58	15.97	15.93	17.25			
Dry Soil, g	12.57	13.20	13.90	17.20			
Water content, %	34.3	34.8	35.0	36.2			
Number of Blows	32	28	24	19			



LL	35
PL	23
PI	12

Symbol from plasticity chart

(CL)

Plastic LIMIT

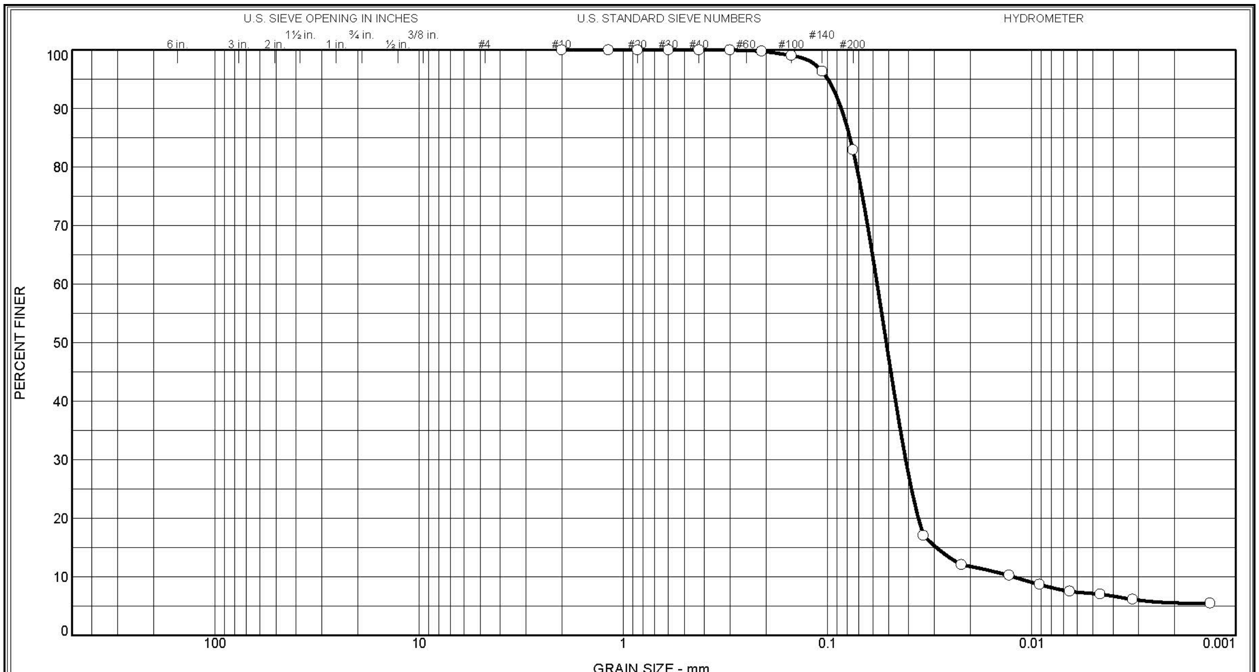
Run No.	1	2	3	4	5	6	7
Tare No.	A22	47					
Tare Plus Wet Soil, g	25.81	25.78					
Tare Plus Dry Soil, g	23.79	23.83					
Water, g	2.02	1.95					
Tare, g	15.19	15.50					
Dry Soil, g	8.60	8.33					
Water content, %	23.5	23.4					
Plastic Limit	23.4						

Remarks Clay (CL), Gray

Technician L.D.D. Computed By L.D.D. Checked By JFB

Revised 5/21/09

MD1514KK-2C:



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
KK-2C		Silty Sand (SM), Gray			NP	

Project Cape Girardeau

Area

Boring No.

Particle Size Distribution Report

Date: 8/6/2014

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/LDD **Checked By:** JFB

GRAIN SIZE DISTRIBUTION TEST DATA

8/6/2014

Project: Cape Girardeau
Sample Number: KK-2C
Material Description: Silty Sand (SM), Gray
PL: NP
Tested by: AT/LDD **Checked by:** JFB

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
96.20	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.20	99.8
			#100	0.90	99.1
			#140	3.50	96.4
			#200	16.40	83.0

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =96.2
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.67 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.0	1.0150	1.0103	0.0136	14.5	12.5	0.0339	17.1
5.00	20.0	1.0120	1.0073	0.0136	11.5	13.3	0.0221	12.1
15.00	20.0	1.0109	1.0062	0.0136	10.4	13.5	0.0129	10.3
30.00	20.5	1.0099	1.0052	0.0135	9.4	13.8	0.0091	8.7
60.00	20.5	1.0092	1.0045	0.0135	8.7	14.0	0.0065	7.5
120.00	20.5	1.0089	1.0042	0.0135	8.4	14.1	0.0046	7.0
250.00	21.0	1.0083	1.0037	0.0134	7.8	14.2	0.0032	6.2
1440.00	21.0	1.0079	1.0033	0.0134	7.4	14.3	0.0013	5.5

CEERD-GS-E

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	17.0	17.0	75.8	7.2	83.0

D_{10}	D_{15}	D_{20}	D_{30}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
0.0122	0.0292	0.0359	0.0414	0.0515	0.0571	0.0719	0.0775	0.0855	0.0993

Fineness Modulus	C_u	C_c
0.01	4.66	2.45

CEERD-GS-E

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

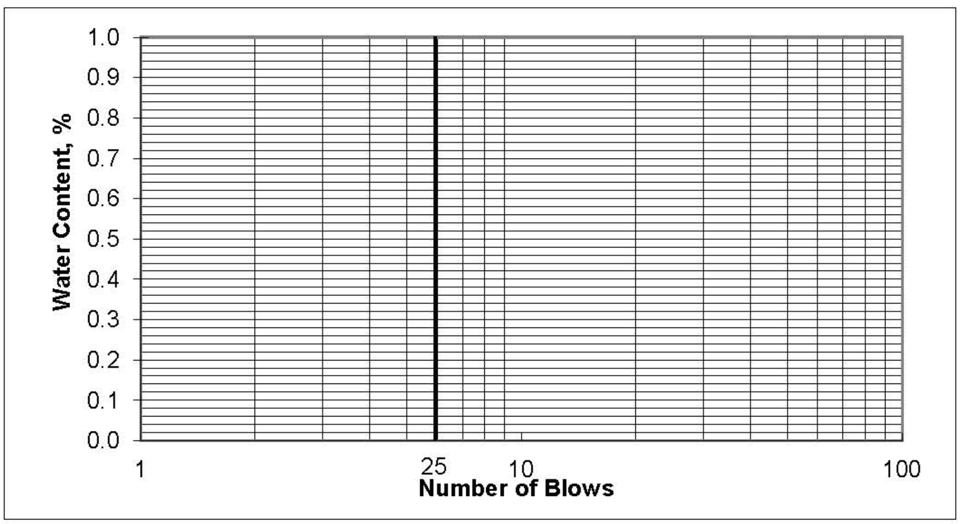
WORK ORDER NO. MD1514 DATE 7/25/2014

PROJECT Cape Girardeau

BORING NO. SAMPLE NO. KK-2C

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL

PL

PI

Symbol from plasticity chart

SM

Plastic LIMIT

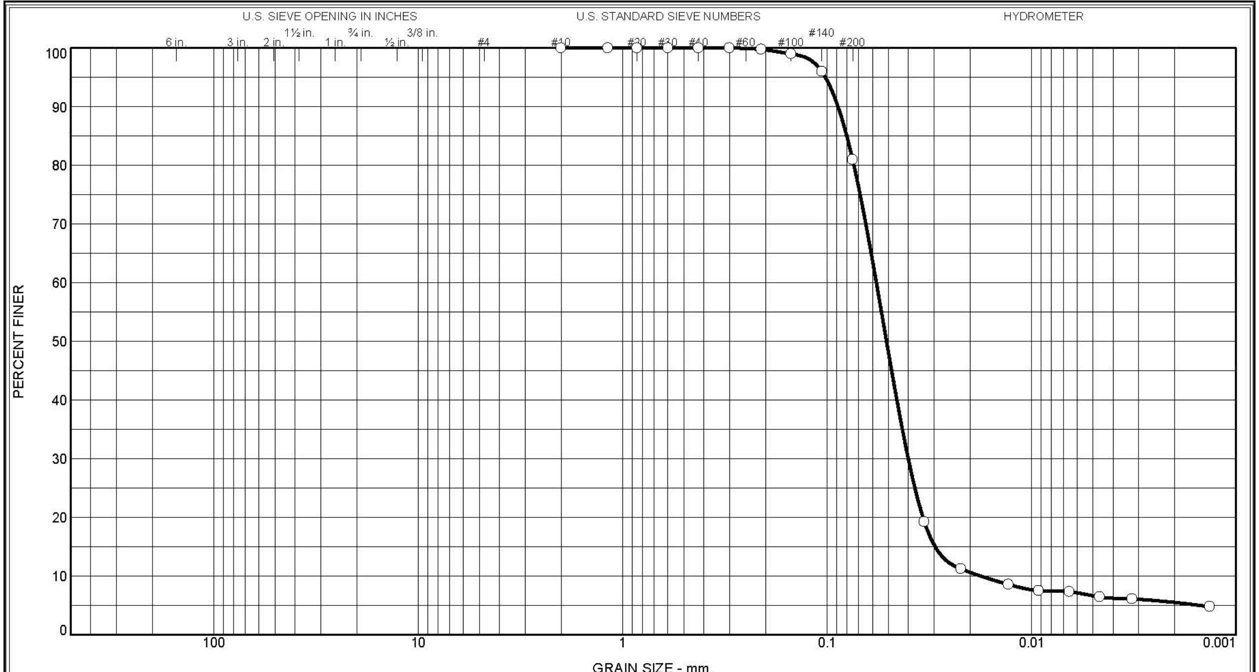
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silty Sand (SM), Gray

Technician AT Computed By AT Checked By JFB

Revised 5/21/09

MD1514KK-3 (0 – 8 in.):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	KK-3	0-8"	Silt (ML) with Sand, Gray			NP	

Project Cape Girardeau

Area

Boring No.

Particle Size Distribution Report

Date: 8/6/2014

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/LDD **Checked By:** JFB

GRAIN SIZE DISTRIBUTION TEST DATA

8/6/2014

Project: Cape Girardeau
Depth: 0-8" **Sample Number:** KK-3
Material Description: Silt (ML) with Sand, Gray
PL: NP
Tested by: AT/LDD **Checked by:** JFB

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
90.00	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.20	99.8
			#100	0.90	99.0
			#140	3.60	96.0
			#200	17.10	81.0

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =90.0
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.67 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 x **Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.5	1.0155	1.0108	0.0135	15.0	12.3	0.0335	19.3
5.00	20.5	1.0110	1.0063	0.0135	10.5	13.5	0.0222	11.3
15.00	20.5	1.0095	1.0048	0.0135	9.0	13.9	0.0130	8.6
30.00	20.5	1.0089	1.0042	0.0135	8.4	14.1	0.0092	7.5
60.00	20.5	1.0088	1.0041	0.0135	8.3	14.1	0.0065	7.4
120.00	20.5	1.0083	1.0036	0.0135	7.8	14.2	0.0046	6.5
250.00	20.5	1.0081	1.0034	0.0135	7.6	14.3	0.0032	6.1
1440.00	21.0	1.0073	1.0027	0.0134	6.8	14.5	0.0013	4.8

CEERD-GS-E

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	19.0	19.0	74.3	6.7	81.0

D_{10}	D_{15}	D_{20}	D_{30}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
0.0176	0.0296	0.0340	0.0401	0.0512	0.0574	0.0739	0.0801	0.0884	0.1018

Fineness Modulus	C_u	C_c
0.01	3.25	1.59

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

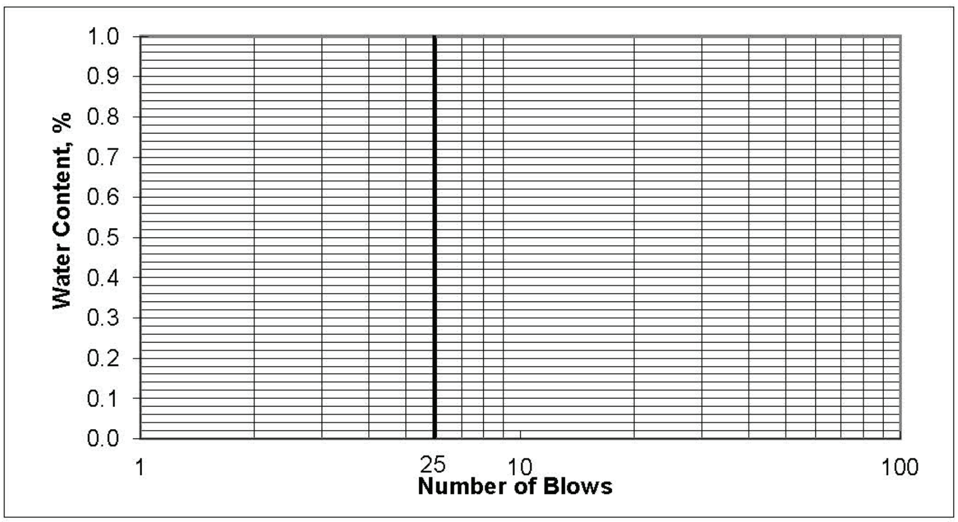
WORK ORDER NO. MD1514 DATE 7/25/2014

PROJECT Cape Girardeau

BORING NO. SAMPLE NO. KK-3 0-8"

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL

PL

PI

Symbol from plasticity chart: SM

Plastic LIMIT

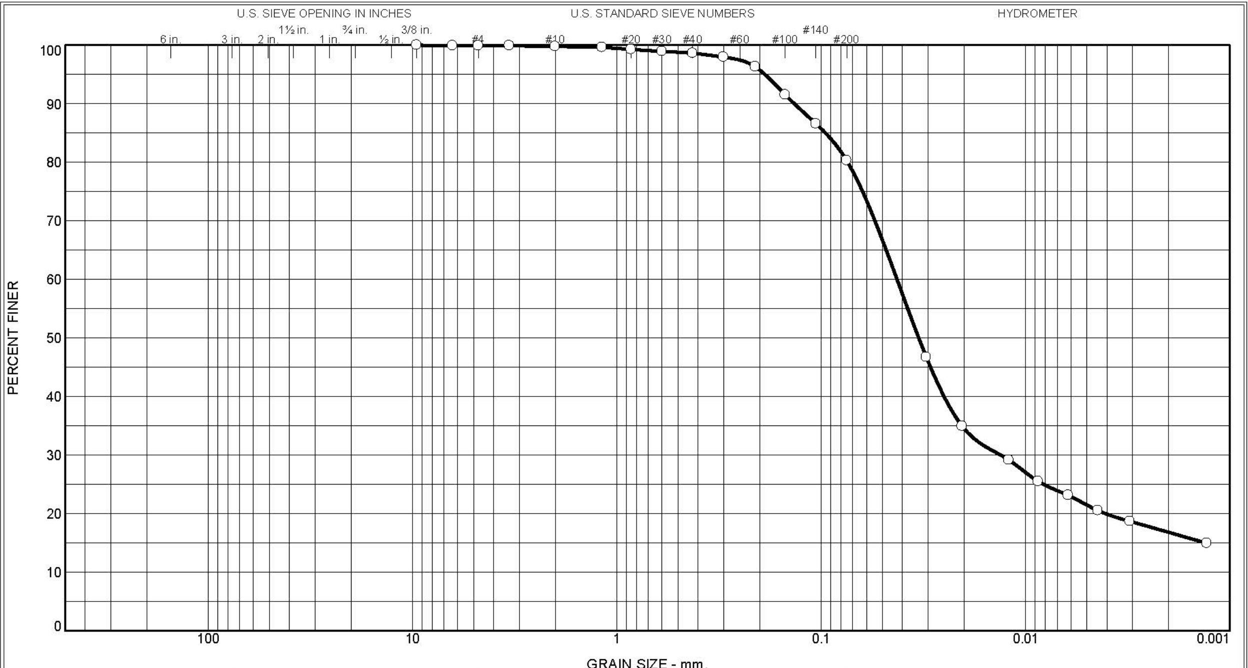
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silty Sand (SM), Gray

Technician AT Computed By AT Checked By JFB

Revised 5/21/09

MD1514KK-3 (0 – 22 in.):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	KK-3	0-22"	Clay (CL) with Sand, Gray		44	19	25

Project Cape Girardeau

Area

Boring No.

Particle Size Distribution Report

Date: 8/15/2014

Corps of Engineers

ENG FORM 1 MAY 63 **2087**

Tested By: AT/LDD **Checked By:** JFB

GRAIN SIZE DISTRIBUTION TEST DATA

8/15/2014

Project: Cape Girardeau
Depth: 0-22" **Sample Number:** KK-3
Material Description: Clay (CL) with Sand, Gray
PL: 19 **LL:** 44
PI: 25
Tested by: AT/LDD **Checked by:** JFB

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
531.00	0.00	0.00	3/8 IN	0.00	100.0
			1/4 IN	0.50	99.9
			#4	0.50	99.9
			#6	0.50	99.9
			#10	1.20	99.8
60.50	0.00	0.00	#16	0.10	99.6
			#20	0.30	99.3
			#30	0.50	98.9
			#40	0.70	98.6
			#50	1.10	98.0
			#70	2.10	96.3
			#100	5.00	91.5
			#140	8.00	86.6
			#200	11.80	80.3

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 99.8
Weight of hydrometer sample =60.5
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.70
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.5	1.0225	1.0178	0.0134	22.0	10.5	0.0306	46.7
5.00	20.5	1.0180	1.0133	0.0134	17.5	11.7	0.0204	34.9
15.00	20.5	1.0158	1.0111	0.0134	15.3	12.2	0.0121	29.2
30.00	20.5	1.0144	1.0097	0.0134	13.9	12.6	0.0087	25.5
60.00	20.5	1.0135	1.0088	0.0134	13.0	12.9	0.0062	23.2
120.00	20.5	1.0125	1.0078	0.0134	12.0	13.1	0.0044	20.5
250.00	20.5	1.0118	1.0071	0.0134	11.3	13.3	0.0031	18.7
1440.00	21.0	1.0103	1.0057	0.0133	9.8	13.7	0.0013	15.0

CEERD-GS-E

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.1	0.1	0.1	1.2	18.3	19.6	58.8	21.5	80.3

D_{10}	D_{15}	D_{20}	D_{30}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
	0.0013	0.0041	0.0132	0.0333	0.0425	0.0741	0.0953	0.1353	0.1883

Fineness Modulus
0.12

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

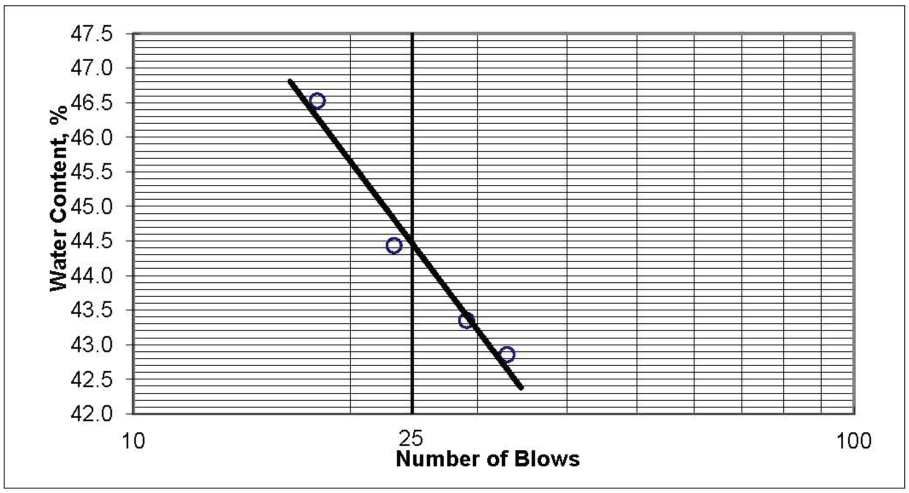
WORK ORDER NO. MD1514 DATE 1 Aug. 14

PROJECT Cape Girardeau

BORING NO. SAMPLE NO. KK-3 0-22"

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.	K66	K10	K9	528			
Tare Plus Wet Soil, g	37.36	32.92	32.74	32.41			
Tare Plus Dry Soil, g	31.36	28.16	27.99	27.12			
Water, g	6.00	4.76	4.75	5.29			
Tare, g	17.36	17.18	17.30	15.75			
Dry Soil, g	14.00	10.98	10.69	11.37			
Water content, %	42.9	43.4	44.4	46.5			
Number of Blows	33	29	23	18			



LL	44
PL	19
PI	25

Symbol from plasticity chart: (CL)

Plastic LIMIT

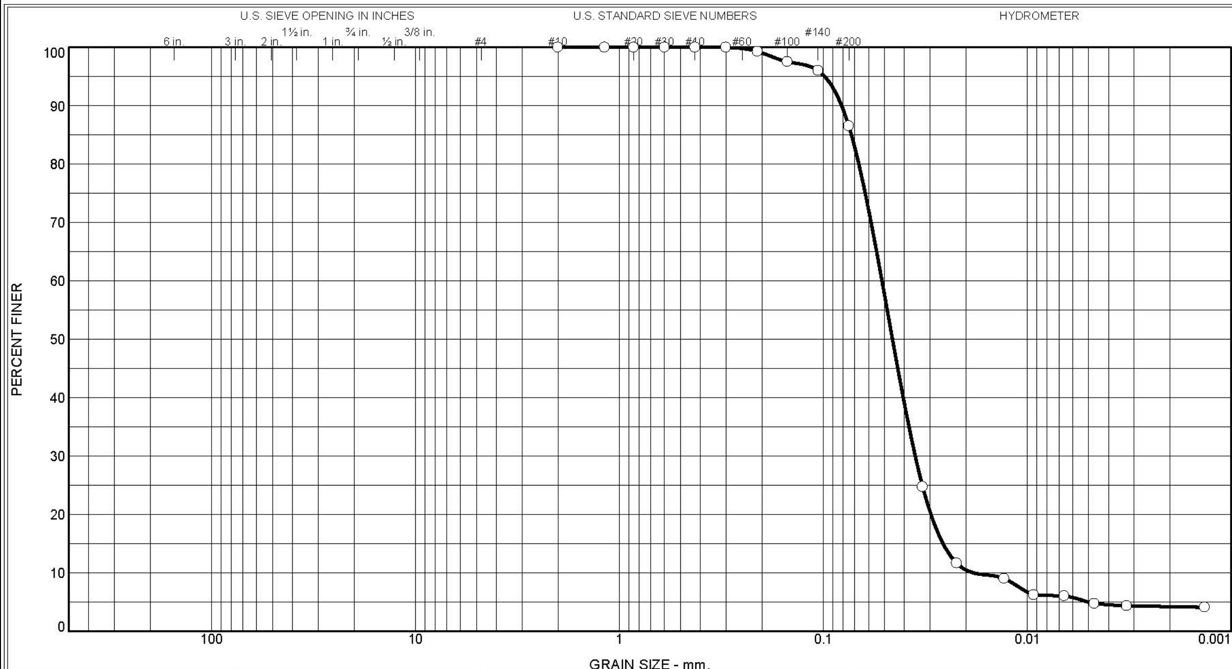
Run No.	1	2	3	4	5	6	7
Tare No.	K24	A40					
Tare Plus Wet Soil, g	26.36	24.91					
Tare Plus Dry Soil, g	24.88	23.42					
Water, g	1.48	1.49					
Tare, g	17.25	15.61					
Dry Soil, g	7.63	7.81					
Water content, %	19.4	19.1					
Plastic Limit	19.2						

Remarks Clay (CL), Gray

Technician L.D.D. Computed By L.D.D. Checked By JFB

Revised 5/21/09

MD1514KK-4 (0 – 8 in.):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
KK-4	0-8"	Silt (ML), Gray			NP	

Project Cape Girardeau

Area

Boring No.

Particle Size Distribution Report

Date: 8/6/2014

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/LDD Checked By: JFB

GRAIN SIZE DISTRIBUTION TEST DATA

8/6/2014

Project: Cape Girardeau
Depth: 0-8" **Sample Number:** KK-4
Material Description: Silt (ML), Gray
PL: NP
Tested by: AT/LDD **Checked by:** JFB

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
85.50	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.60	99.3
			#100	2.10	97.5
			#140	3.40	96.0
			#200	11.50	86.5

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =85.5
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.67 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 **-** 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.5	1.0179	1.0132	0.0135	17.4	11.7	0.0326	24.8
5.00	20.5	1.0109	1.0062	0.0135	10.4	13.5	0.0222	11.7
15.00	20.5	1.0095	1.0048	0.0135	9.0	13.9	0.0130	9.1
30.00	20.5	1.0080	1.0033	0.0135	7.5	14.3	0.0093	6.2
60.00	20.5	1.0079	1.0032	0.0135	7.4	14.3	0.0066	6.1
120.00	20.5	1.0072	1.0025	0.0135	6.7	14.5	0.0047	4.7
250.00	20.5	1.0070	1.0023	0.0135	6.5	14.6	0.0033	4.4
1440.00	21.0	1.0068	1.0022	0.0134	6.3	14.6	0.0014	4.1

CEERD-GS-E

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	13.5	13.5	81.5	5.0	86.5

D_{10}	D_{15}	D_{20}	D_{30}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
0.0183	0.0259	0.0297	0.0354	0.0458	0.0516	0.0670	0.0728	0.0812	0.0982

Fineness Modulus	C_u	C_c
0.02	2.82	1.33

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

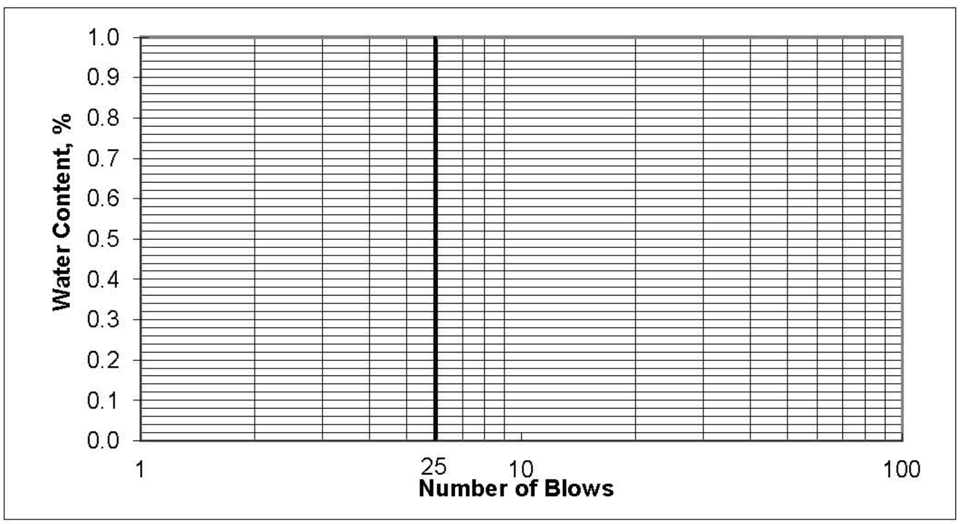
WORK ORDER NO. MD1514 DATE 7/25/2014

PROJECT Cape Girardeau

BORING NO. SAMPLE NO. KK-4 0-8"

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL
PL
PI

Symbol from plasticity chart: SM

Plastic LIMIT

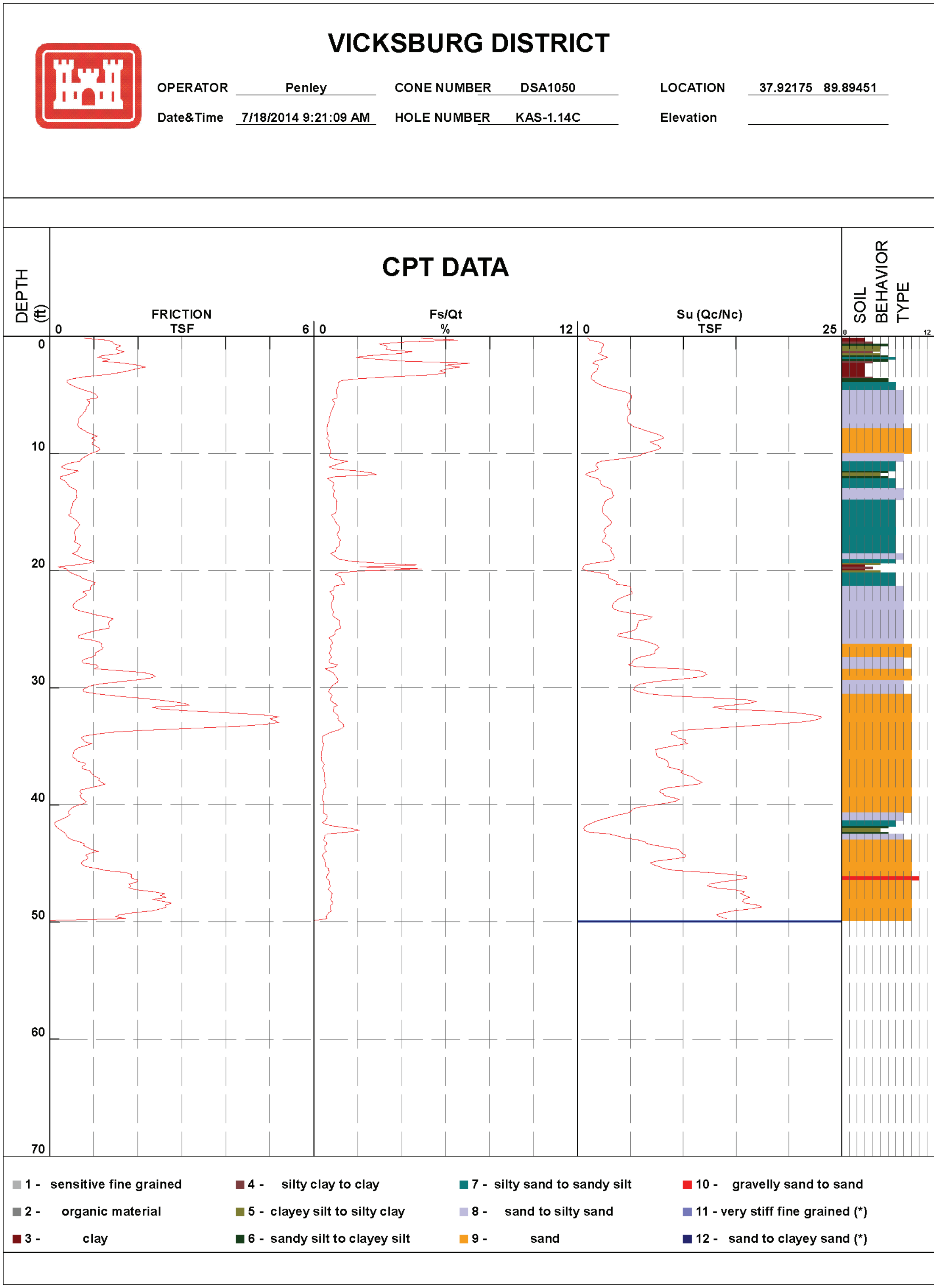
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silty Sand (SM), Gray

Technician AT Computed By AT Checked By JFB

Revised 5/21/09

Appendix B: CPT Boring Logs

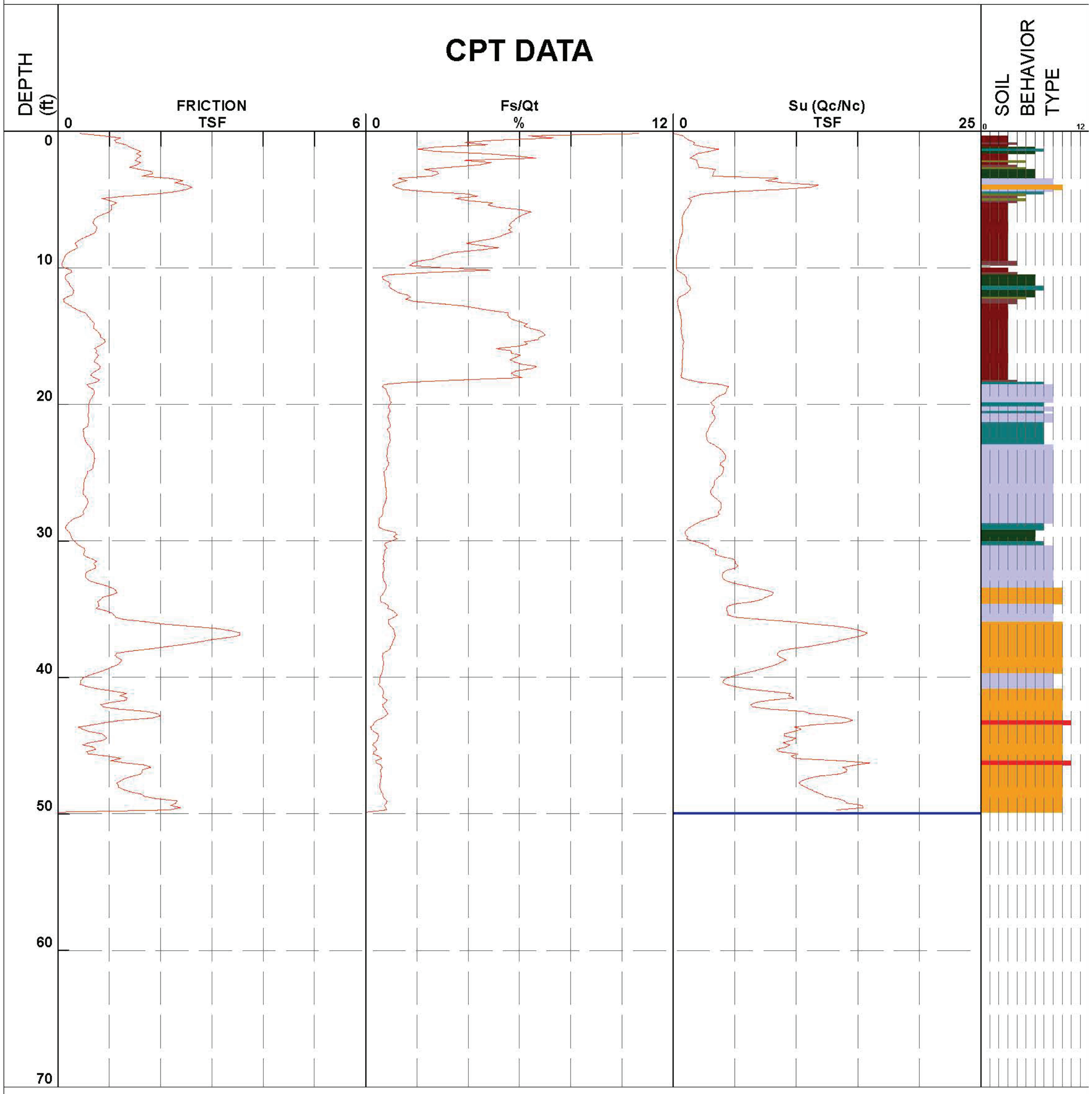

VICKSBURG DISTRICT
OPERATOR Penley
Date&Time 7/18/2014 9:21:09 AM
CONE NUMBER DSA1050
HOLE NUMBER KAS-1.14C
LOCATION 37.92175 89.89451
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
Su (Qc/Nc) TSF
SOIL BEHAVIOR TYPE
0
6
12
25
10
20
30
40
50
60
70
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR Penley | CONE NUMBER DSA1050 | LOCATION 37.91963 89.89130

Date&Time 7/18/2014 10:15:53 AM | HOLE NUMBER KAS-2.14C | Elevation

CPT DATA



1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.91861 89.88972
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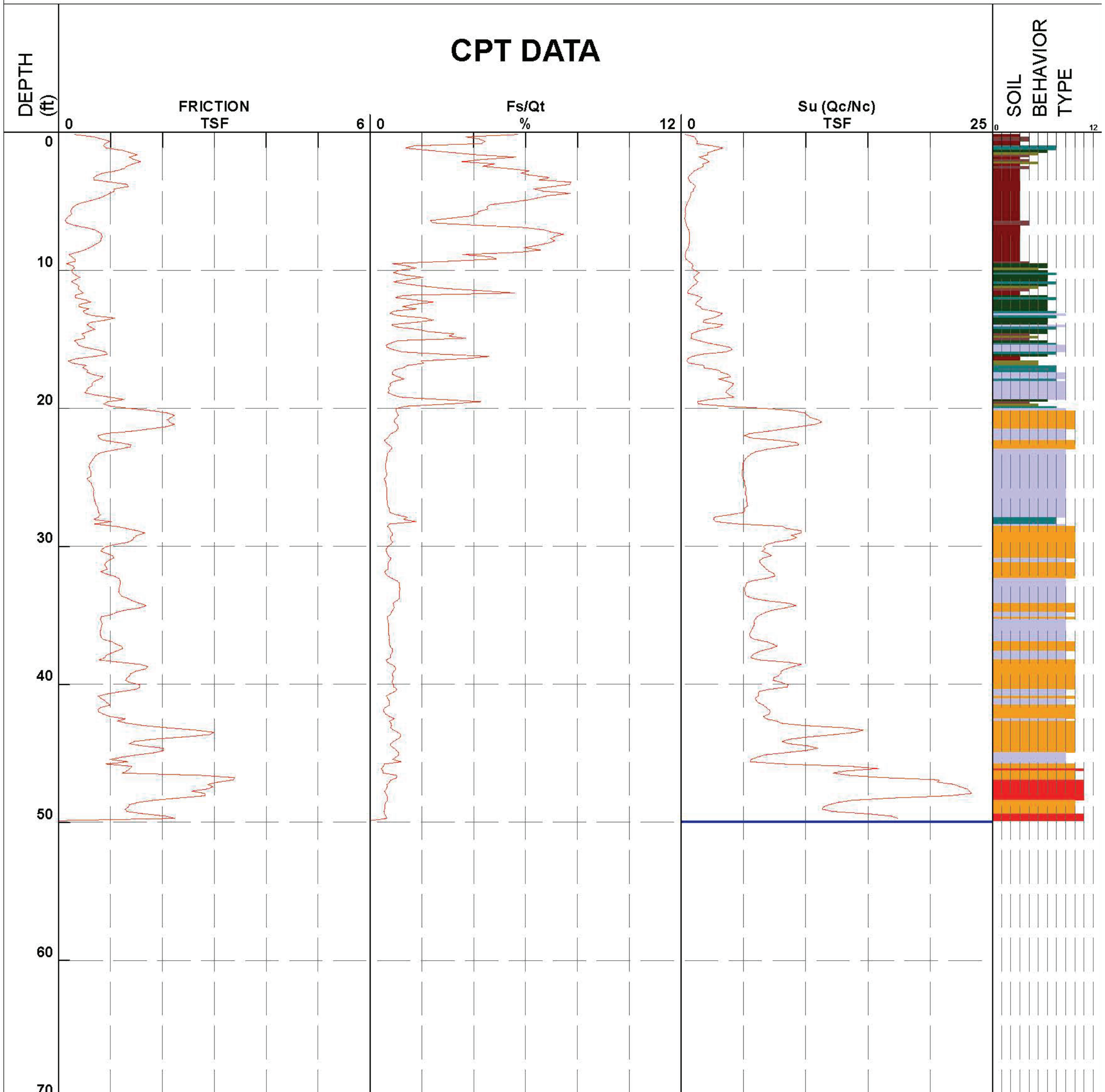
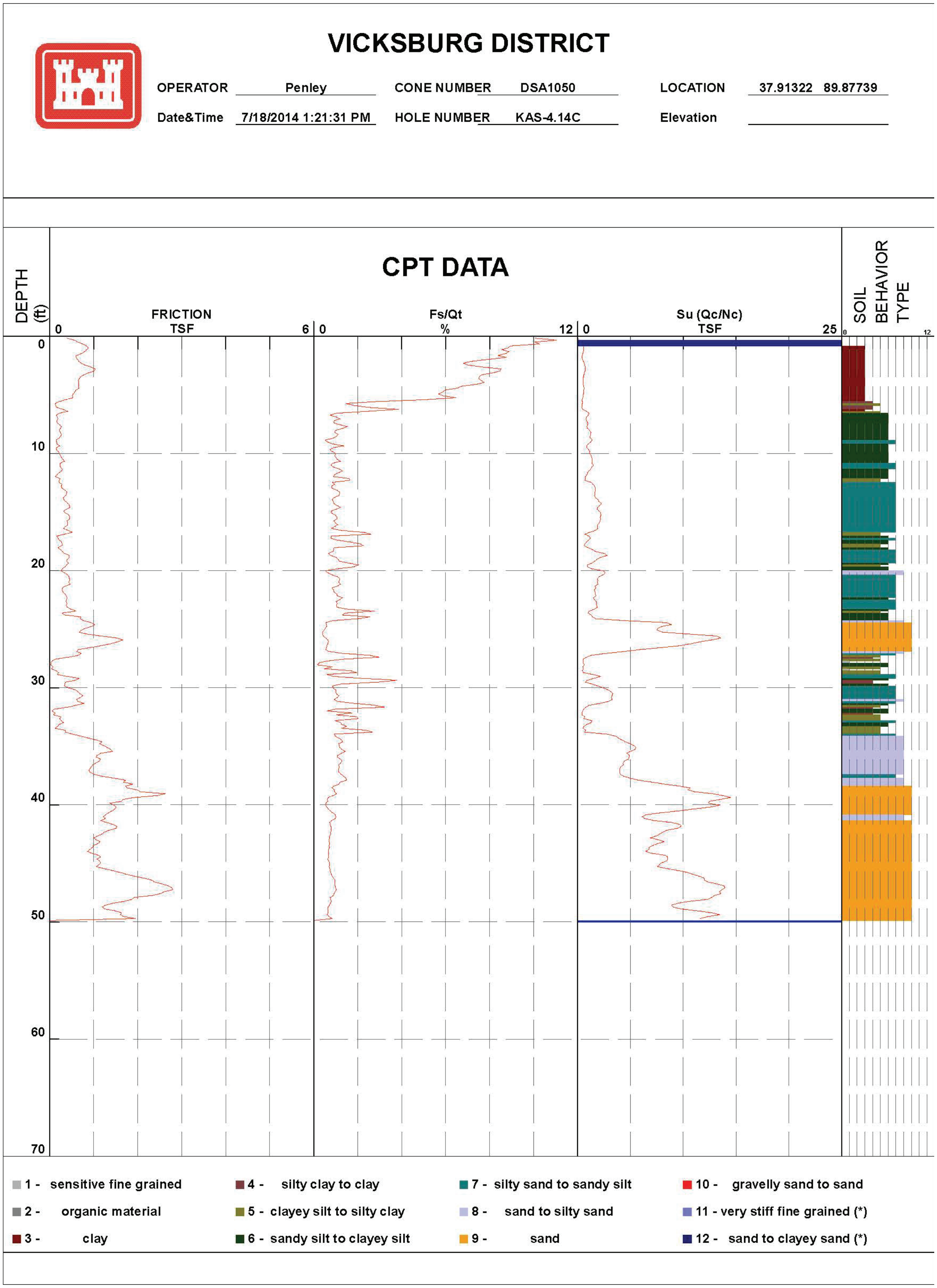


1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)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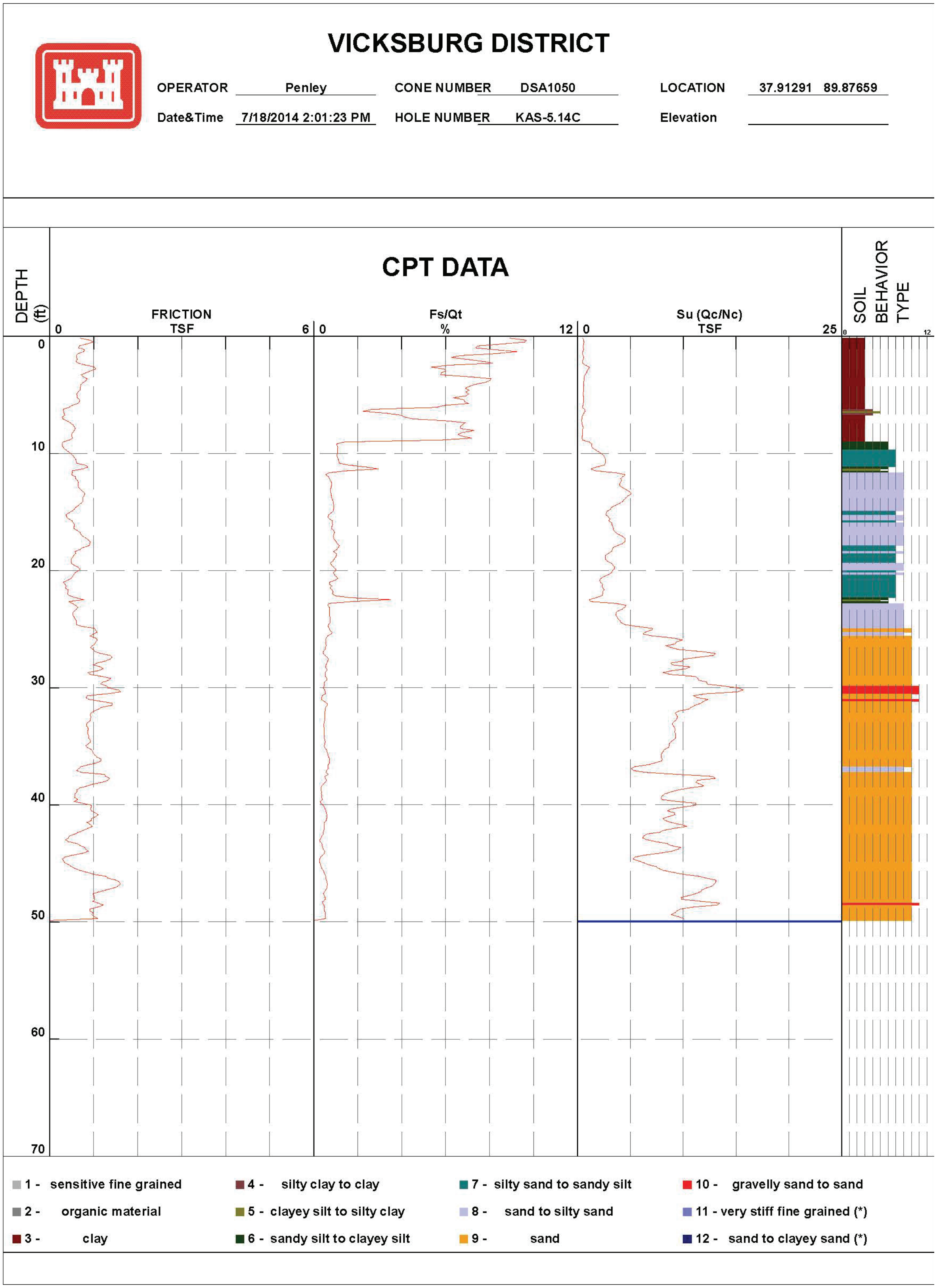
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.91322 89.87739
Date&Time 7/18/2014 1:21:31 PM
HOLE NUMBER KAS-4.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
Su (Qc/Nc) TSF
SOIL BEHAVIOR TYPE
0
6
12
25
10
20
30
40
50
60
70
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)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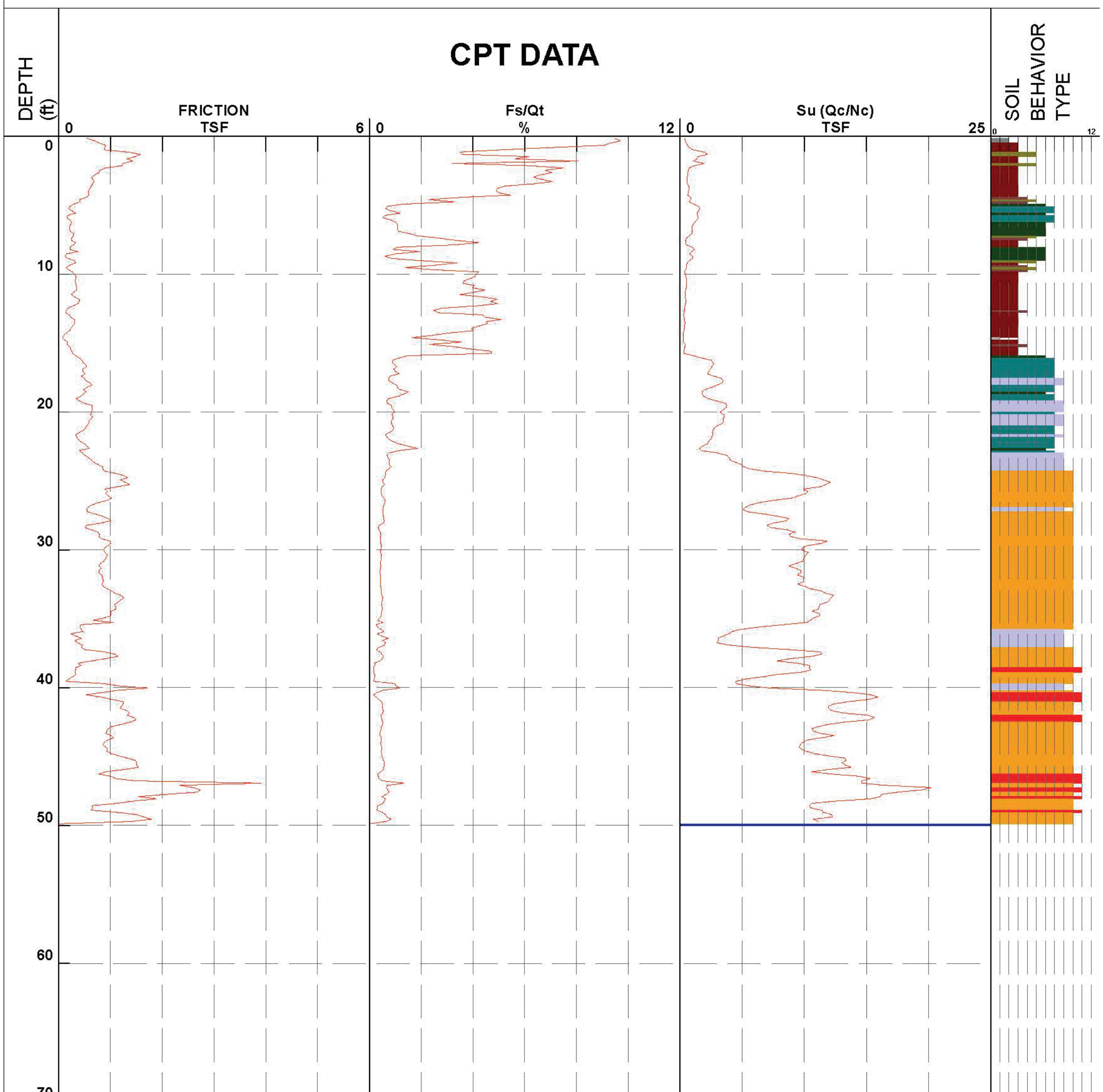
OPERATOR Penley
Date&Time 7/18/2014 2:01:23 PM
CONE NUMBER DSA1050
HOLE NUMBER KAS-5.14C
LOCATION 37.91291 89.87659
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
0 6
Fs/Qt %
0 12
Su (Qc/Nc) TSF
0 25
SOIL BEHAVIOR TYPE
0 12
0
10
20
30
40
50
60
70
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.91254 89.87622
Date&Time	7/19/2014 10:06:54 AM	HOLE NUMBER	KAS-6.14C	Elevation	

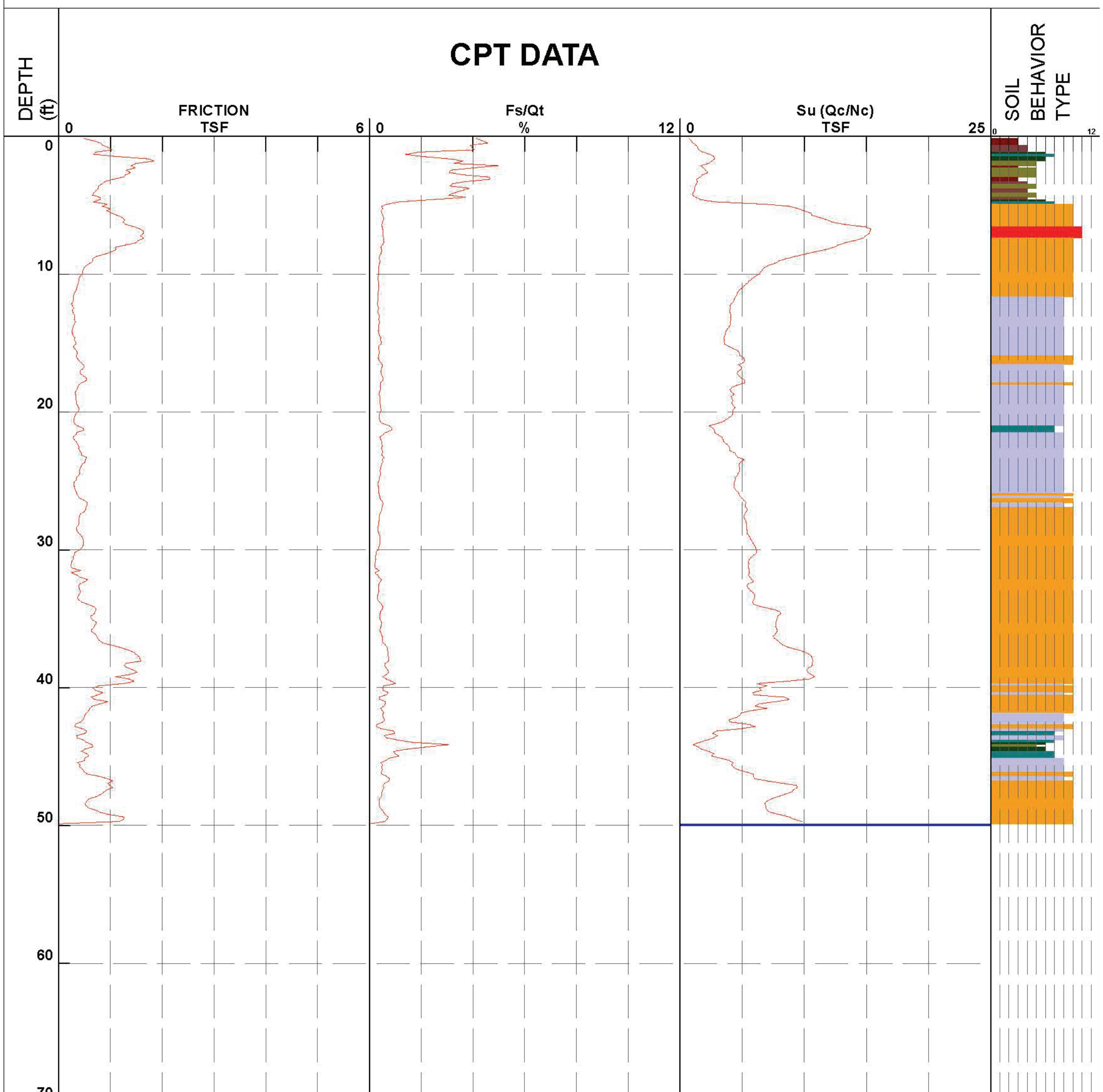


1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.91222 89.87565
Date&Time	7/19/2014 11:21:25 AM	HOLE NUMBER	KAS-7.14C	Elevation	

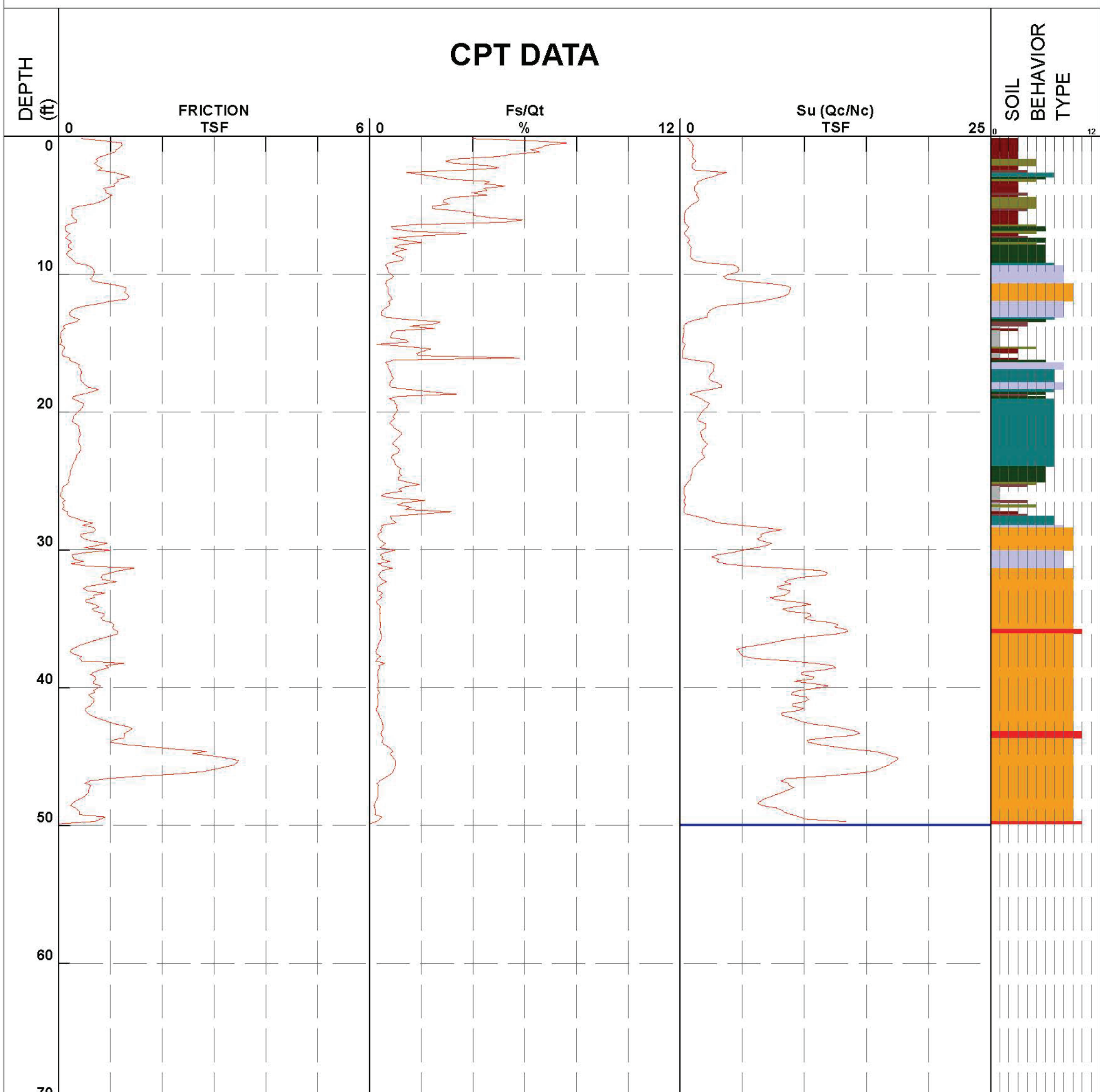
CPT DATA



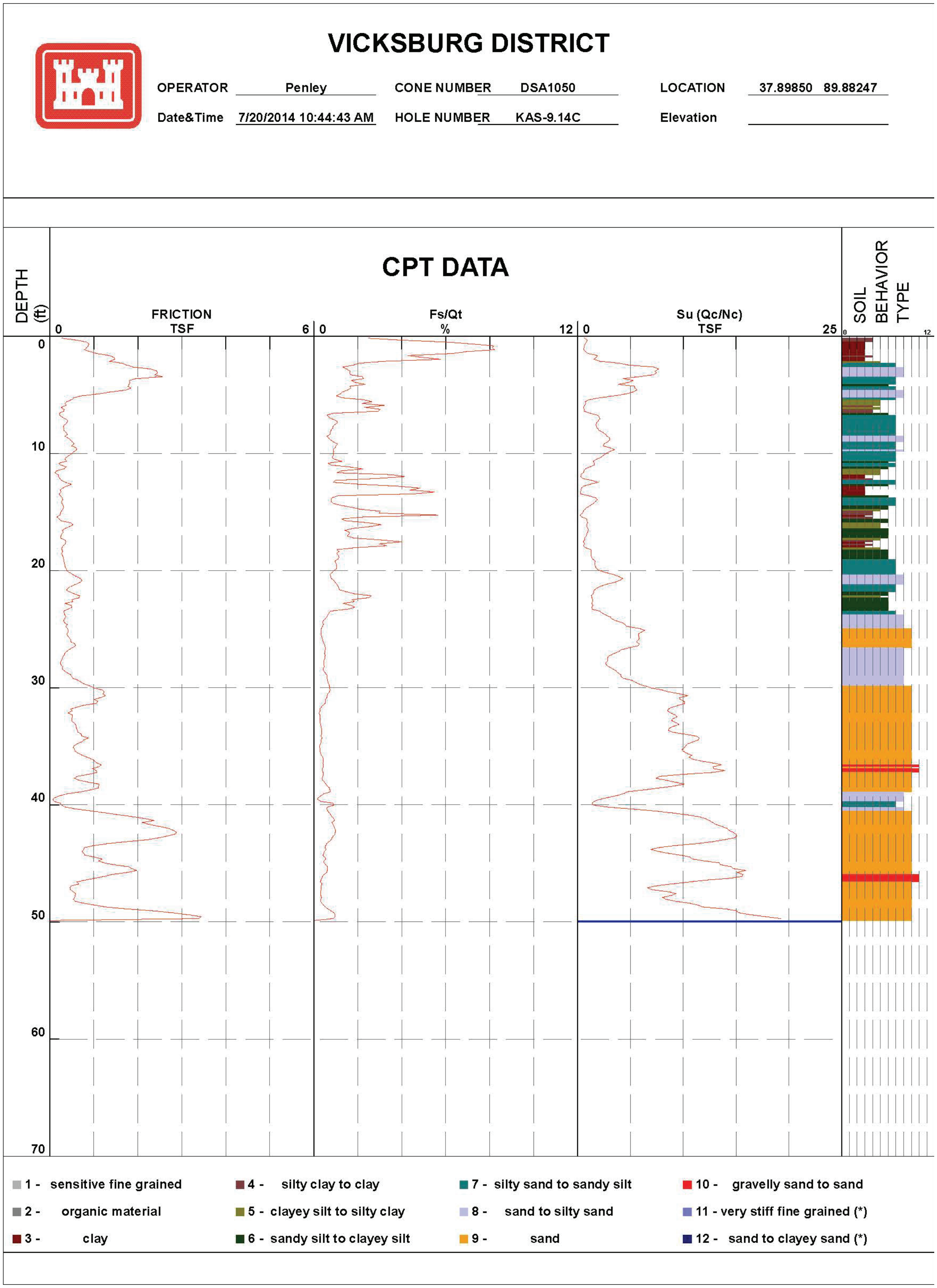
1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90188 89.87722
Date&Time 7/19/2014 2:14:23 PM
HOLE NUMBER KAS-8.14C
Elevation



1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)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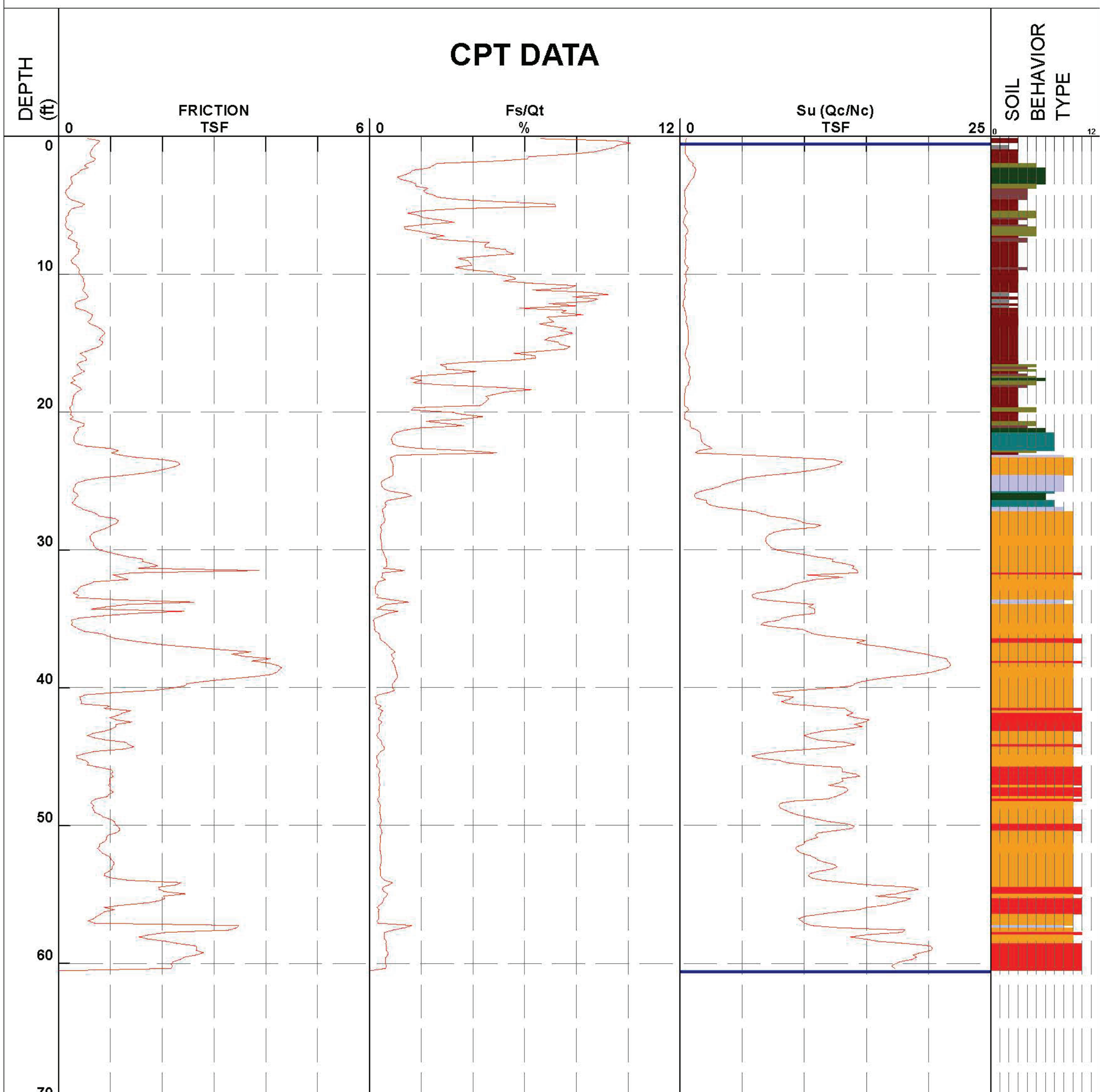
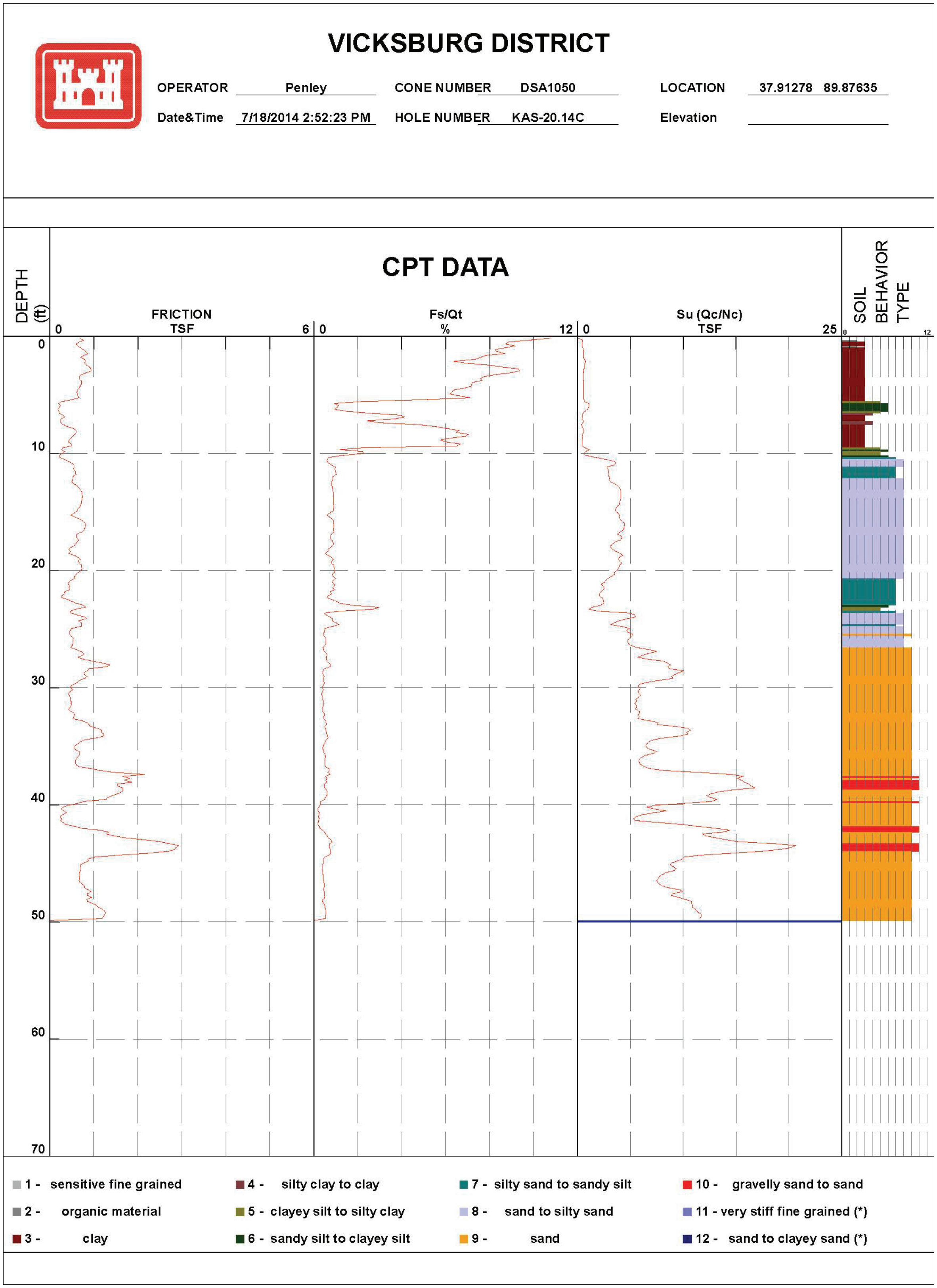
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.89850 89.88247
Date&Time 7/20/2014 10:44:43 AM
HOLE NUMBER KAS-9.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
0
6
Fs/Qt %
0
12
Su (Qc/Nc) TSF
0
25
SOIL BEHAVIOR TYPE
0
12
0
10
20
30
40
50
60
70
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR Penley
Date&Time 7/20/2014 1:15:36 PM
CONE NUMBER DSA1050
HOLE NUMBER KAS-12.14C
LOCATION 37.90012 89.87850
Elevation



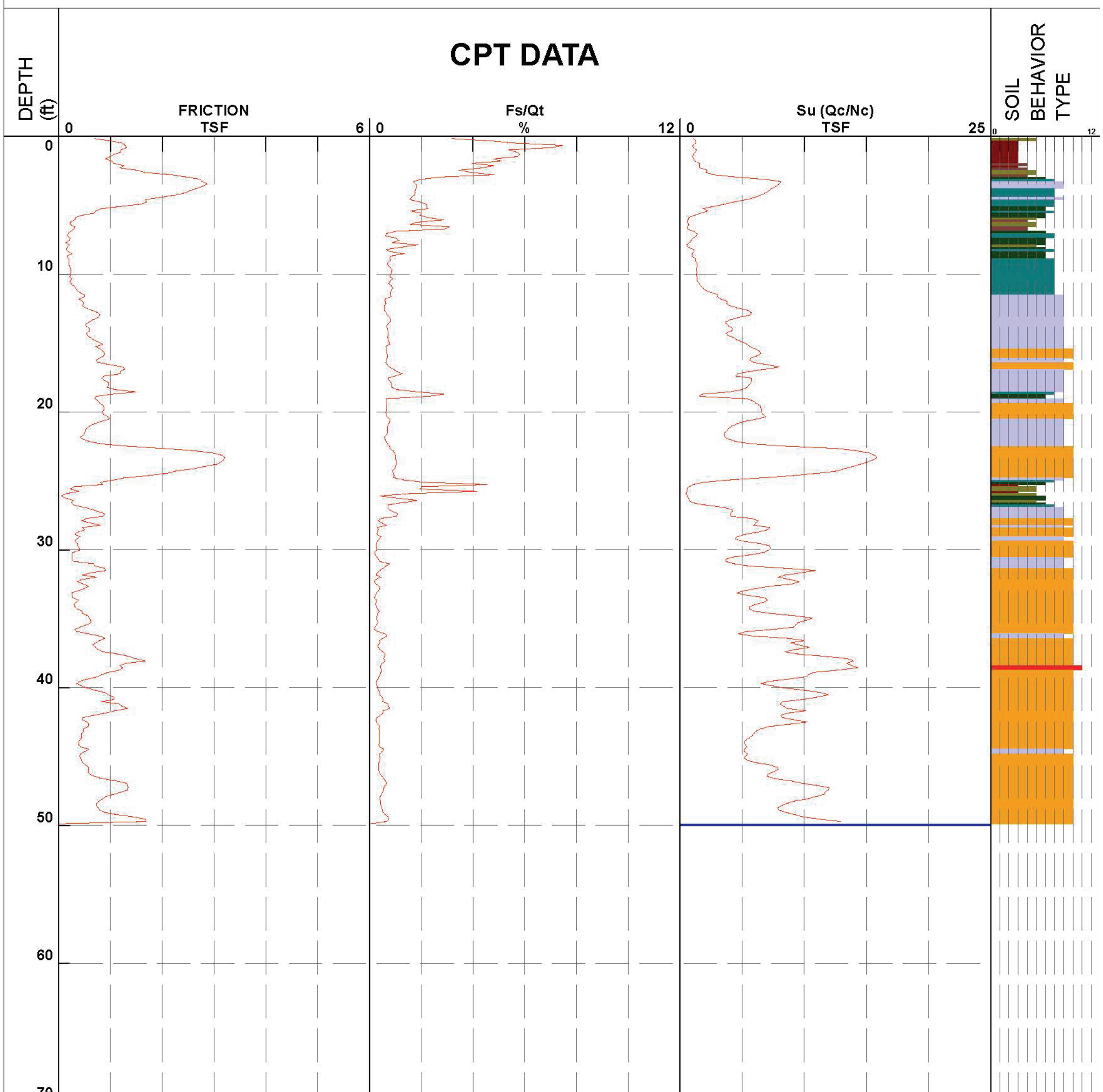
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)



VICKSBURG DISTRICT
OPERATOR Penley
Date&Time 7/18/2014 2:52:23 PM
CONE NUMBER DSA1050
HOLE NUMBER KAS-20.14C
LOCATION 37.91278 89.87635
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
Su (Qc/Nc) TSF
SOIL BEHAVIOR TYPE
0
6
12
25
10
20
30
40
50
60
70
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

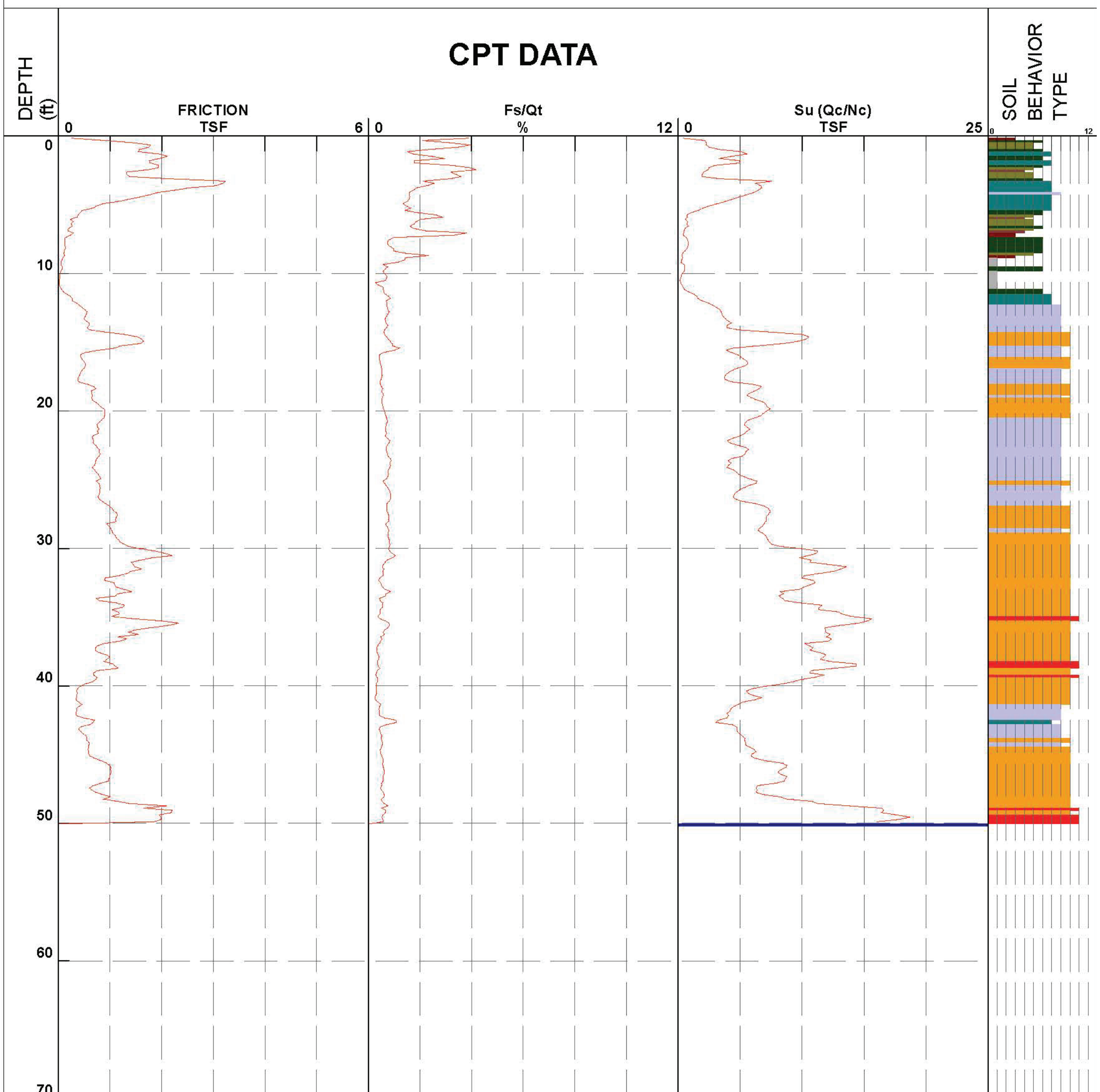
OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90138 89.87763
Date&Time	7/19/2014 2:57:23 PM	HOLE NUMBER	KAS-21.14C	Elevation	



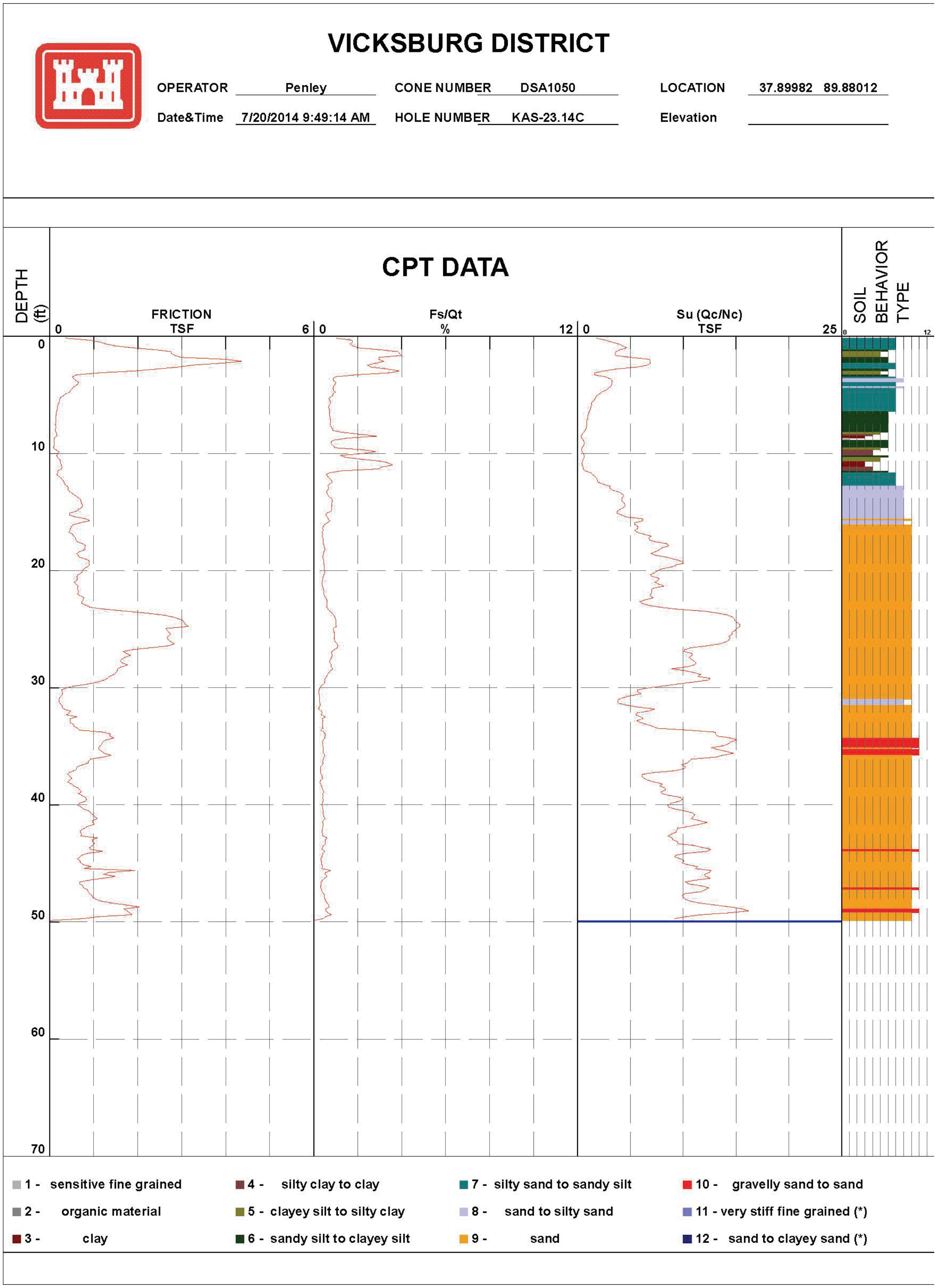
1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90070 89.87878
Date&Time	7/20/2014 8:51:16 AM	HOLE NUMBER	KAS-22.14C	Elevation	

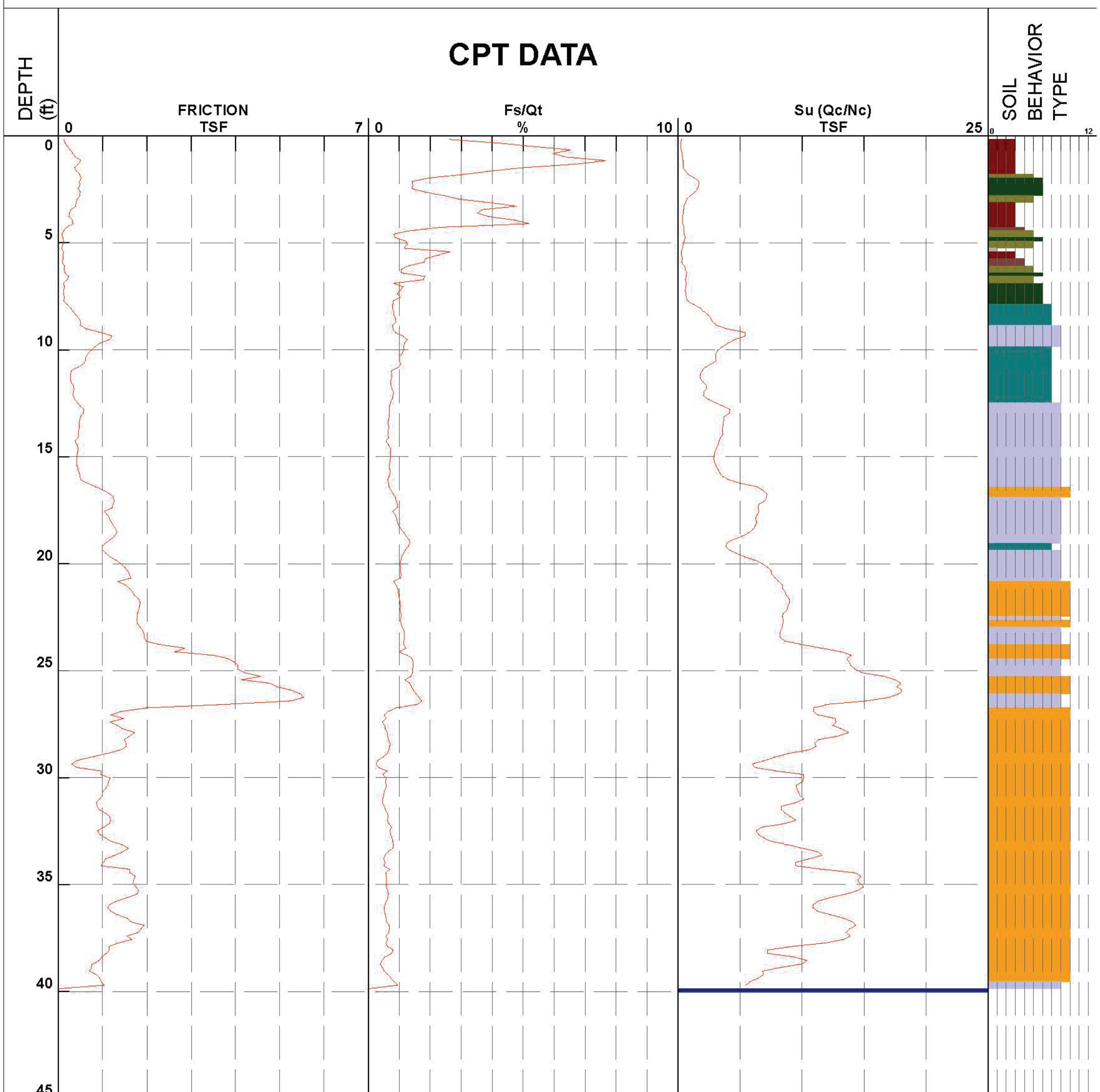


1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.89982 89.88012
Date&Time 7/20/2014 9:49:14 AM
HOLE NUMBER KAS-23.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
Su (Qc/Nc) TSF
SOIL BEHAVIOR TYPE
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90084 89.87872
Date&Time	7/25/2014 1:48:18 PM	HOLE NUMBER	KAS-B01.14C	Elevation	

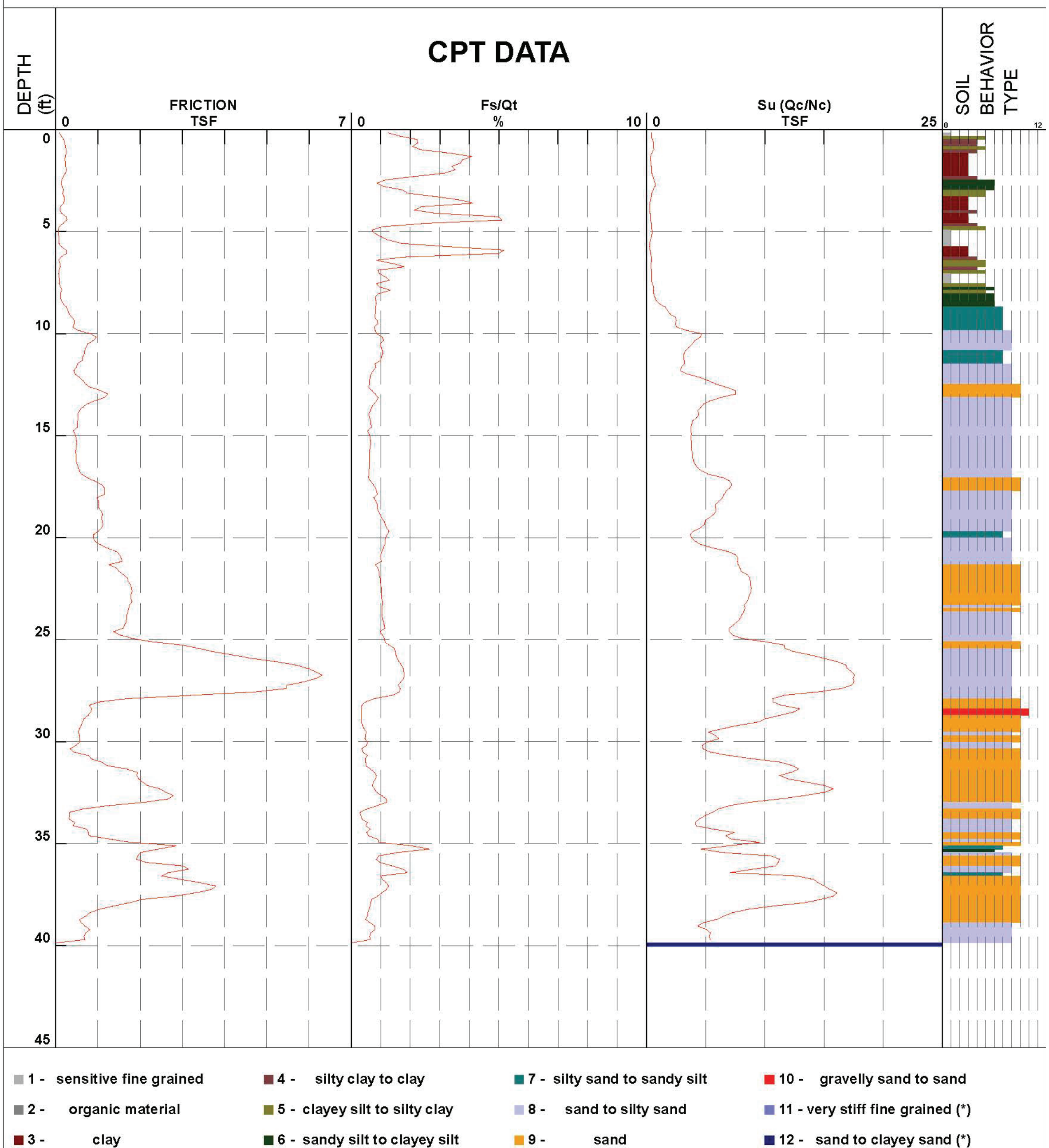


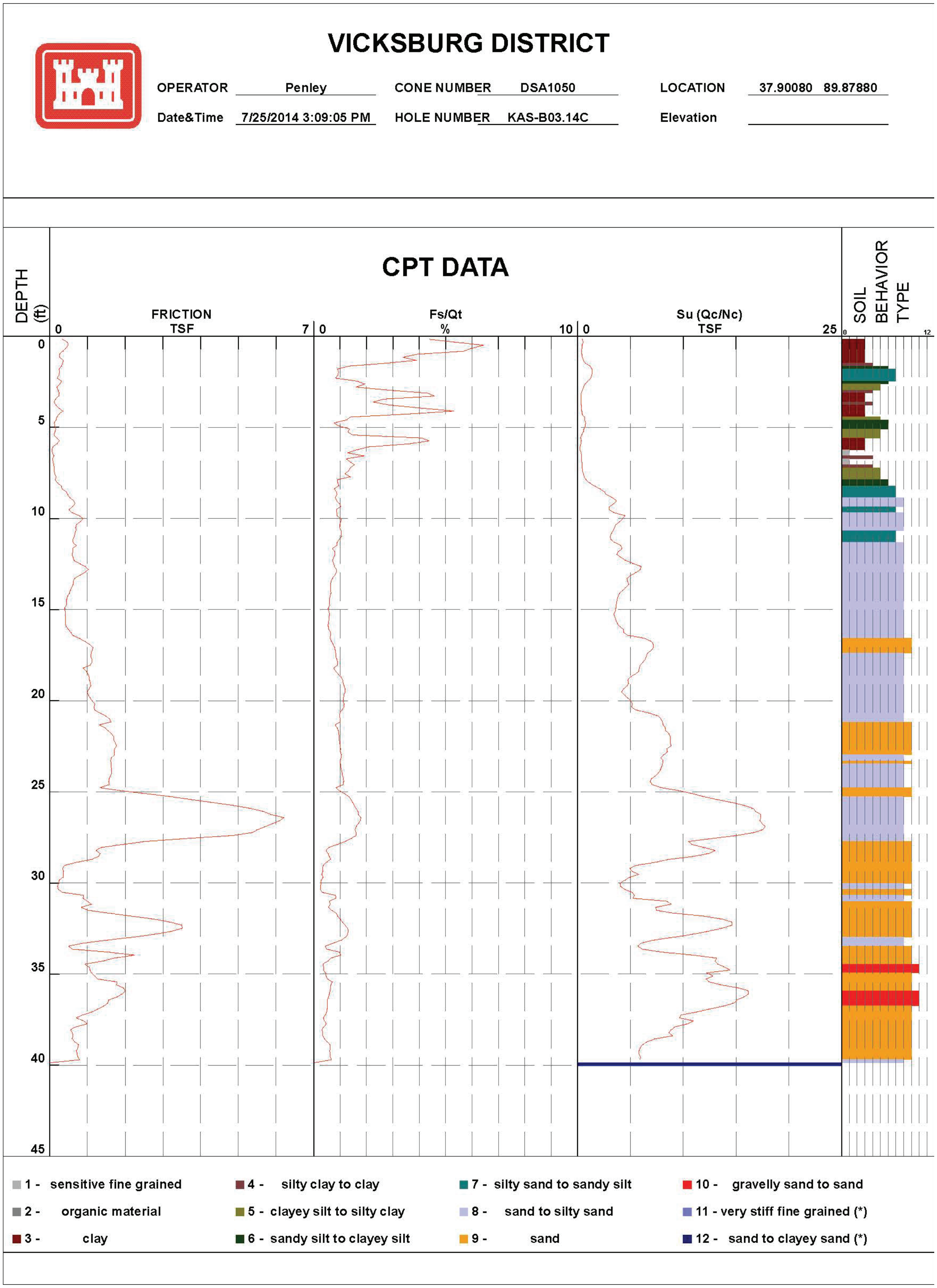
■ 1 - sensitive fine grained
■ 2 - organic material
■ 3 - clay
■ 4 - silty clay to clay
■ 5 - clayey silt to silty clay
■ 6 - sandy silt to clayey silt
■ 7 - silty sand to sandy silt
■ 8 - sand to silty sand
■ 9 - sand
■ 10 - gravelly sand to sand
■ 11 - very stiff fine grained (*)
■ 12 - sand to clayey sand (*)

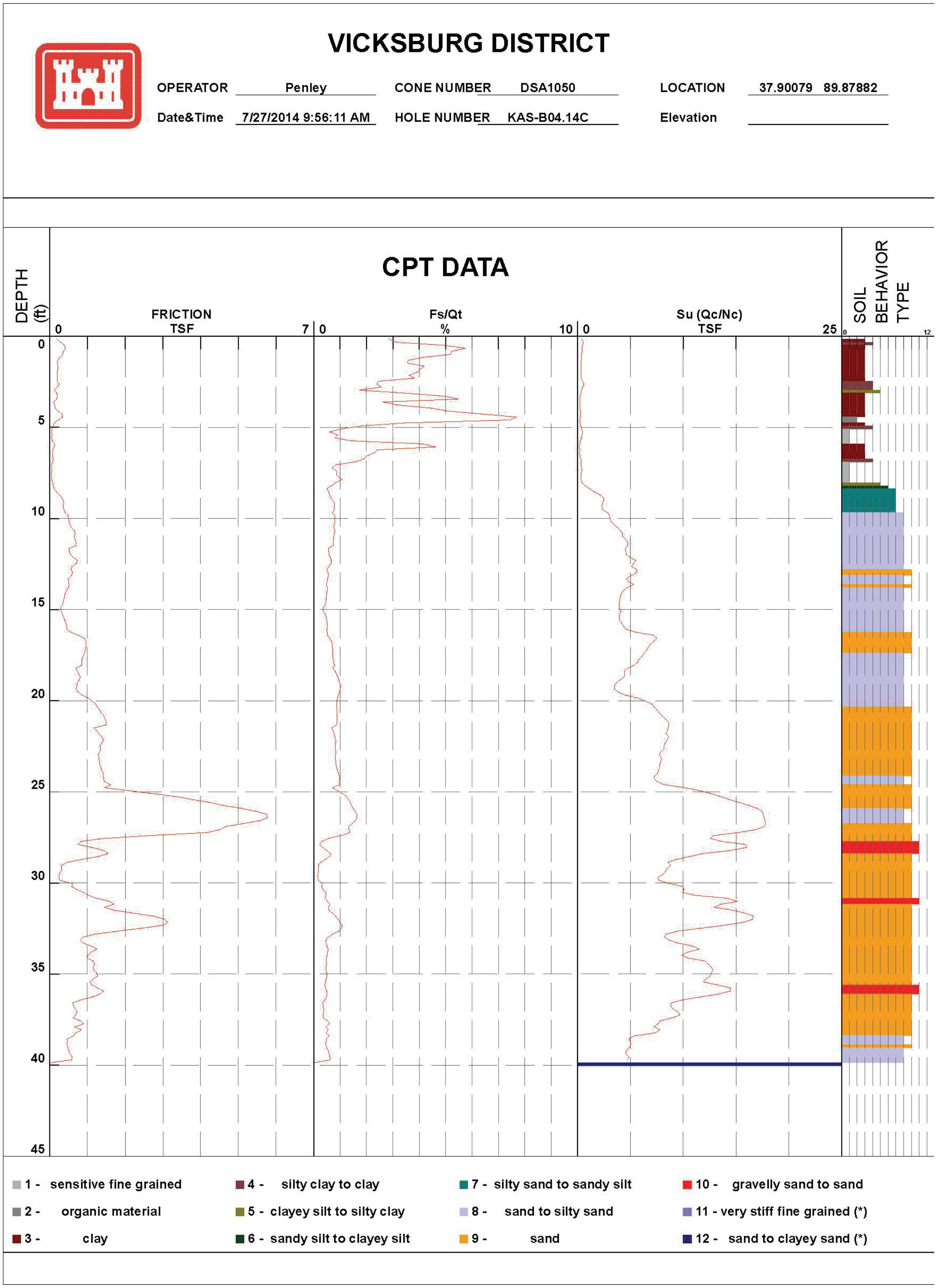
VICKSBURG DISTRICT

OPERATOR Penley | CONE NUMBER DSA1050 | LOCATION 37.90079 89.87879

Date&Time 7/25/2014 2:29:11 PM | HOLE NUMBER KAS-B02.14C | Elevation

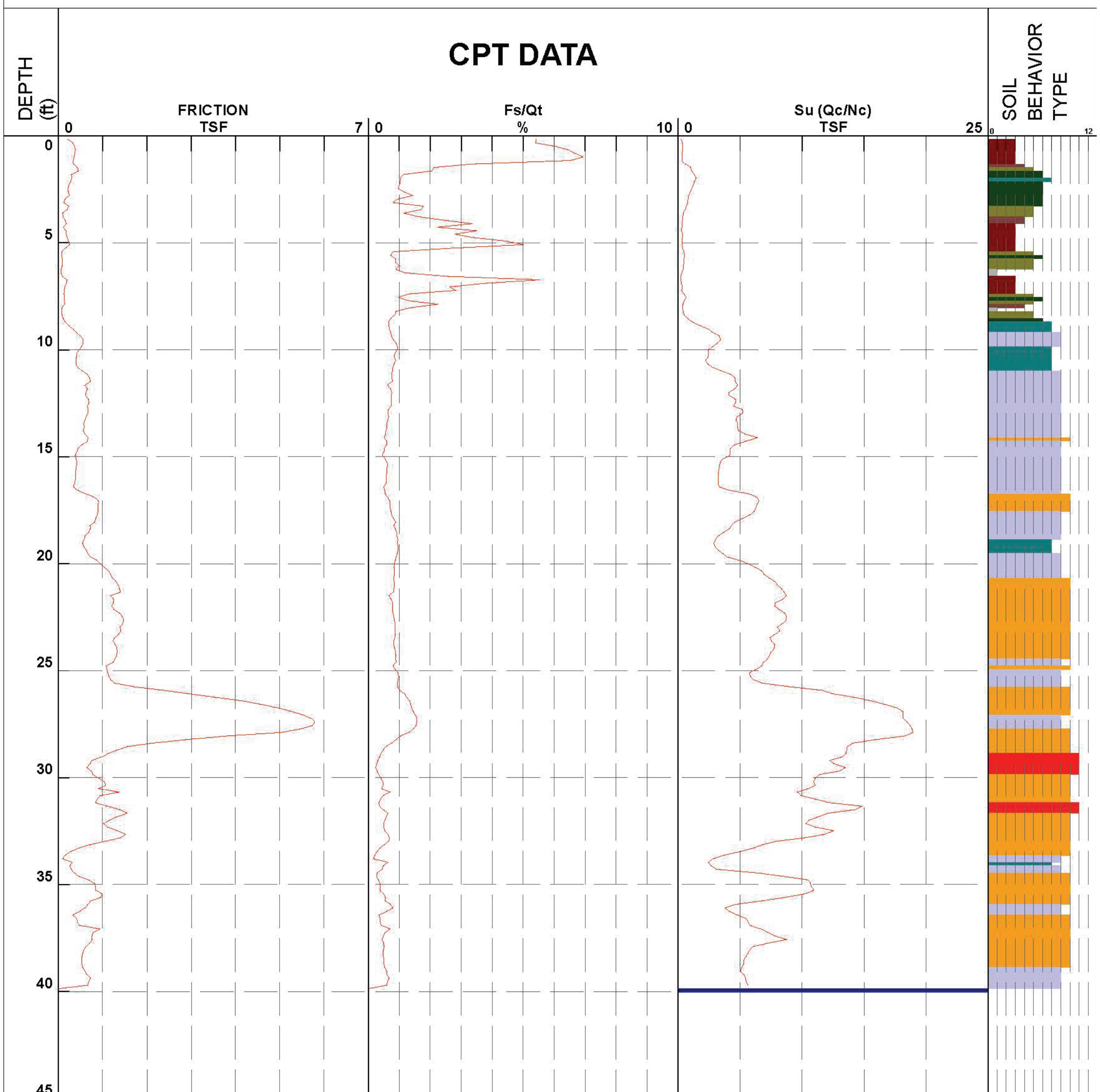



VICKSBURG DISTRICT
OPERATOR Penley
Date&Time 7/25/2014 3:09:05 PM
CONE NUMBER DSA1050
HOLE NUMBER KAS-B03.14C
LOCATION 37.90080 89.87880
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
Su (Qc/Nc) TSF
SOIL BEHAVIOR TYPE
0 7 0 10 0 25 0 12
0 5 10 15 20 25 30 35 40 45
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90079 89.87882
Date&Time 7/27/2014 9:56:11 AM
HOLE NUMBER KAS-B04.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
Su (Qc/Nc) TSF
SOIL BEHAVIOR TYPE
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

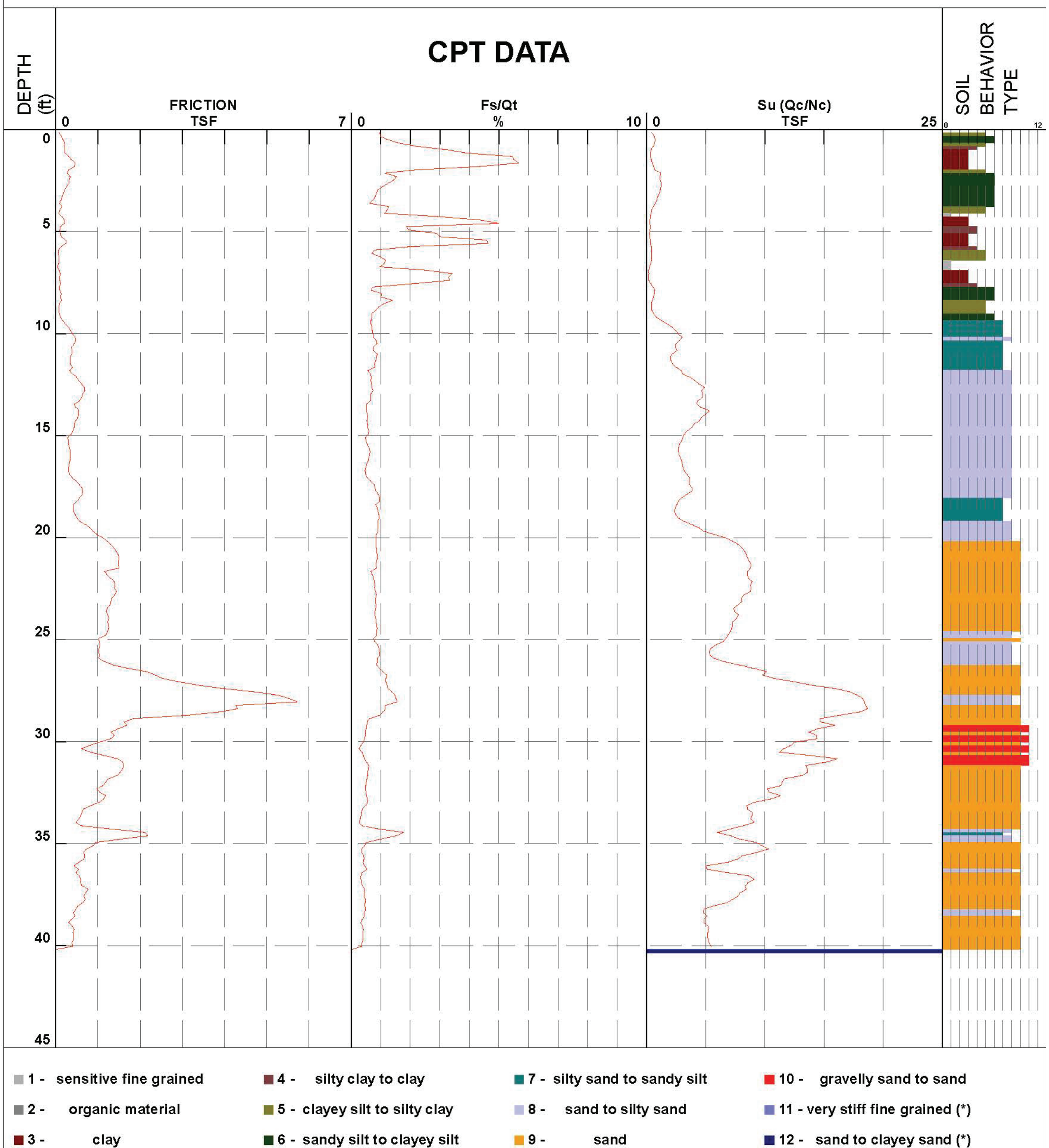
OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90076 89.87885
Date&Time	7/27/2014 10:34:58 AM	HOLE NUMBER	KAS-B05.14C	Elevation	



1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

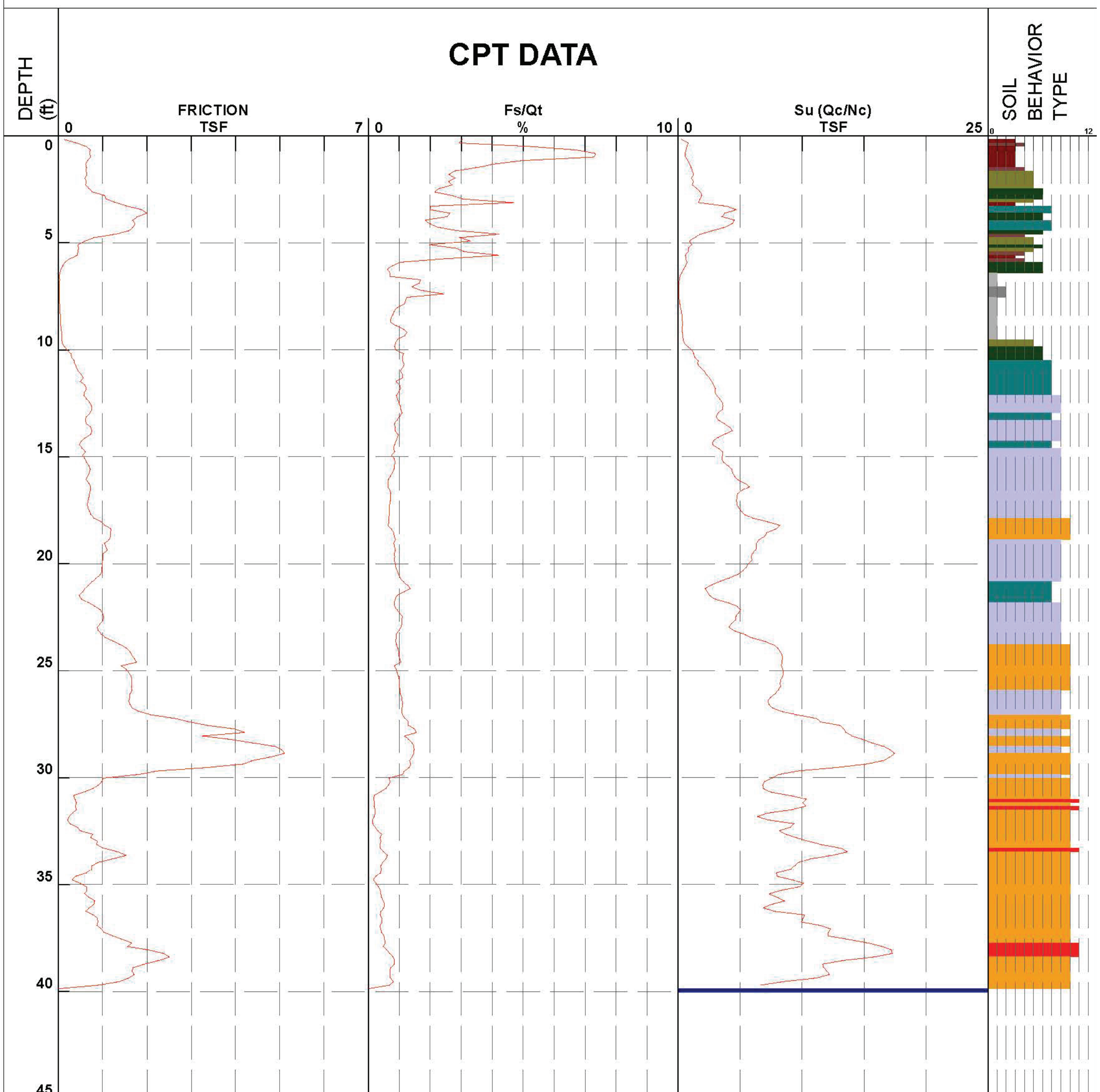
OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90074 89.87894
Date&Time	7/27/2014 11:09:37 AM	HOLE NUMBER	KAS-B06.14C	Elevation	



VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90082 89.87869
Date&Time	7/26/2014 8:43:20 AM	HOLE NUMBER	KAS-B08.14C	Elevation	

CPT DATA

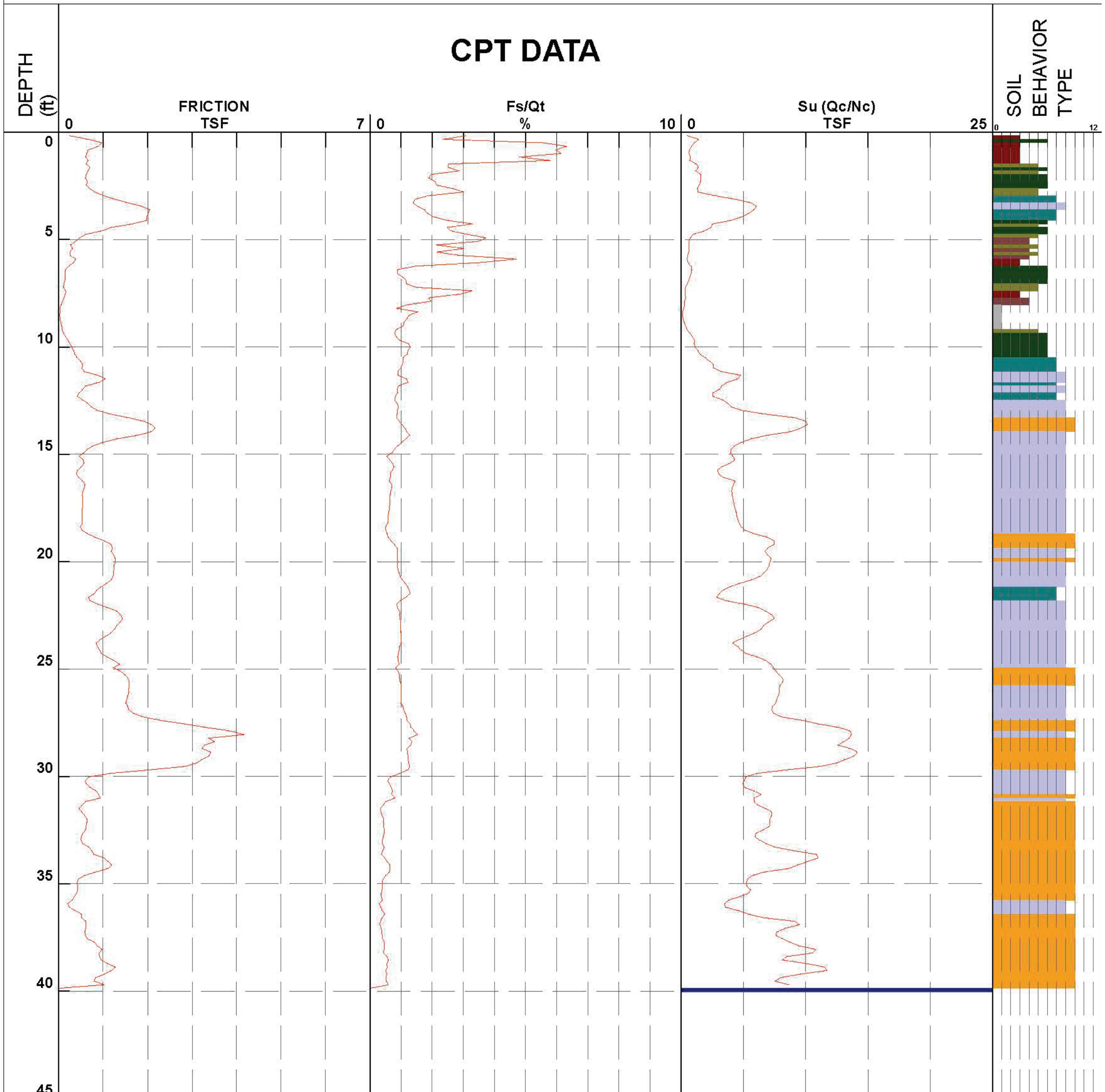


1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90078 89.87875
Date&Time	7/26/2014 9:28:31 AM	HOLE NUMBER	KAS-B09.14C	Elevation	

CPT DATA

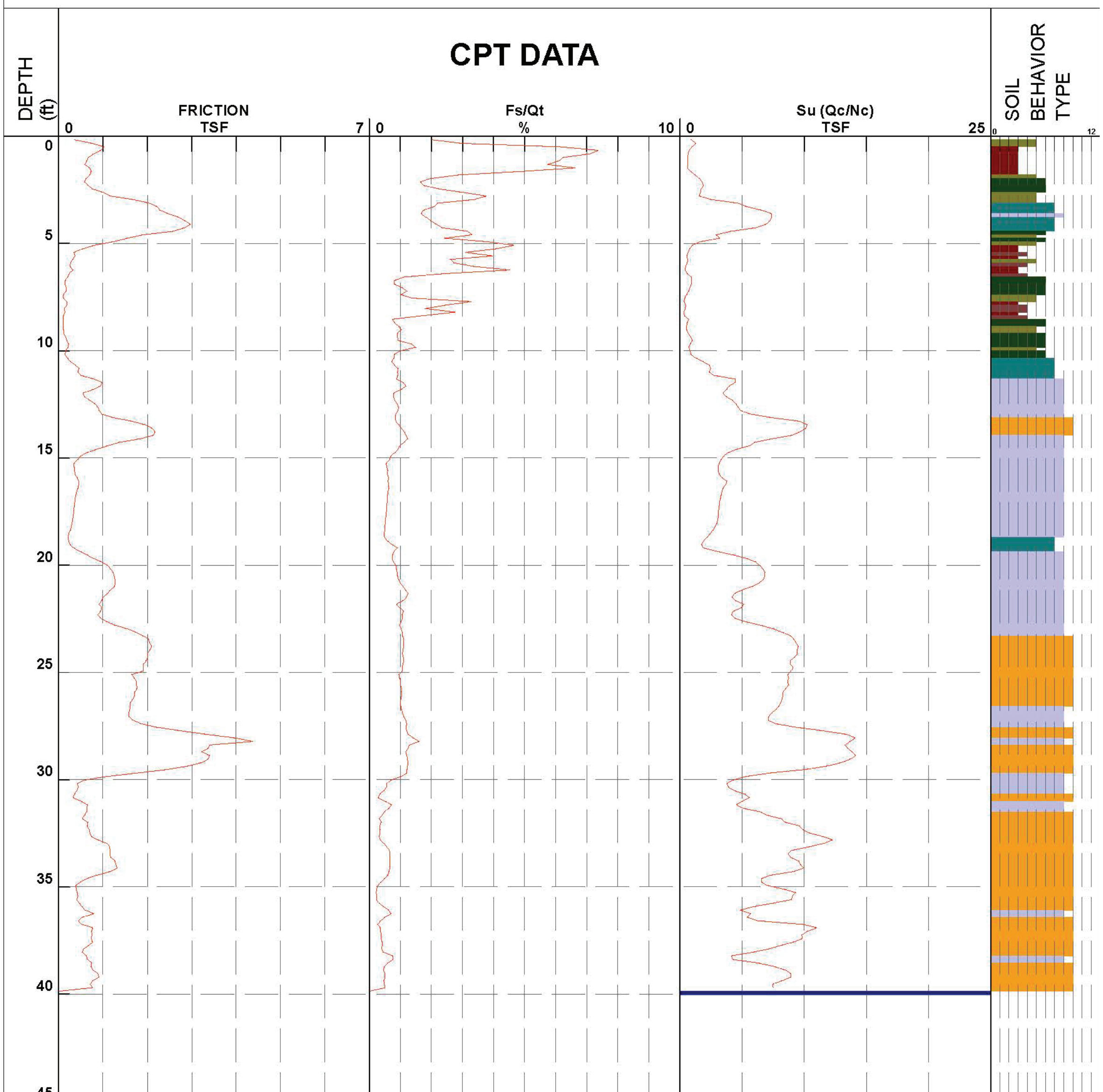


1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

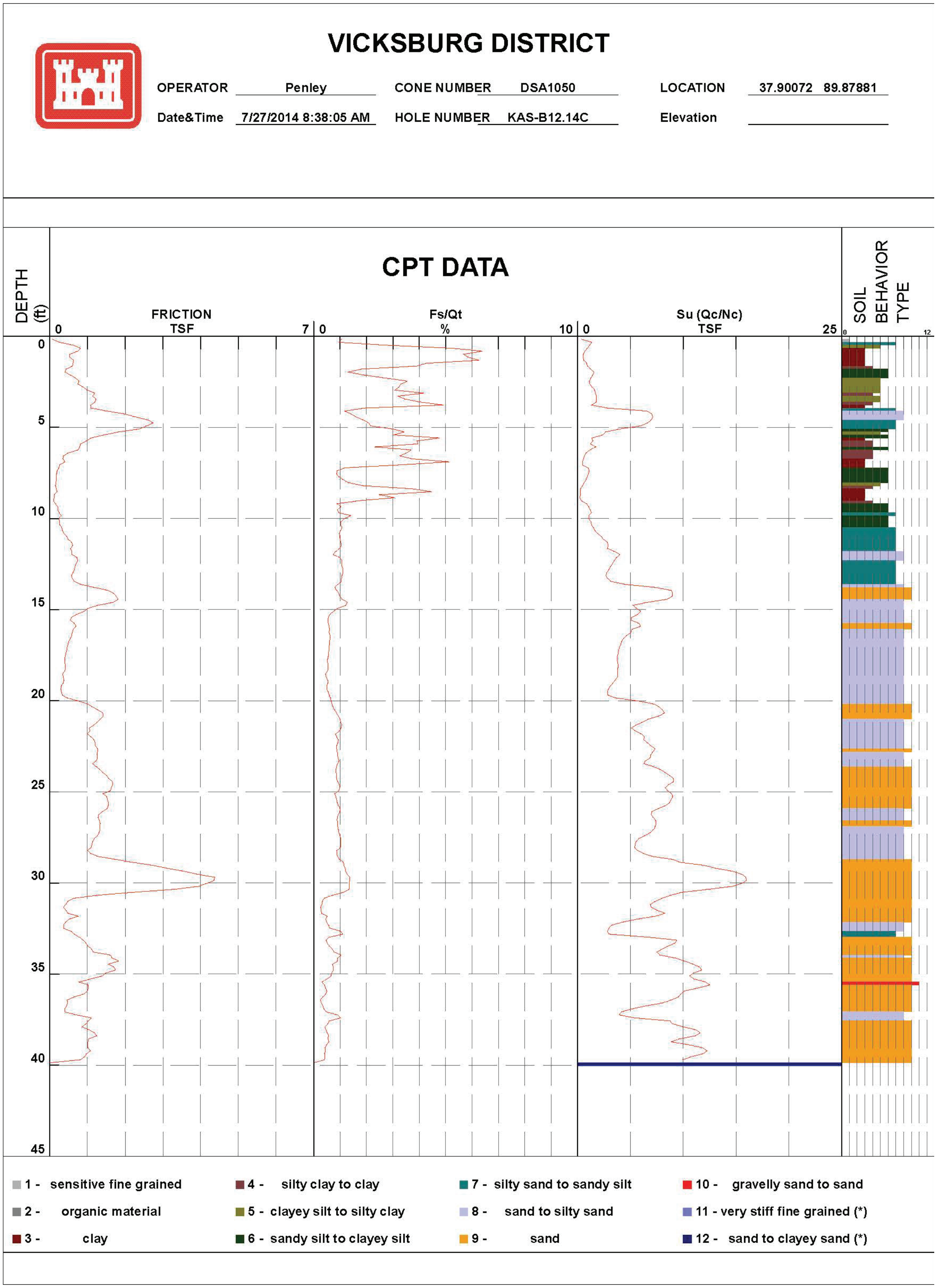
VICKSBURG DISTRICT

OPERATOR Penley | CONE NUMBER DSA1050 | LOCATION 37.90078 89.87876

Date&Time 7/26/2014 10:13:16 AM | HOLE NUMBER KAS-B10.14C | Elevation



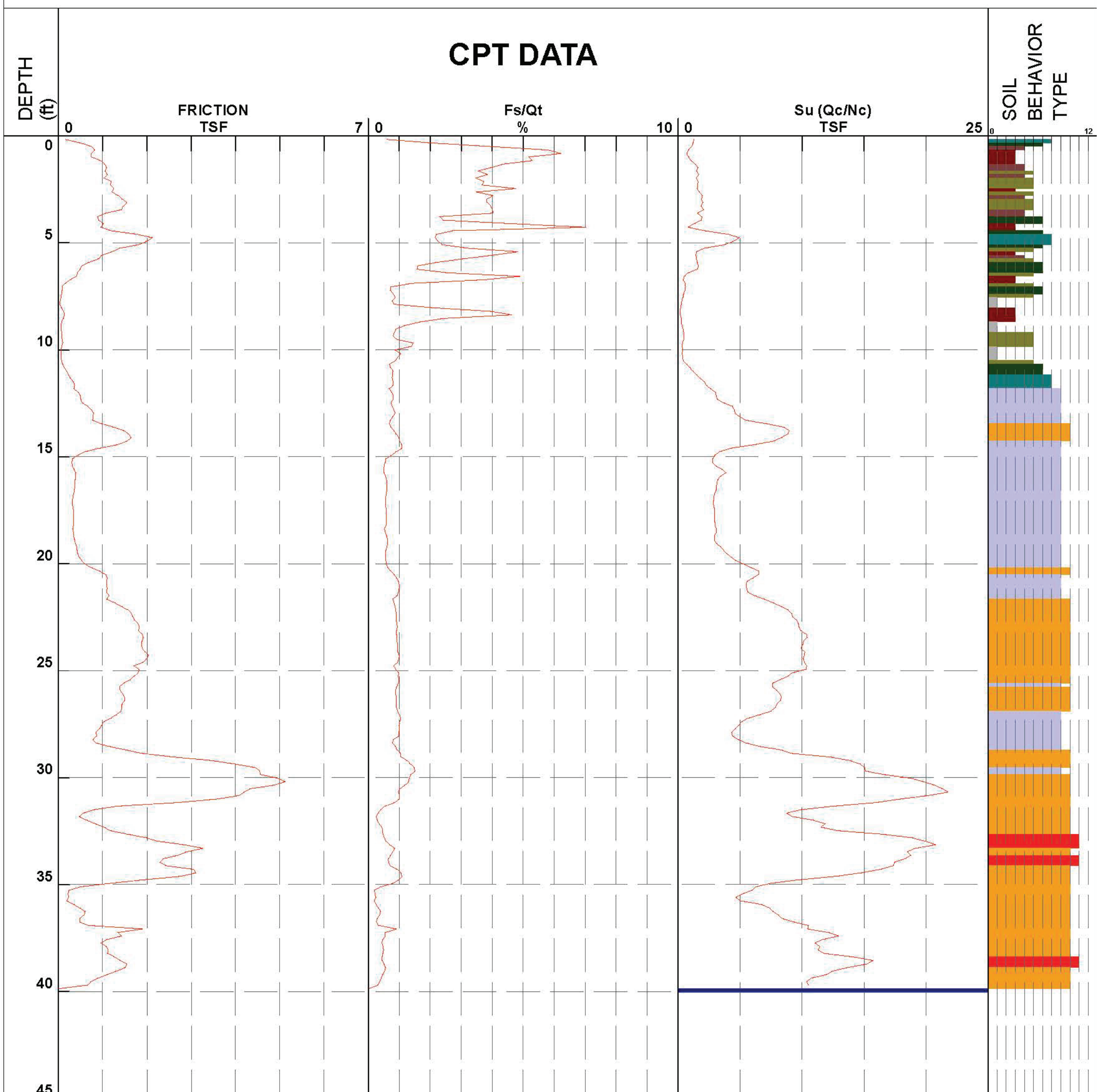
■ 1 - sensitive fine grained
■ 2 - organic material
■ 3 - clay
■ 4 - silty clay to clay
■ 5 - clayey silt to silty clay
■ 6 - sandy silt to clayey silt
■ 7 - silty sand to sandy silt
■ 8 - sand to silty sand
■ 9 - sand
■ 10 - gravelly sand to sand
■ 11 - very stiff fine grained (*)
■ 12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90072 89.87881
Date&Time 7/27/2014 8:38:05 AM
HOLE NUMBER KAS-B12.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
0
7
Fs/Qt %
0
10
Su (Qc/Nc) TSF
0
25
SOIL BEHAVIOR TYPE
0
12
0
5
10
15
20
25
30
35
40
45
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

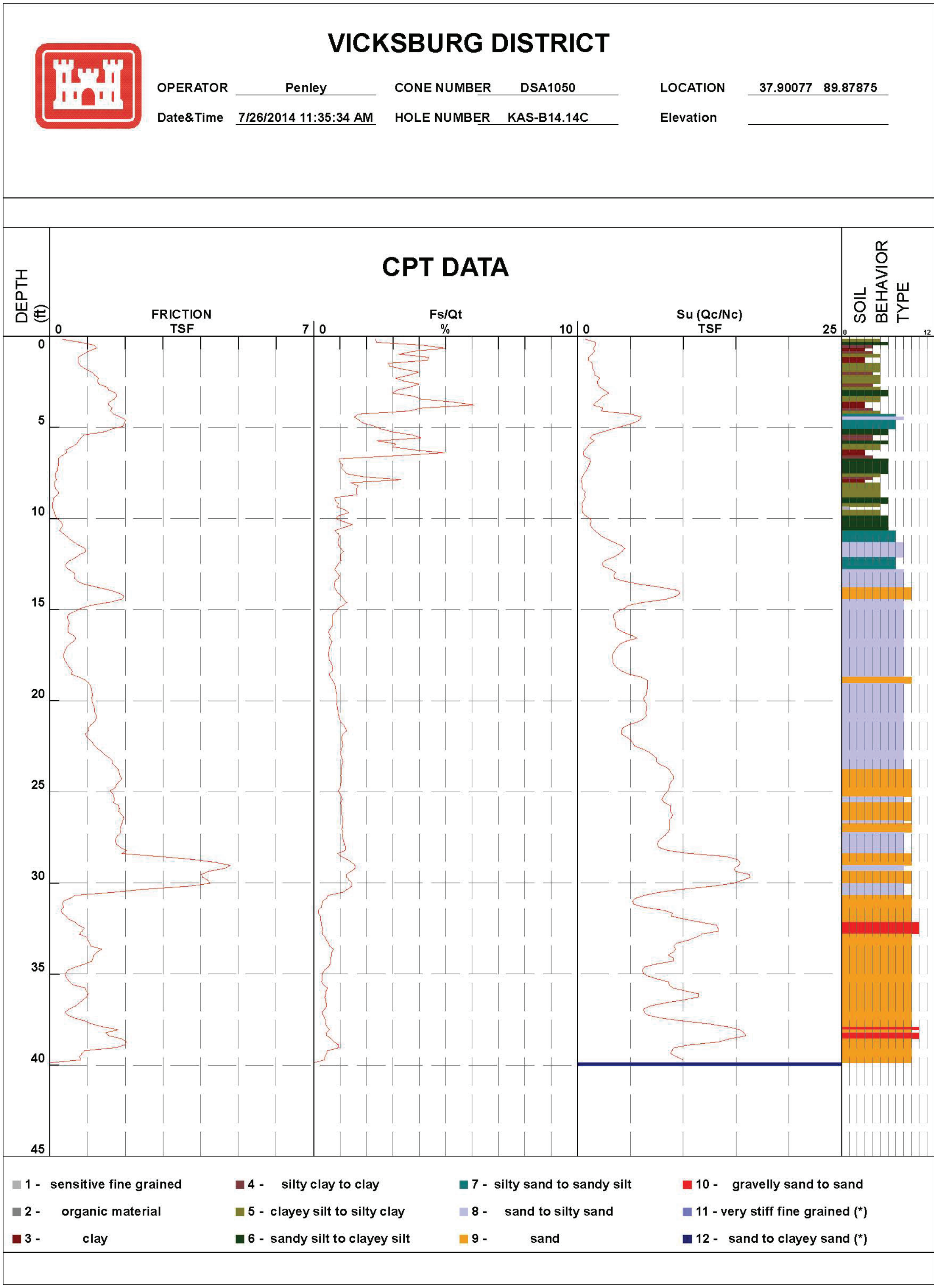
VICKSBURG DISTRICT

OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90069 89.87889

Date&Time 7/27/2014 9:14:21 AM
HOLE NUMBER KAS-B13.14C
Elevation



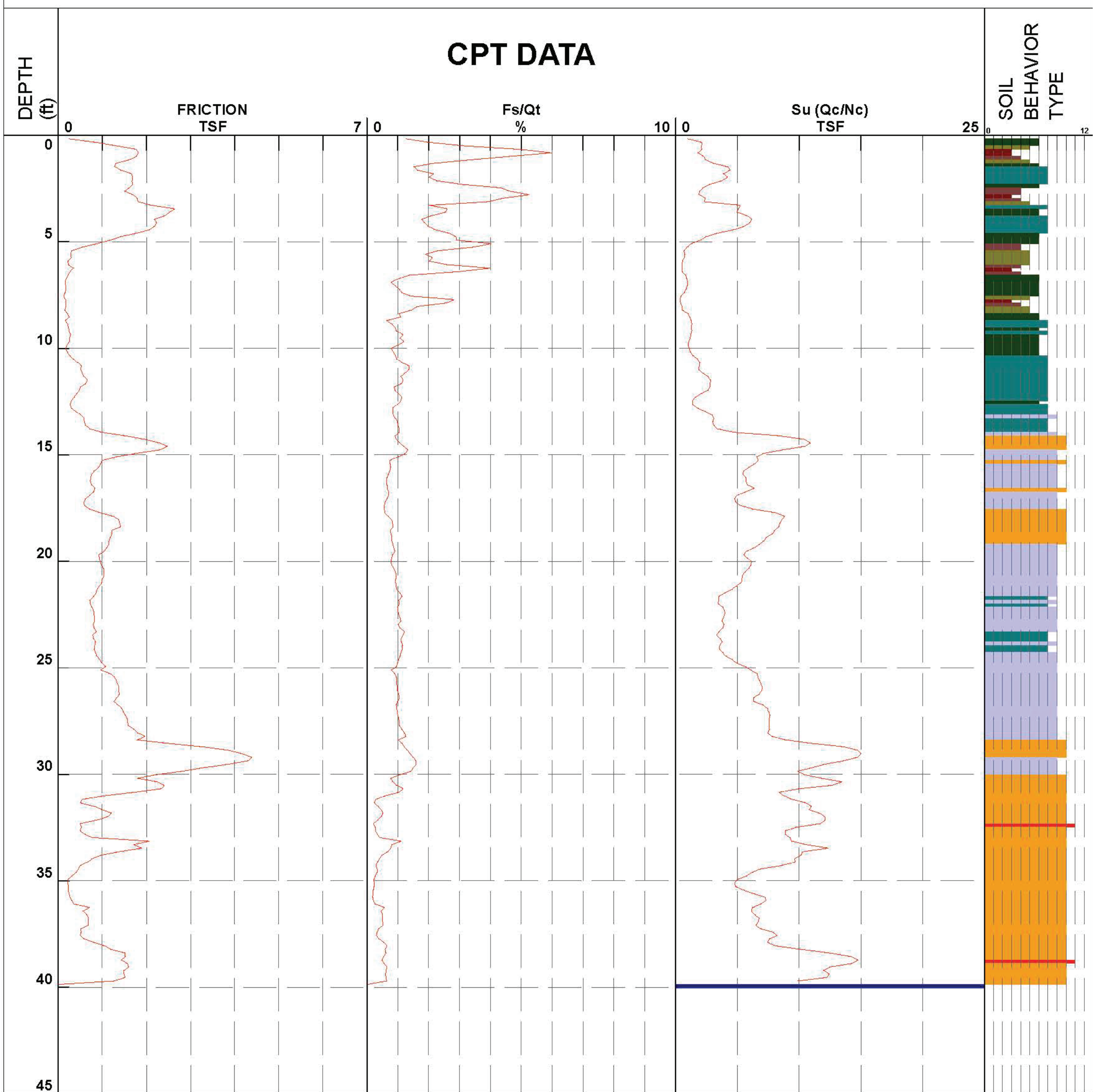
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90077 89.87875
Date&Time 7/26/2014 11:35:34 AM
HOLE NUMBER KAS-B14.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
Su (Qc/Nc) TSF
SOIL BEHAVIOR TYPE
0
7
10
25
12
5
15
20
30
35
40
45
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR Penley | CONE NUMBER DSA1050 | LOCATION 37.90076 89.87872

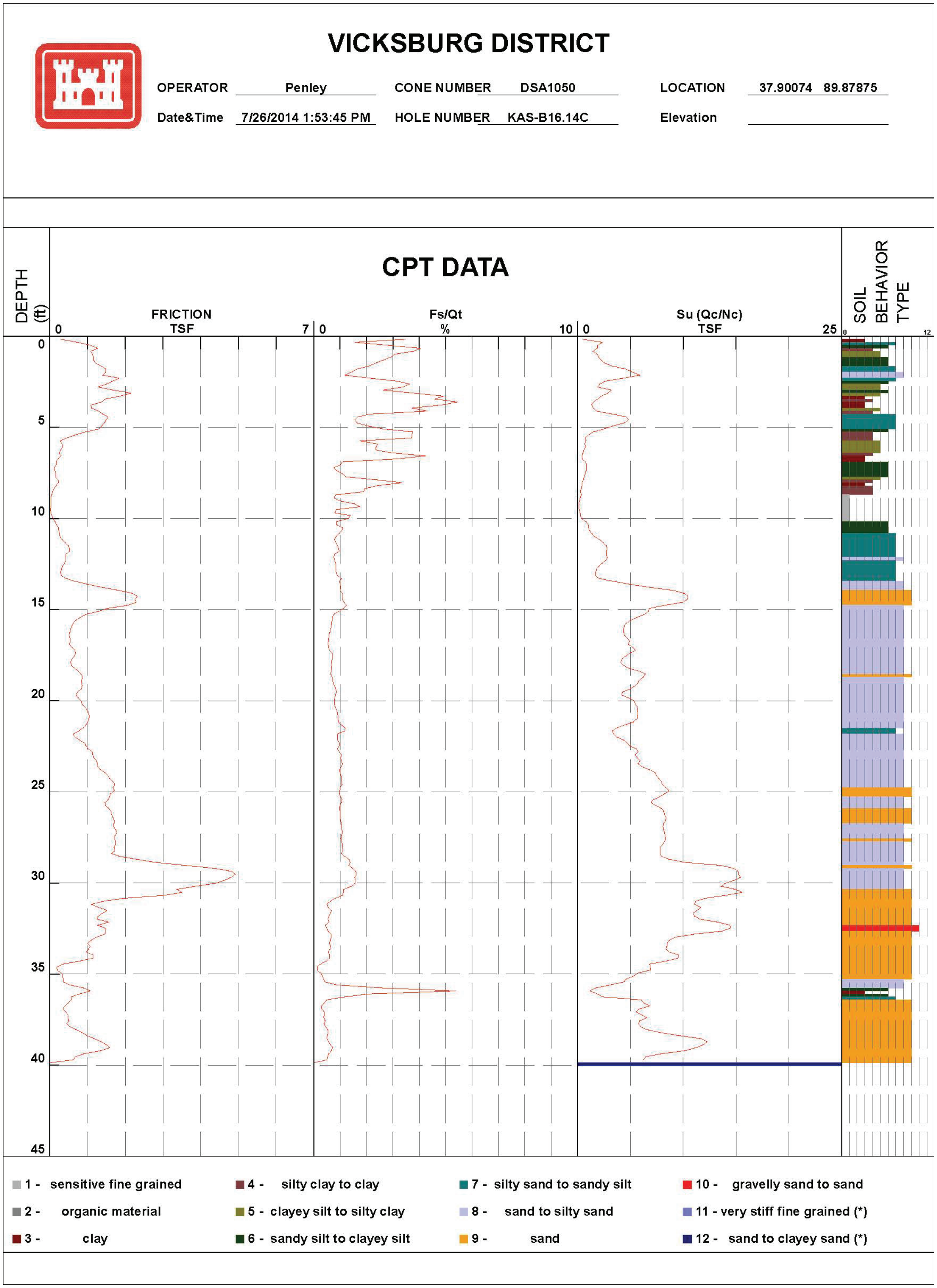
Date&Time 7/26/2014 1:17:28 PM | HOLE NUMBER KAS-B15.14C | Elevation



1 - sensitive fine grained | 4 - silty clay to clay | 7 - silty sand to sandy silt | 10 - gravelly sand to sand

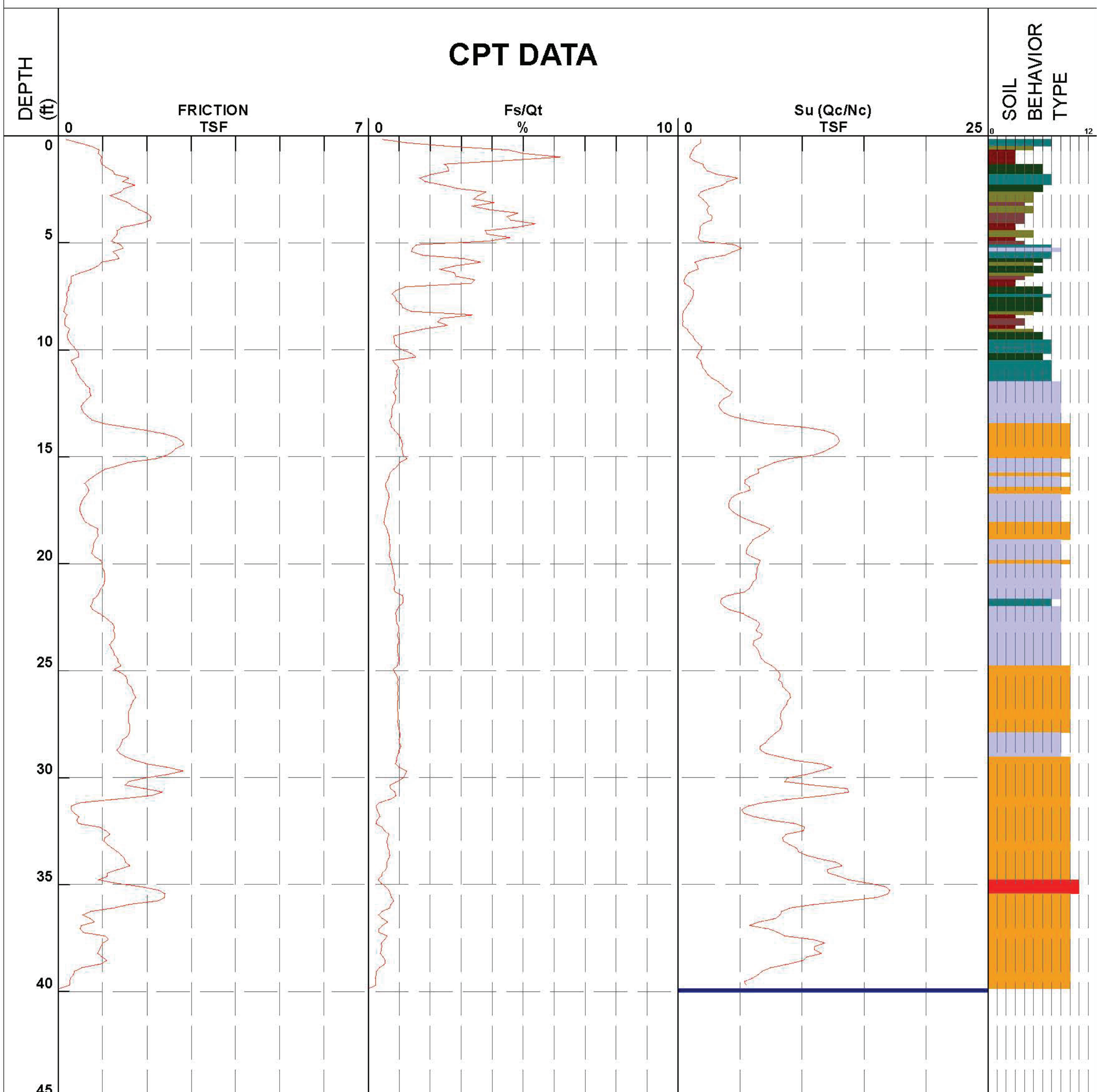
2 - organic material | 5 - clayey silt to silty clay | 8 - sand to silty sand | 11 - very stiff fine grained (*)

3 - clay | 6 - sandy silt to clayey silt | 9 - sand | 12 - sand to clayey sand (*)

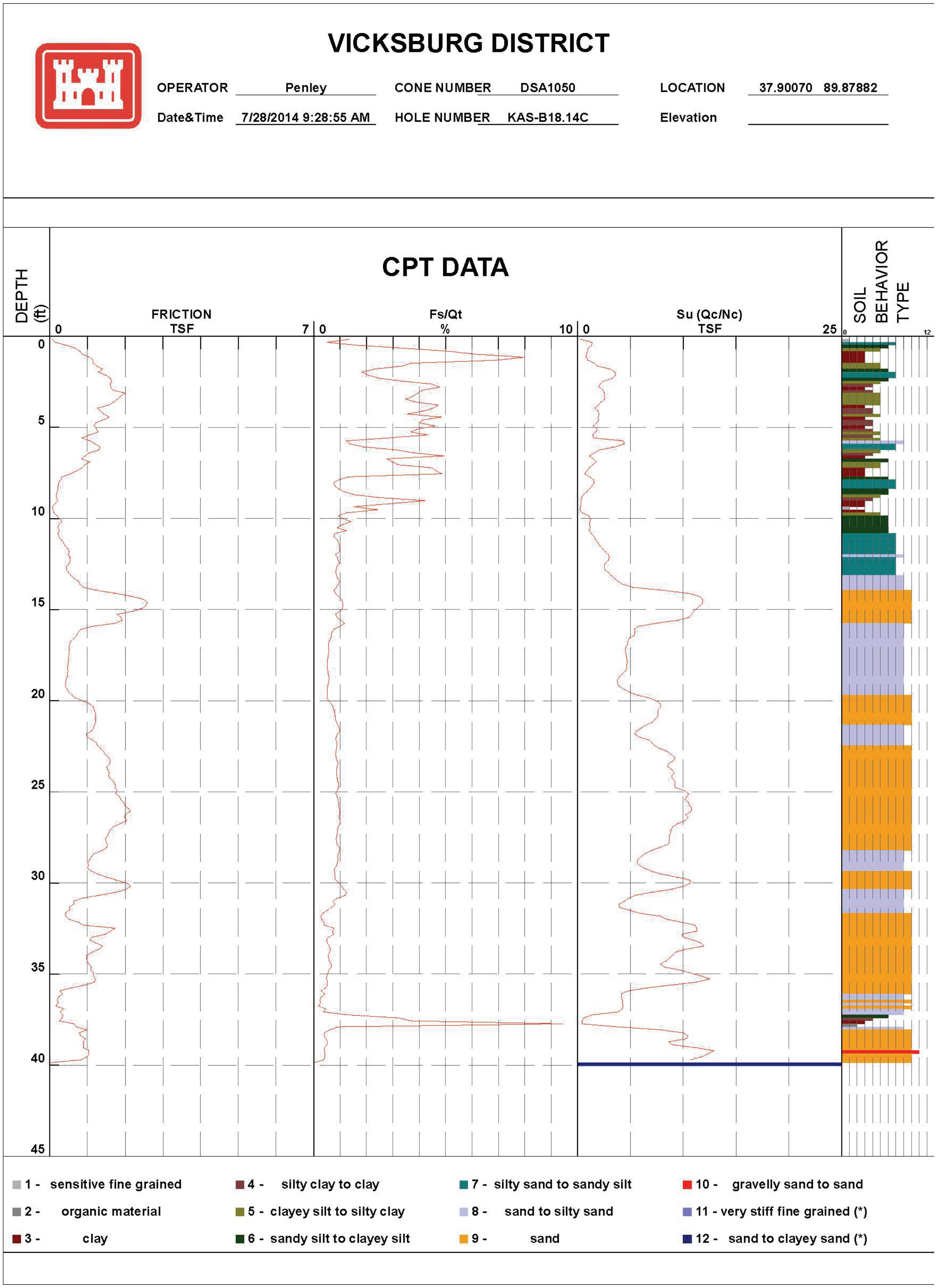

VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90074 89.87875
Date&Time 7/26/2014 1:53:45 PM
HOLE NUMBER KAS-B16.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
Su (Qc/Nc) TSF
SOIL BEHAVIOR TYPE
0 5 10 15 20 25 30 35 40 45
0 7
0 10
0 25
0 12
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

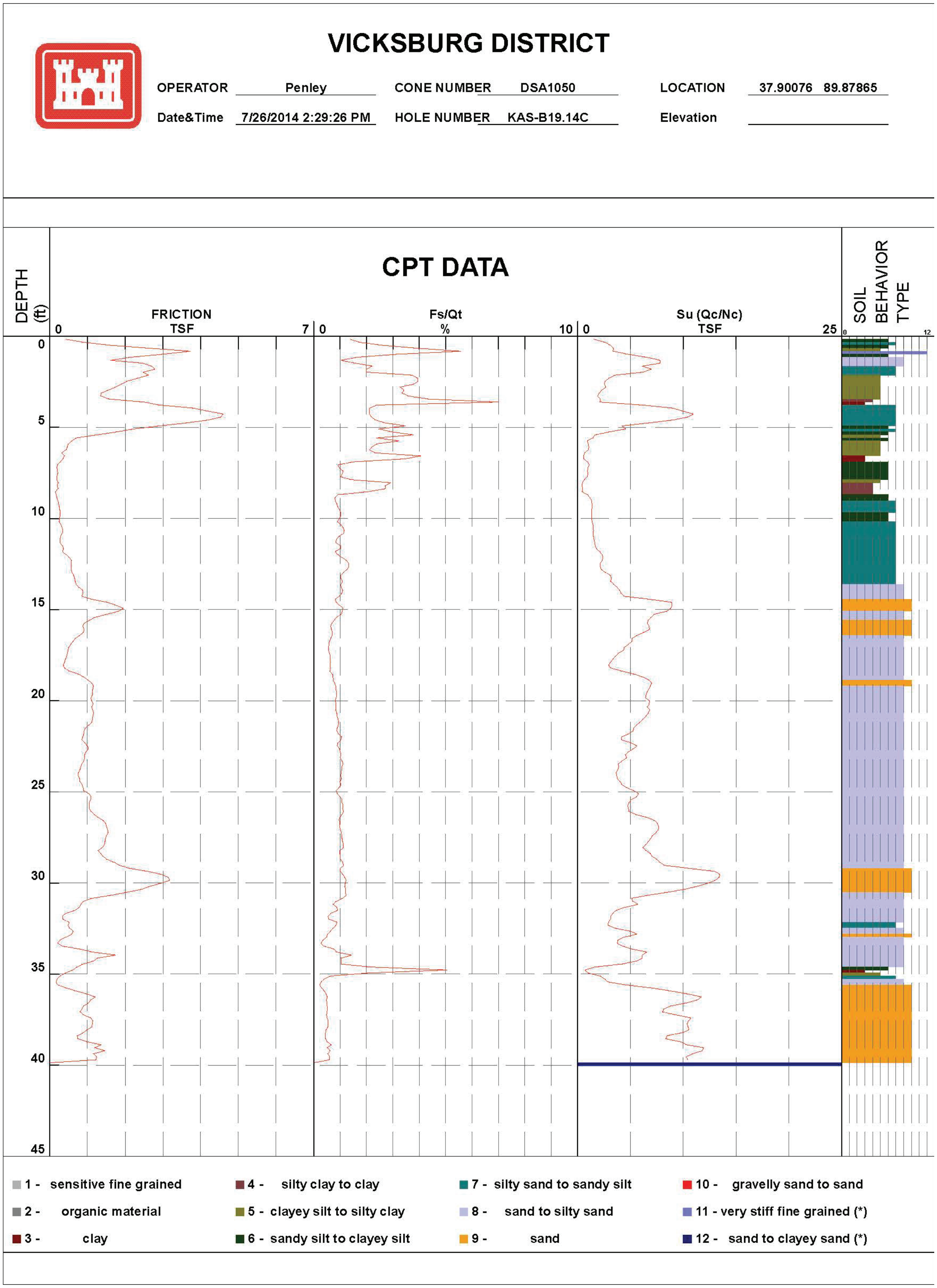
VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90074 89.87878
Date&Time	7/28/2014 8:53:30 AM	HOLE NUMBER	KAS-B17.14C	Elevation	



1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

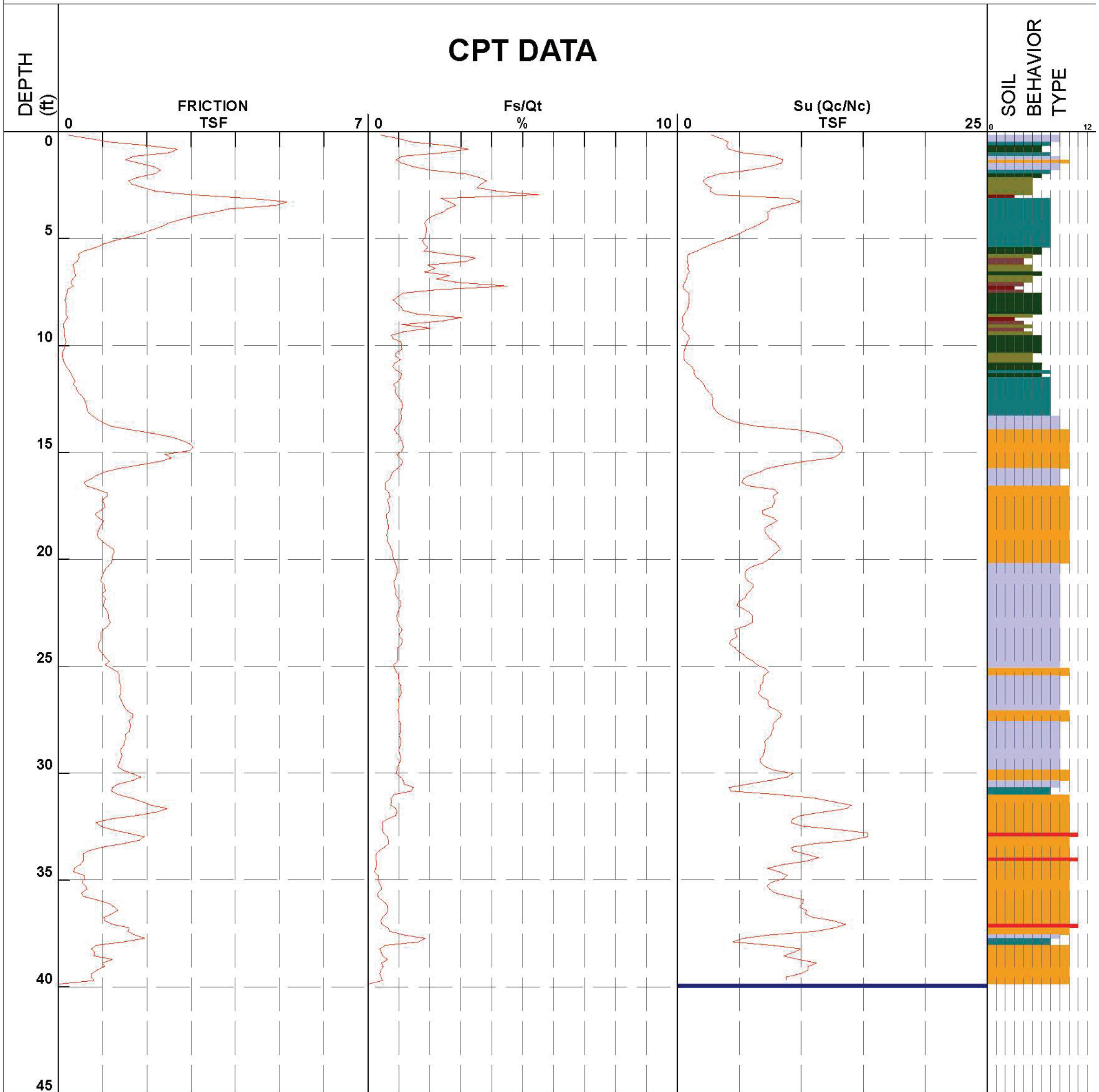

VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90070 89.87882
Date&Time 7/28/2014 9:28:55 AM
HOLE NUMBER KAS-B18.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
Su (Qc/Nc) TSF
SOIL BEHAVIOR TYPE
0 5 10 15 20 25 30 35 40 45
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90076 89.87865
Date&Time 7/26/2014 2:29:26 PM
HOLE NUMBER KAS-B19.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
Su (Qc/Nc) TSF
SOIL BEHAVIOR TYPE
0 5 10 15 20 25 30 35 40 45
0 7
0 10
0 25
0 12
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR Penley | CONE NUMBER DSA1050 | LOCATION 37.90070 89.87878

Date&Time 7/26/2014 3:07:02 PM | HOLE NUMBER KAS-B20.14C | Elevation

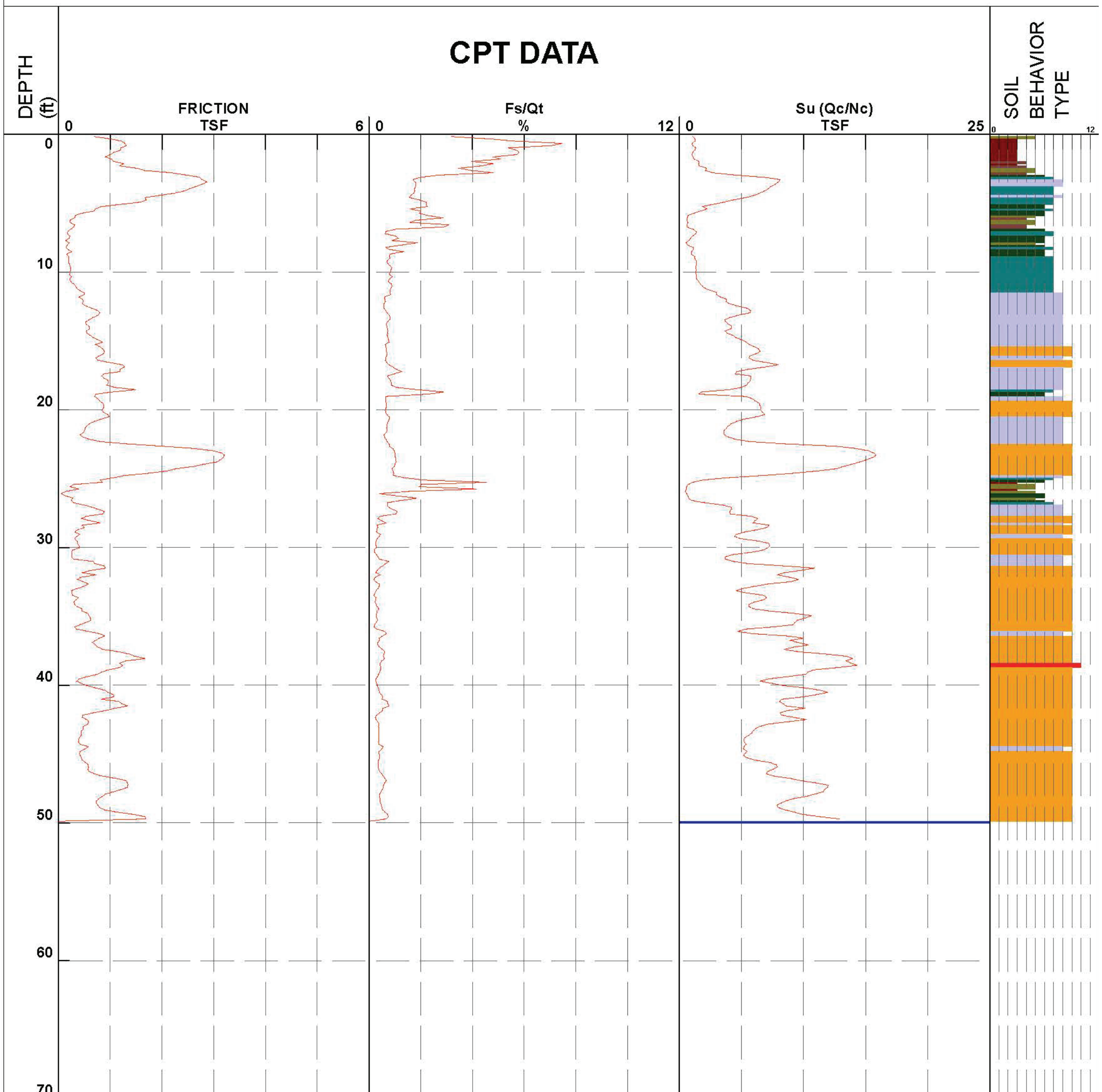


1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR Penley | CONE NUMBER DSA1050 | LOCATION 37.90138 89.87763

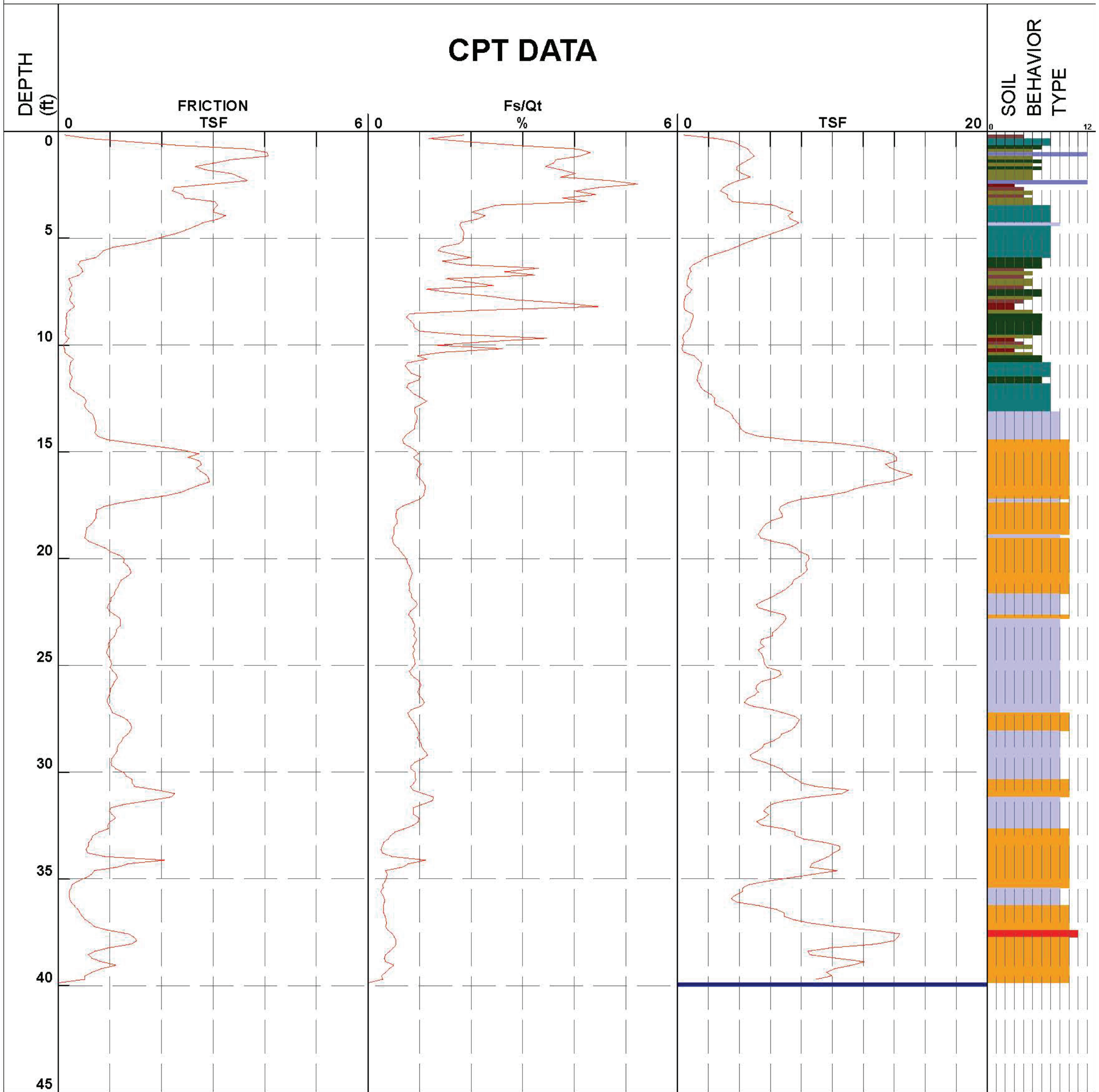
Date&Time 7/19/2014 2:57:23 PM | HOLE NUMBER KAS-21.14C | Elevation



1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

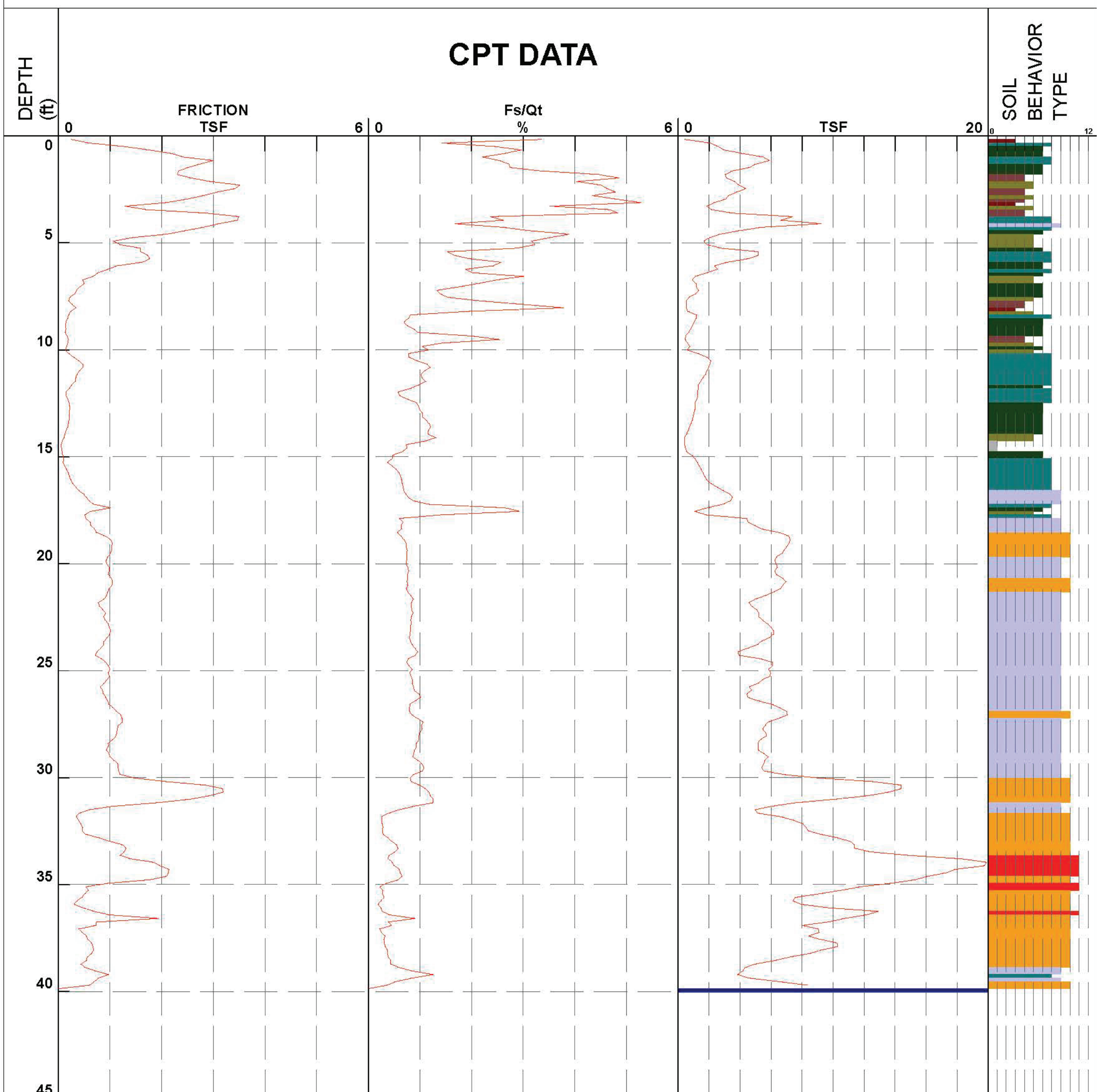
OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90067 89.87876
Date&Time	7/28/2014 11:09:43 AM	HOLE NUMBER	KAS-B23.14C	Elevation	



1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

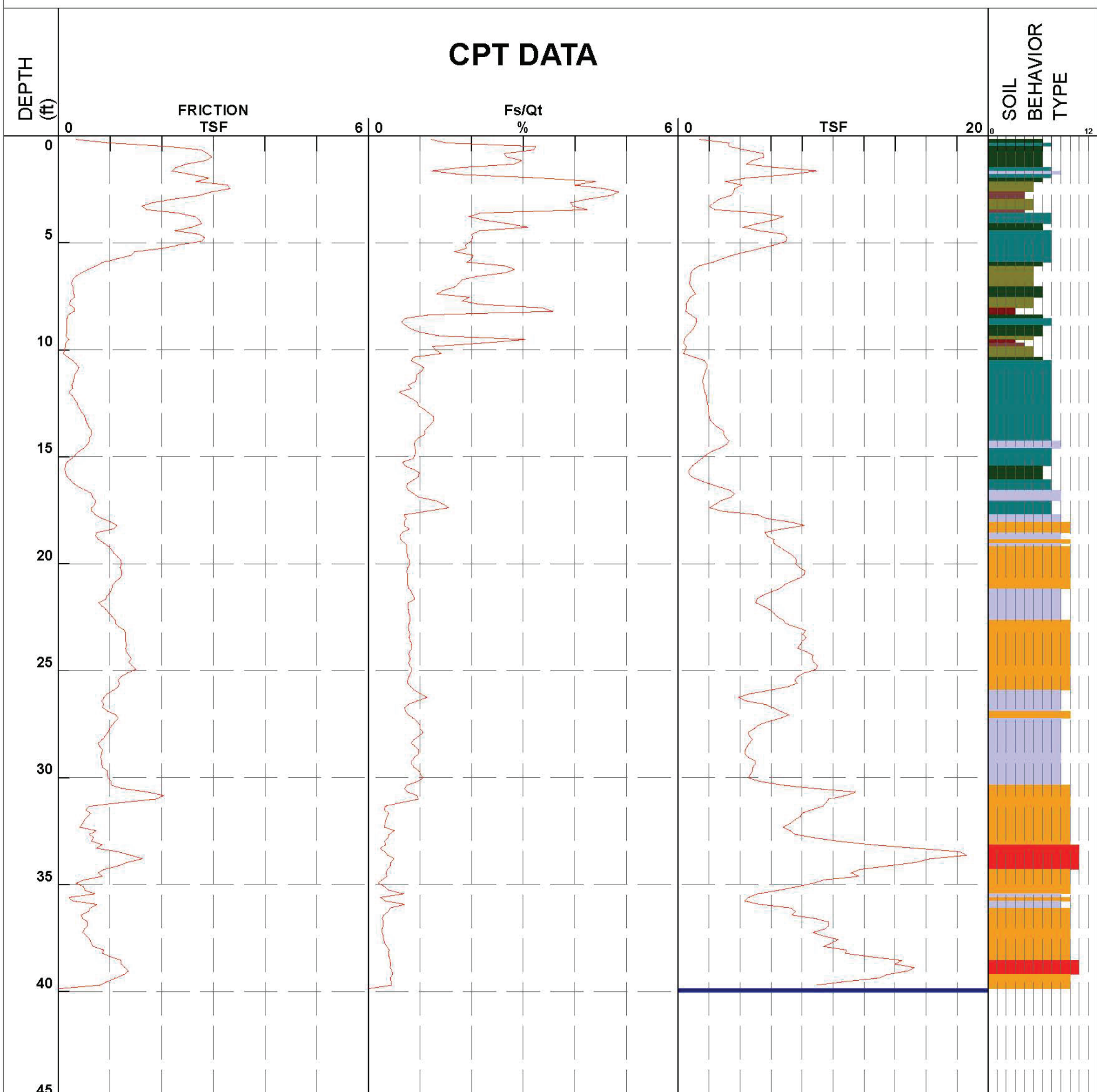
OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90068 89.87862
Date&Time	7/28/2014 1:42:21 PM	HOLE NUMBER	KAS-B24.14C	Elevation	



1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

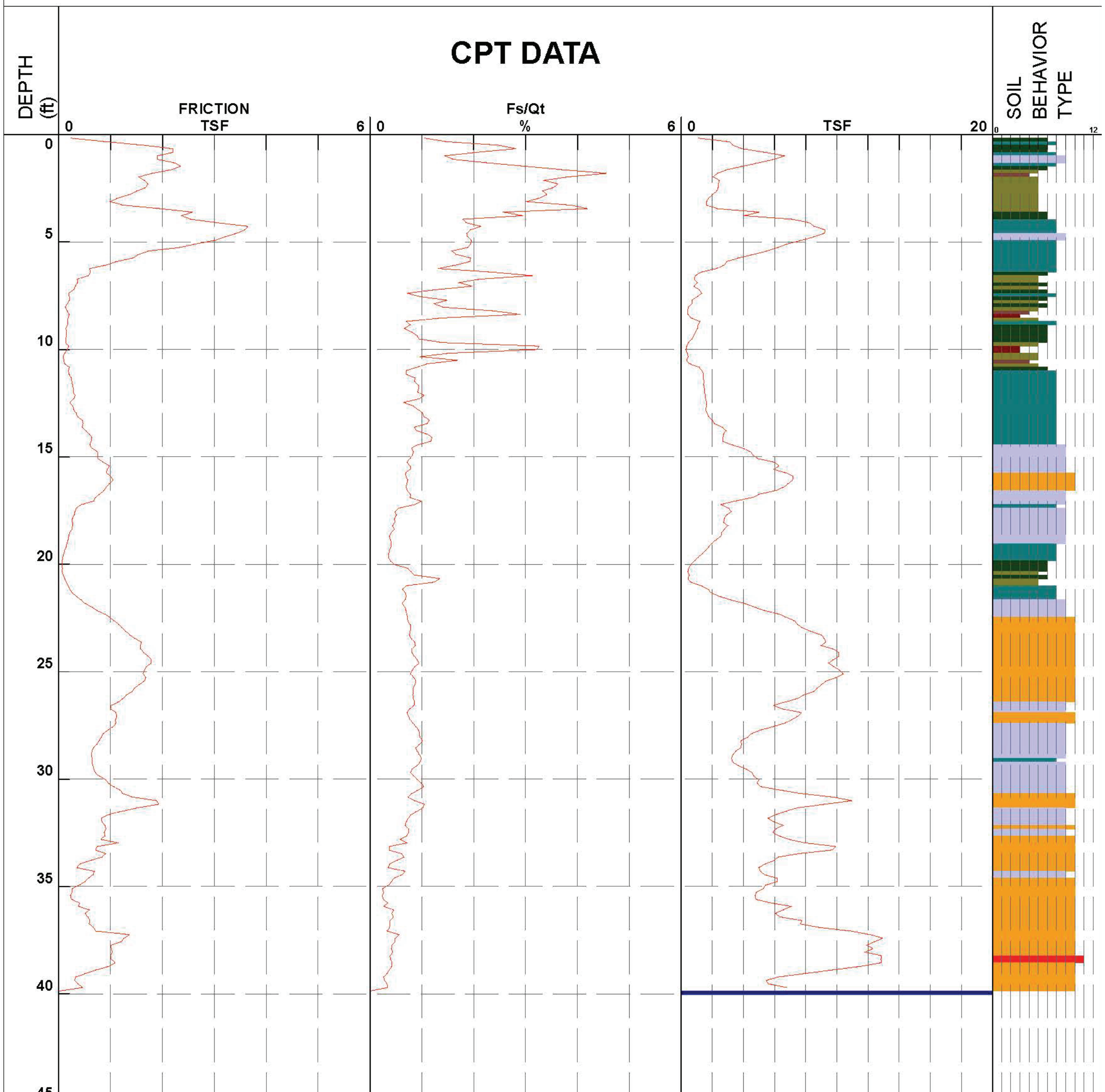
OPERATOR Penley
Date&Time 7/29/2014 8:49:44 AM
CONE NUMBER DSA1050
HOLE NUMBER KAS-B25.14C
LOCATION 37.90069 89.87865
Elevation



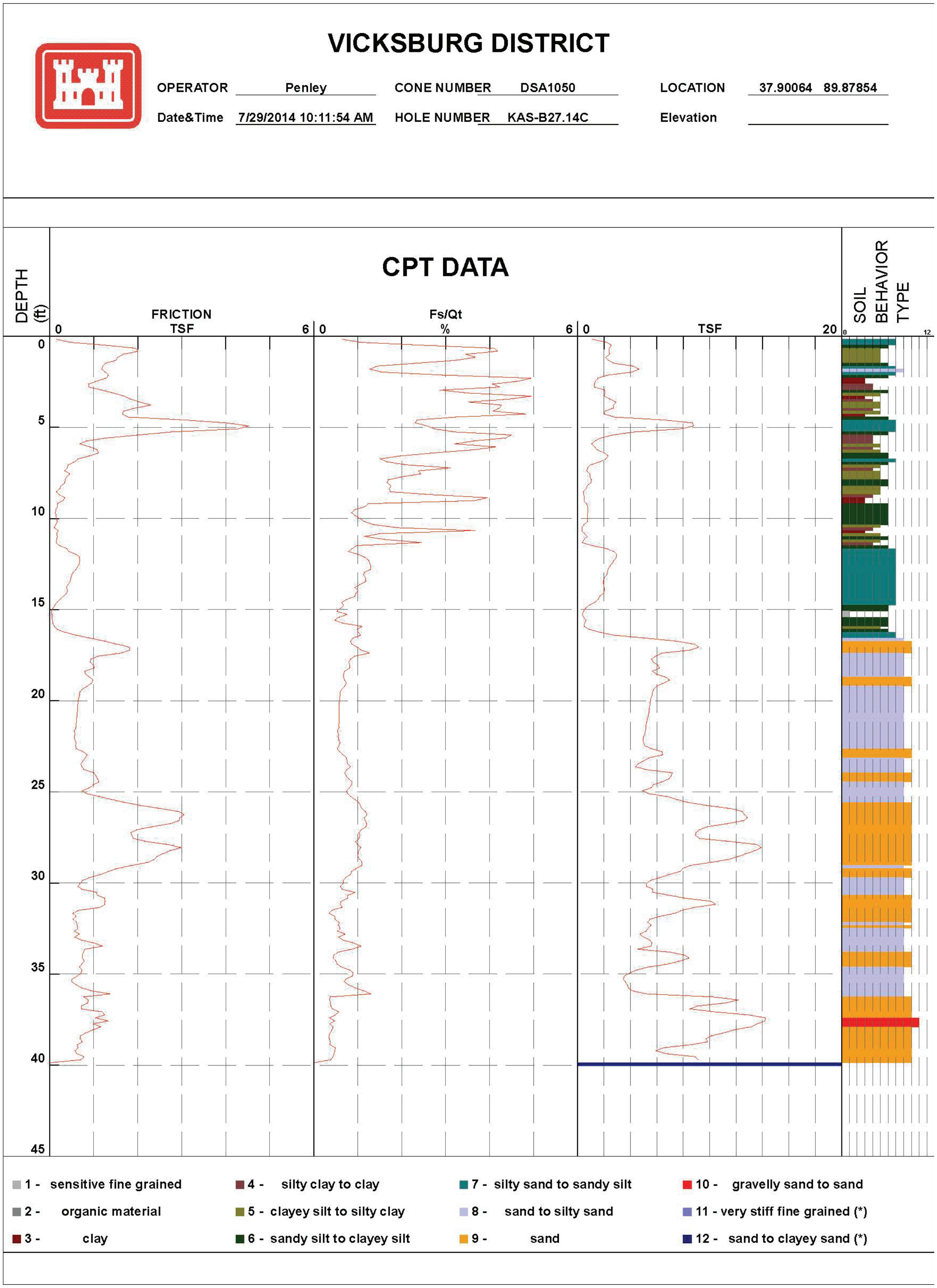
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90057 89.87880
Date&Time	7/29/2014 9:32:56 AM	HOLE NUMBER	KAS-B26.14C	Elevation	



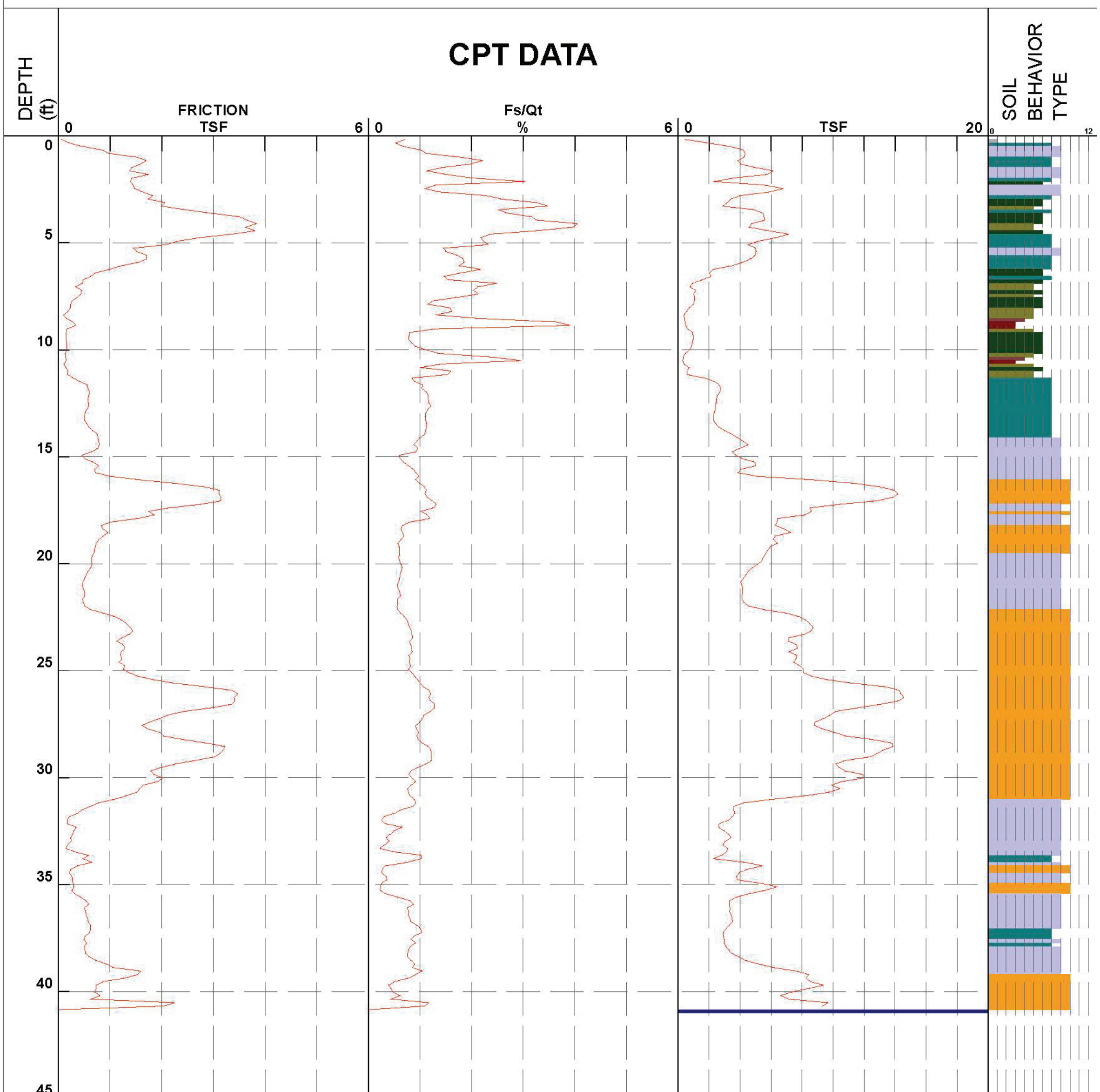
1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90064 89.87854
Date&Time 7/29/2014 10:11:54 AM
HOLE NUMBER KAS-B27.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
0
6
Fs/Qt %
0
6
TSF
0
20
SOIL BEHAVIOR TYPE
0
12
0
5
10
15
20
25
30
35
40
45
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

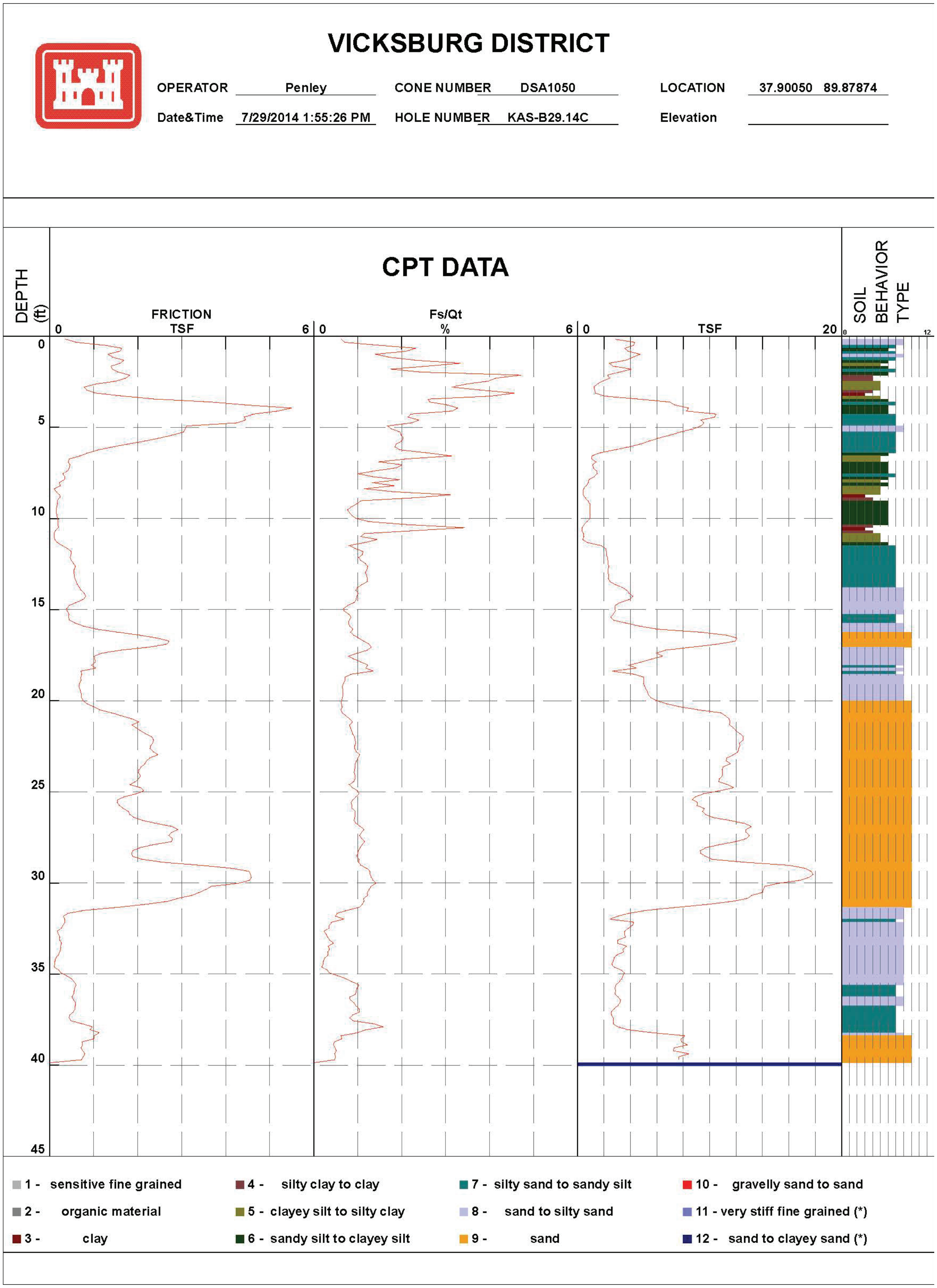
VICKSBURG DISTRICT

OPERATOR Penley | CONE NUMBER DSA1050 | LOCATION 37.90057 89.87863

Date&Time 7/29/2014 1:09:55 PM | HOLE NUMBER KAS-B28.14C | Elevation

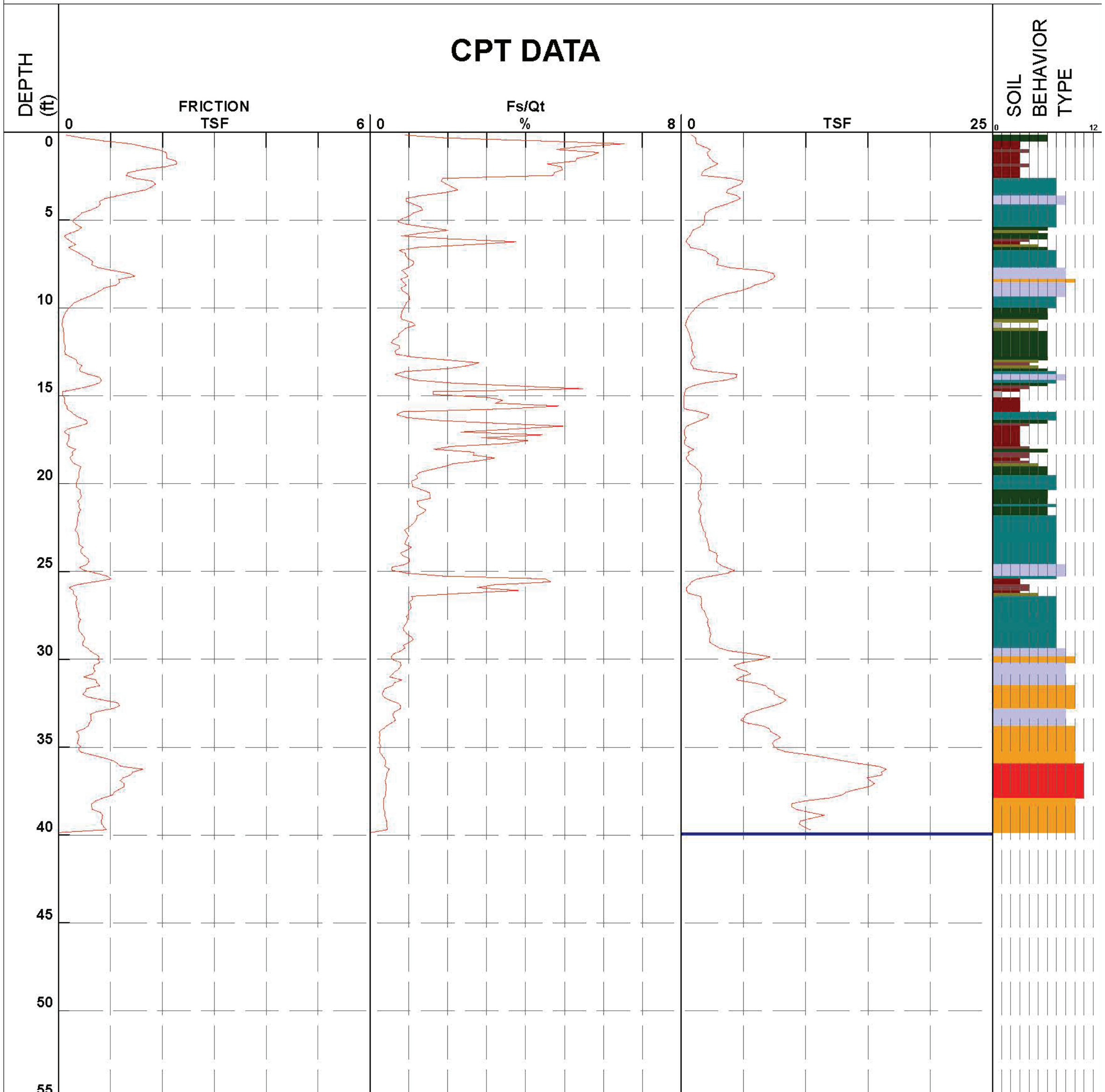


1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90050 89.87874
Date&Time 7/29/2014 1:55:26 PM
HOLE NUMBER KAS-B29.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
TSF
SOIL BEHAVIOR TYPE
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

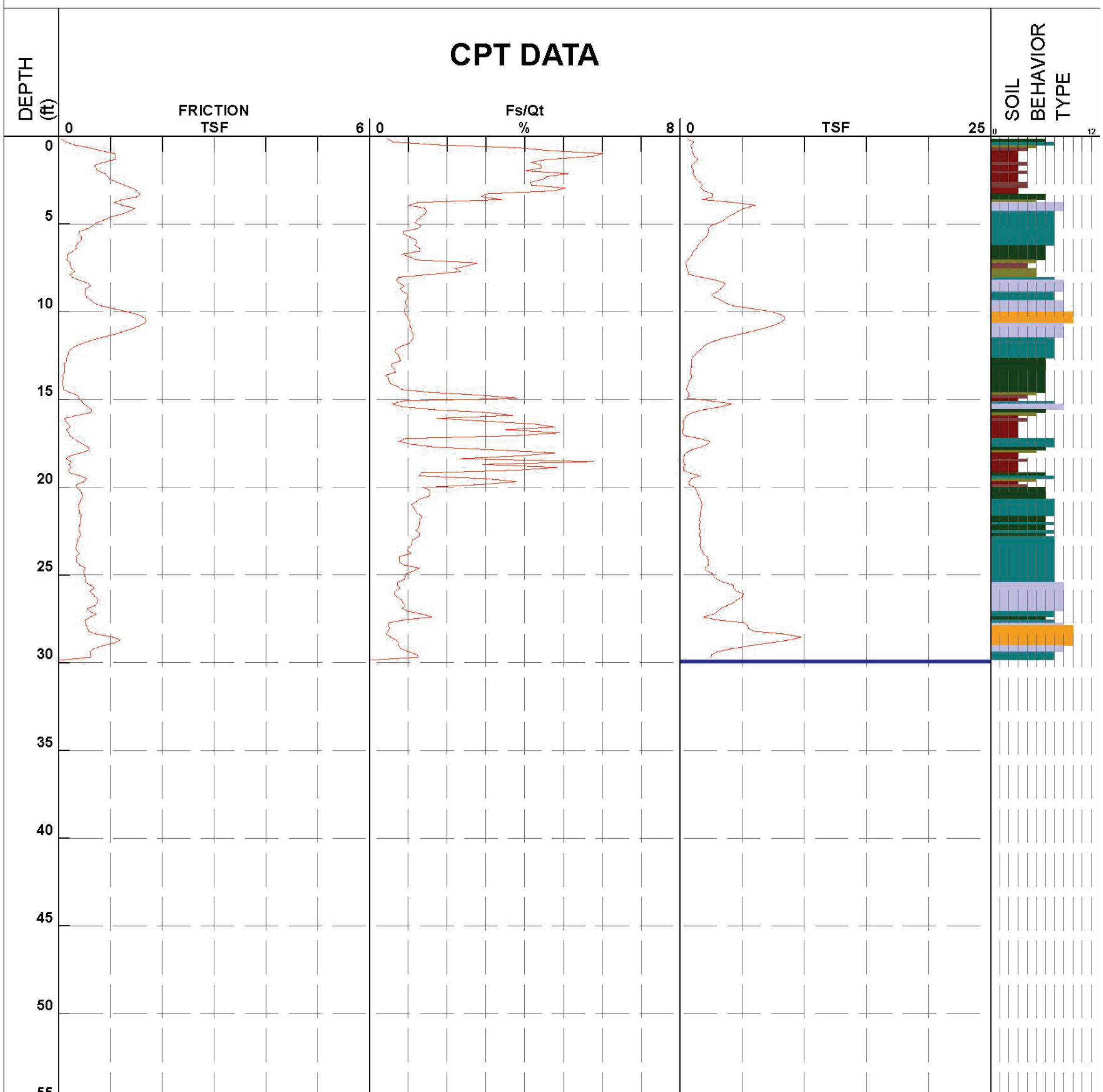
OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.89784 89.88342
Date&Time	7/30/2014 10:31:17 AM	HOLE NUMBER	KAS-C3.14C	Elevation	



1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

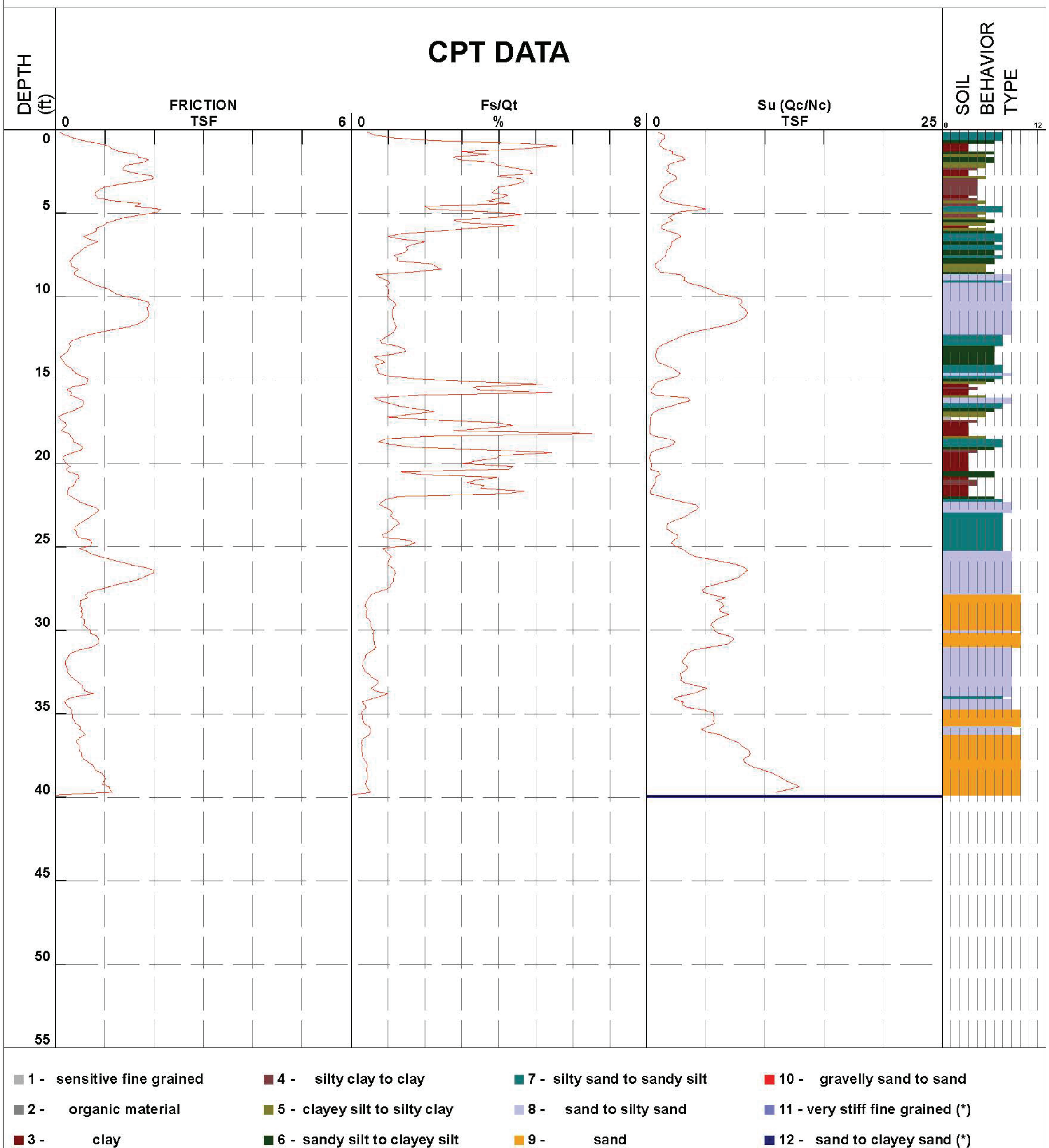
OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.89782 89.88339
Date&Time	7/30/2014 11:09:46 AM	HOLE NUMBER	KAS-C7.14C	Elevation	

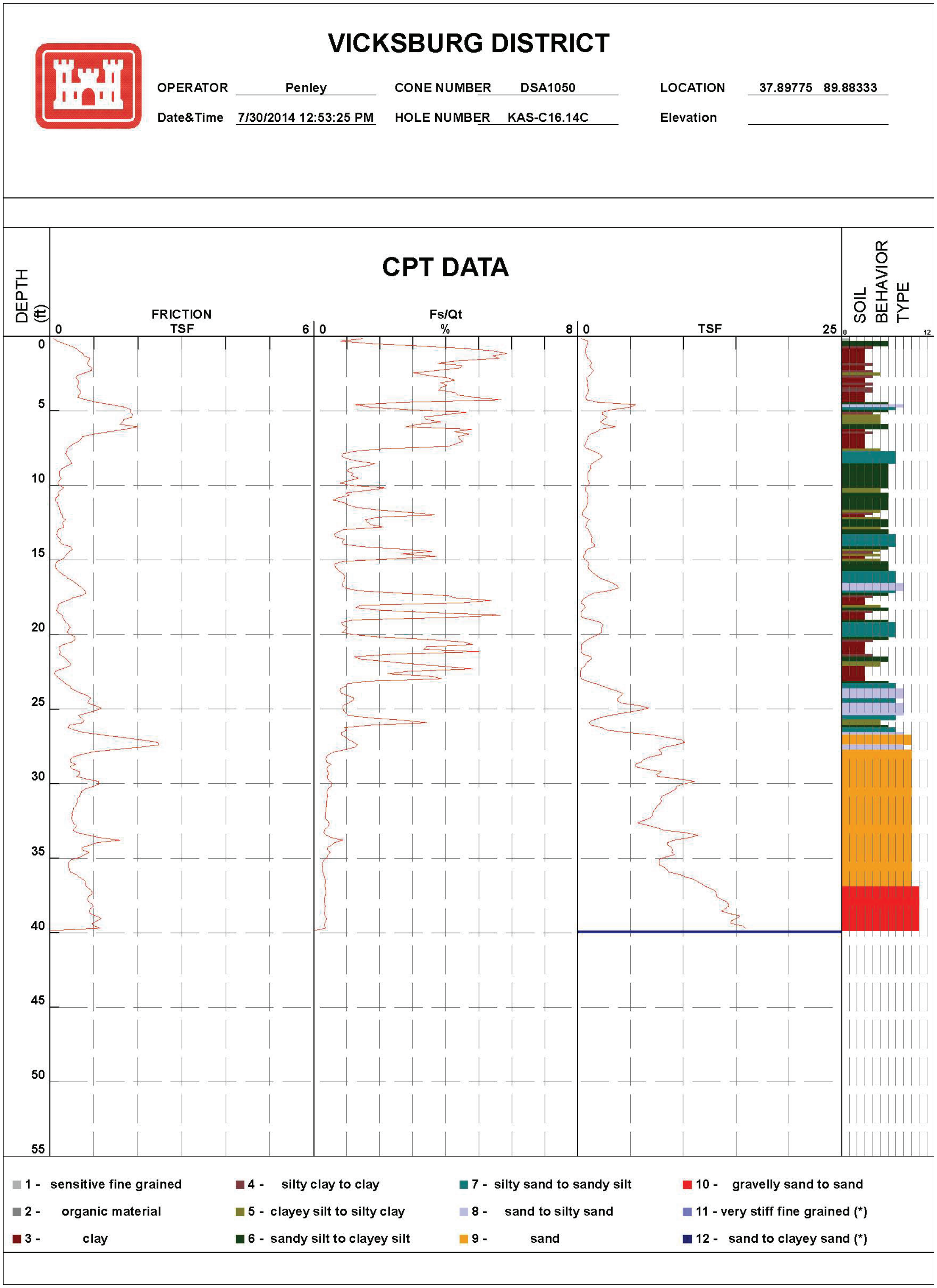


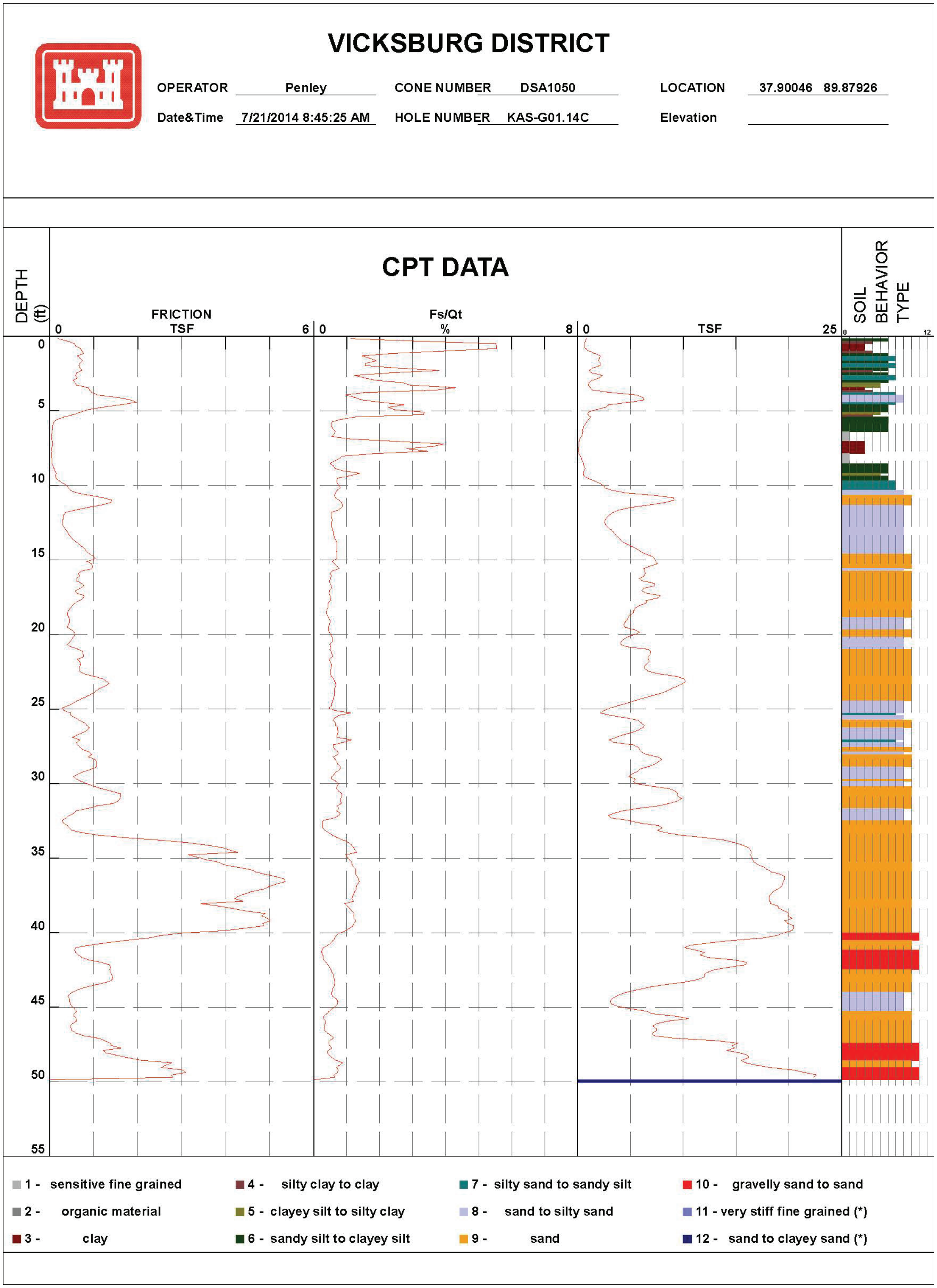
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

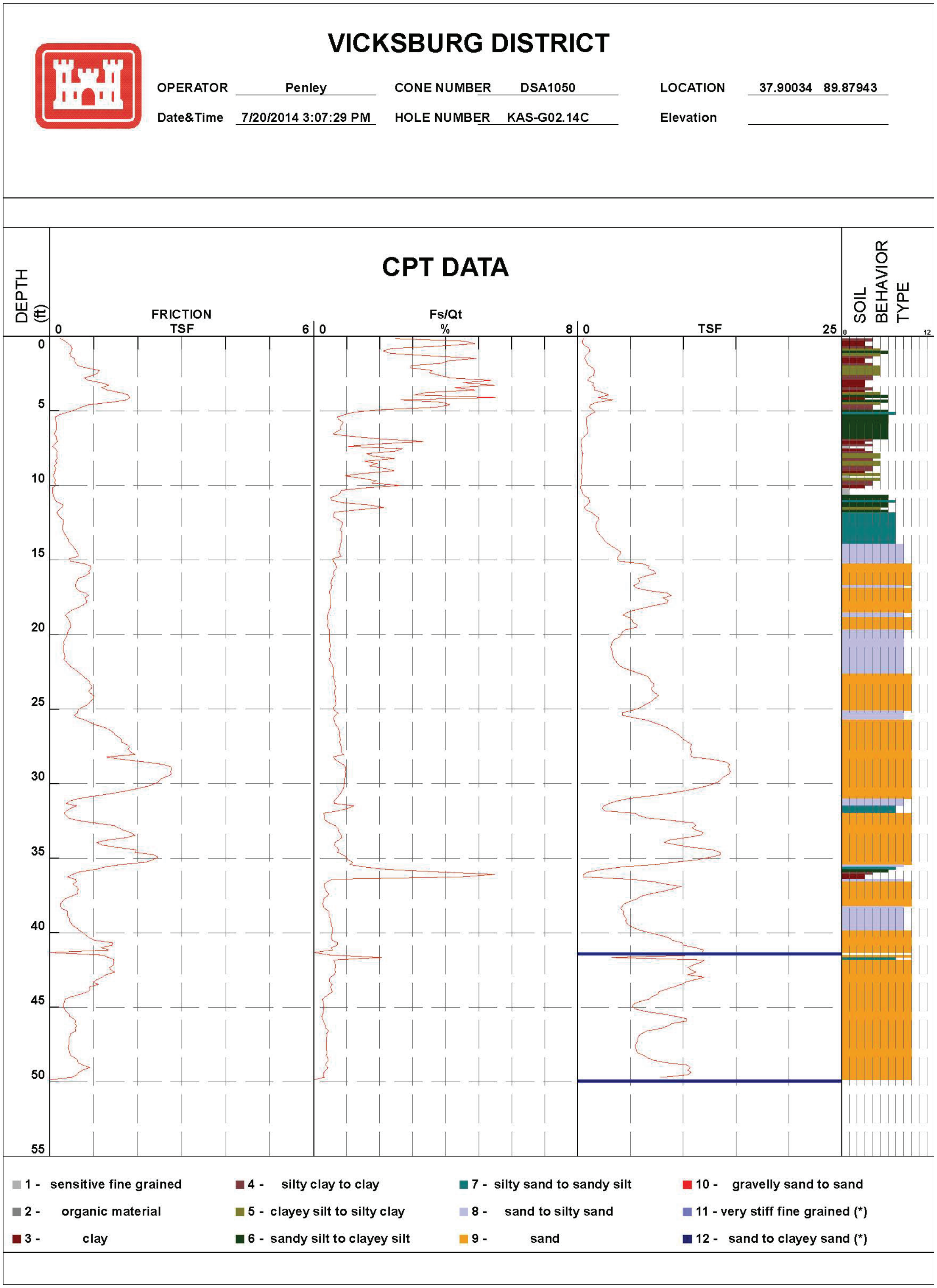
VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.89779 89.88337
Date&Time	7/30/2014 11:38:18 AM	HOLE NUMBER	KAS-C10.14C	Elevation	




VICKSBURG DISTRICT
OPERATOR Penley
Date&Time 7/30/2014 12:53:25 PM
CONE NUMBER DSA1050
HOLE NUMBER KAS-C16.14C
LOCATION 37.89775 89.88333
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
TSF
SOIL BEHAVIOR TYPE
0 6 0 8 0 25 0 12
0 5 10 15 20 25 30 35 40 45 50 55
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

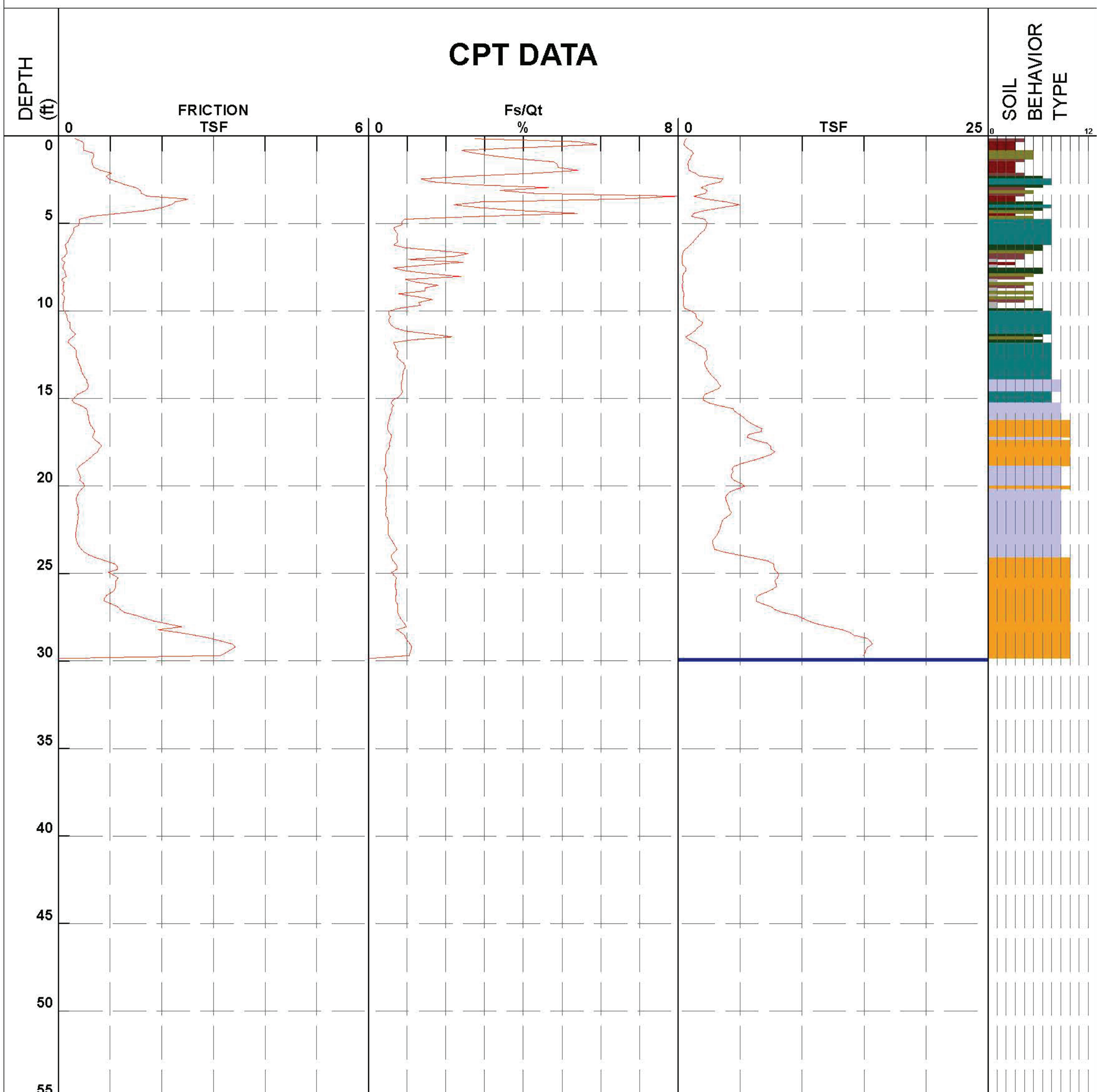

VICKSBURG DISTRICT
OPERATOR Penley
Date&Time 7/21/2014 8:45:25 AM
CONE NUMBER DSA1050
HOLE NUMBER KAS-G01.14C
LOCATION 37.90046 89.87926
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
TSF
SOIL BEHAVIOR TYPE
0 6 0 8 0 25 0 12
0 5 10 15 20 25 30 35 40 45 50 55
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
Date&Time 7/20/2014 3:07:29 PM
CONE NUMBER DSA1050
HOLE NUMBER KAS-G02.14C
LOCATION 37.90034 89.87943
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
TSF
SOIL BEHAVIOR TYPE
0 5 10 15 20 25 30 35 40 45 50 55
0 6
0 8
0 25
0 12
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR Penley | CONE NUMBER DSA1050 | LOCATION 37.90037 89.87940

Date&Time 7/21/2014 2:46:04 PM | HOLE NUMBER KAS-G03.14C | Elevation



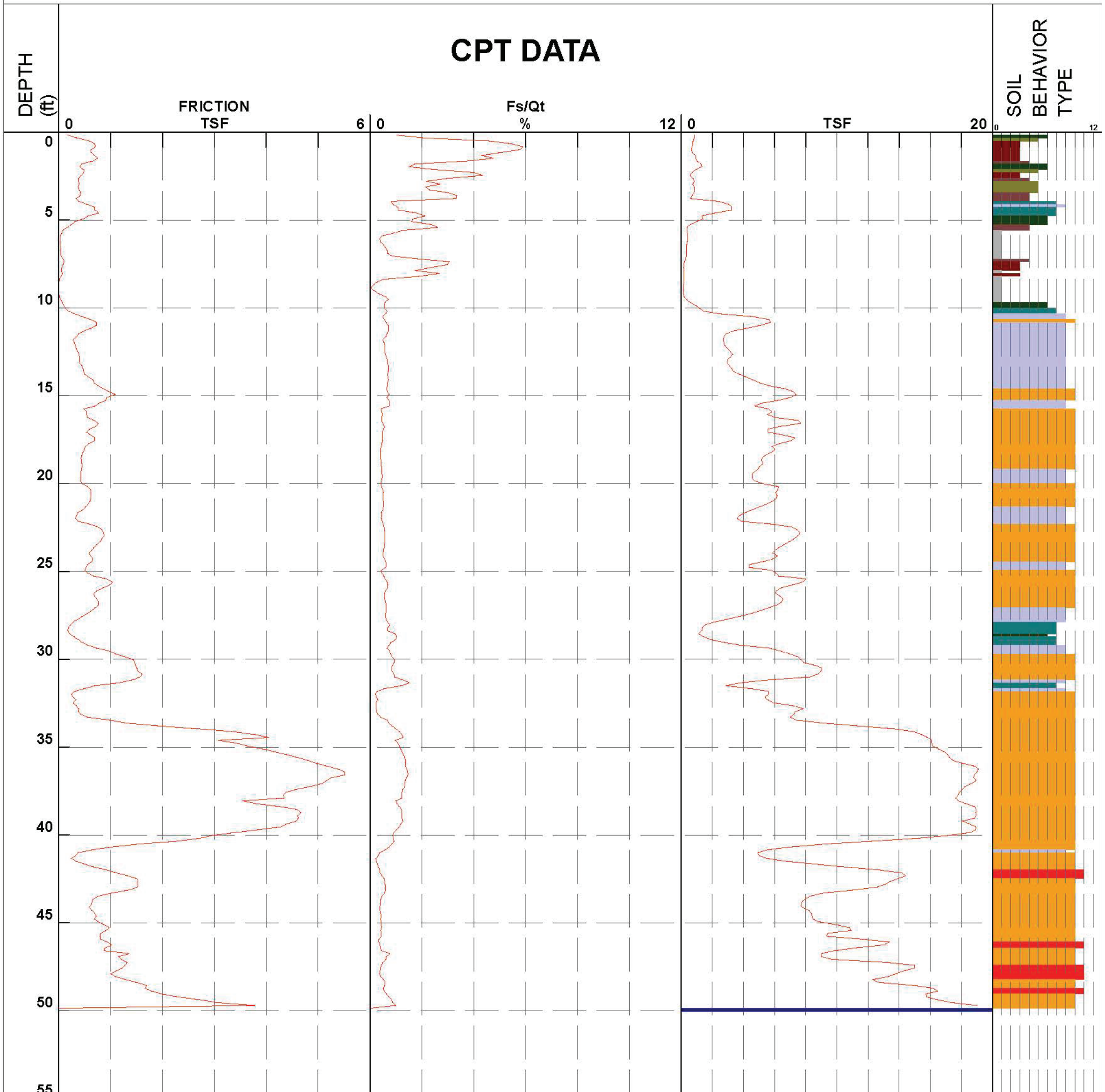
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

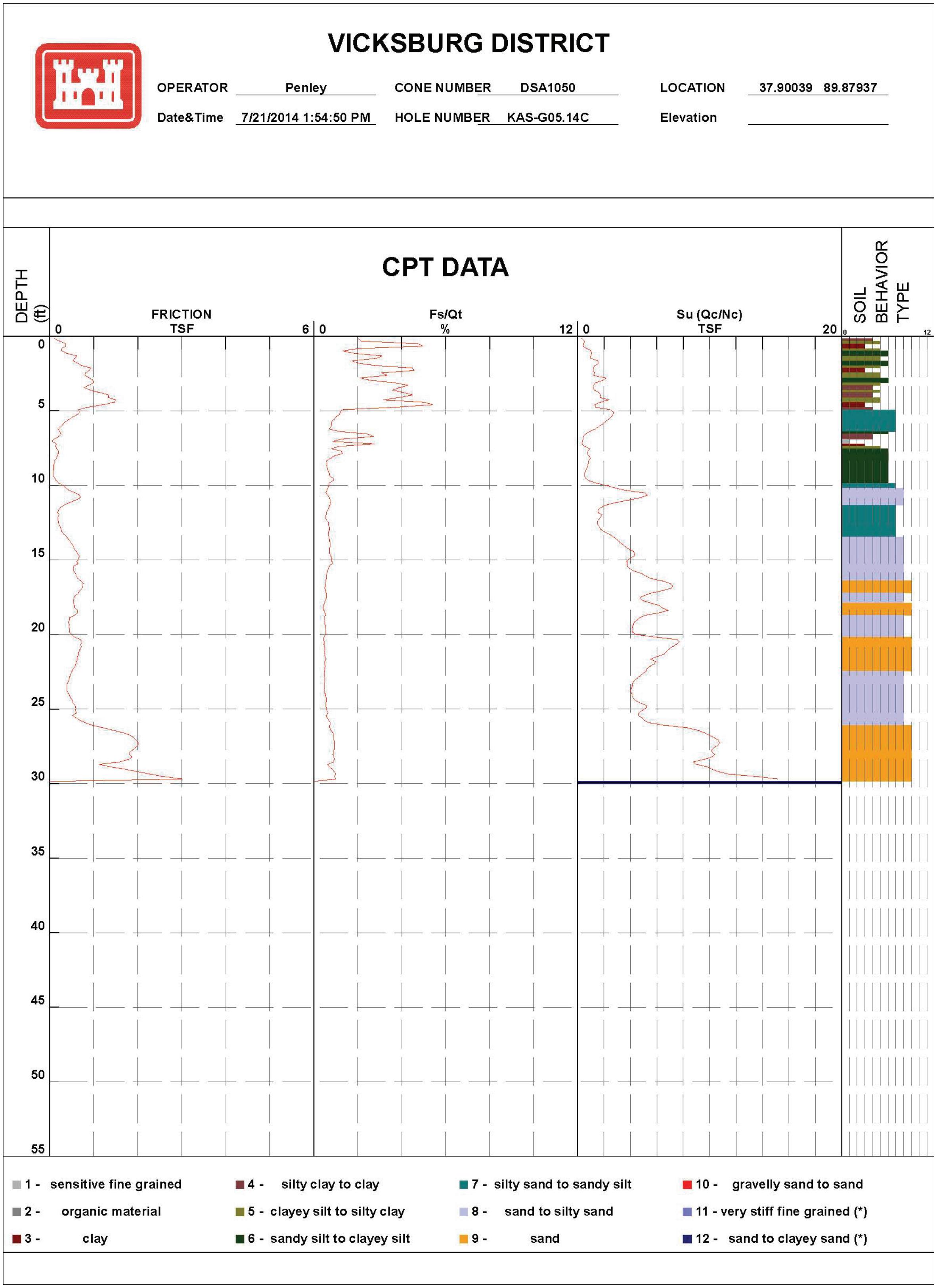
OPERATOR Penley | CONE NUMBER DSA1050 | LOCATION 37.90047 89.87924

Date&Time 7/21/2014 9:33:47 AM | HOLE NUMBER KAS-G10.14C | Elevation

CPT DATA



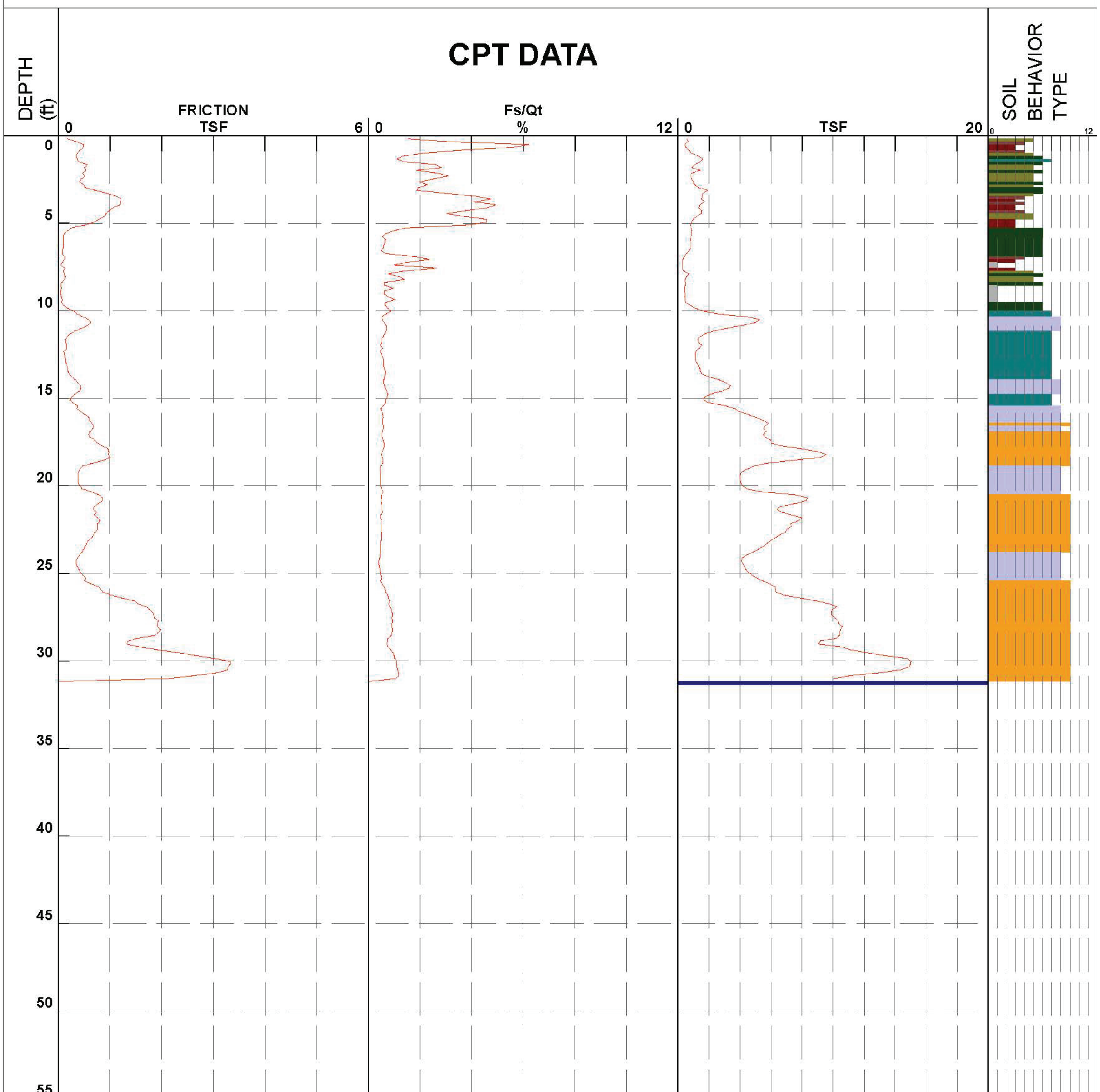
1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90039 89.87937
Date&Time 7/21/2014 1:54:50 PM
HOLE NUMBER KAS-G05.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
Su (Qc/Nc) TSF
SOIL BEHAVIOR TYPE
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

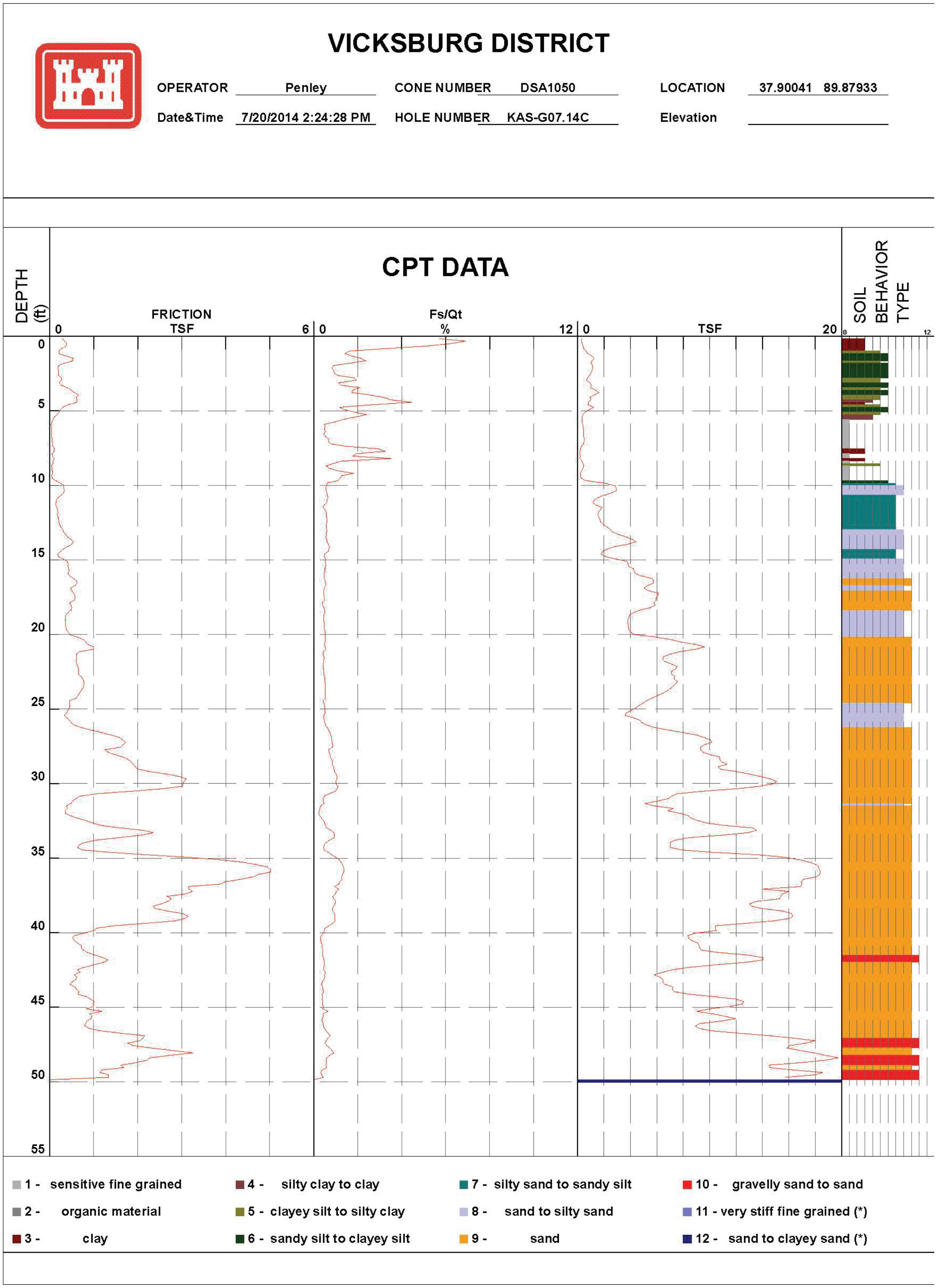
VICKSBURG DISTRICT

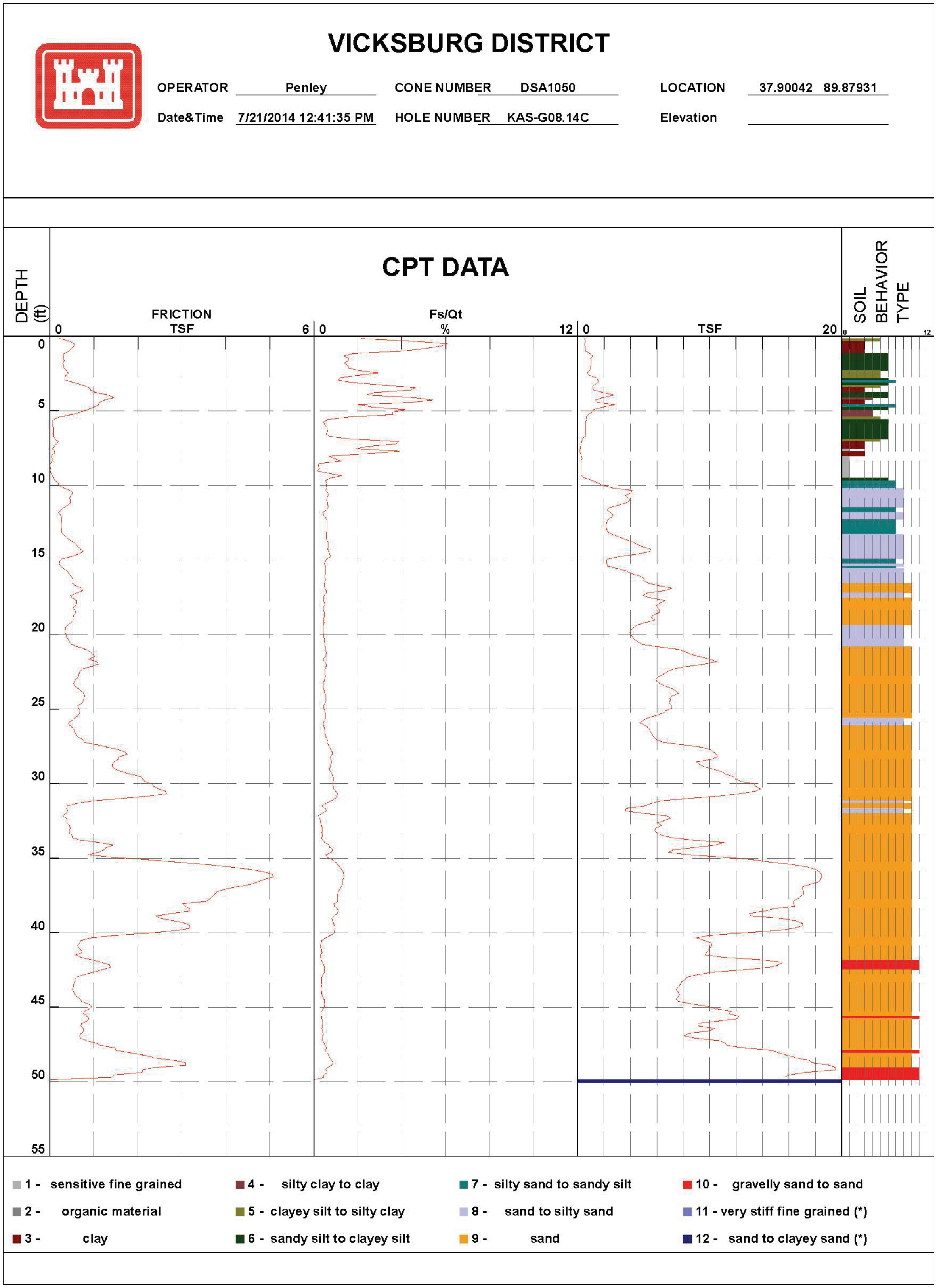
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90041 89.87934
Date&Time 7/21/2014 1:21:49 PM
HOLE NUMBER KAS-G06.14C
Elevation

CPT DATA



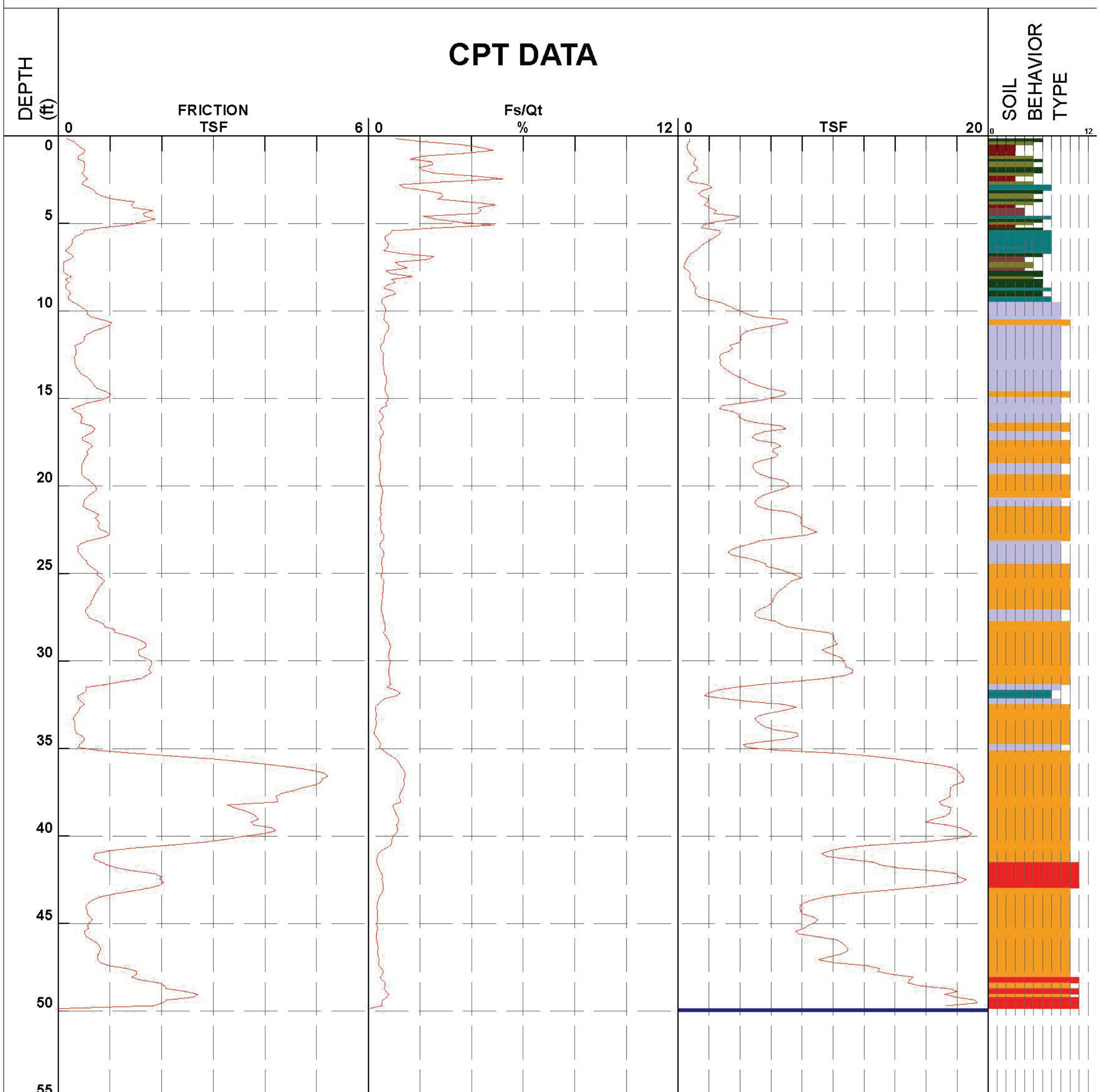
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
Date&Time 7/20/2014 2:24:28 PM
CONE NUMBER DSA1050
HOLE NUMBER KAS-G07.14C
LOCATION 37.90041 89.87933
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
TSF
SOIL BEHAVIOR TYPE
0
6
12
20
5
10
15
25
30
35
40
45
50
55
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90042 89.87931
Date&Time 7/21/2014 12:41:35 PM
HOLE NUMBER KAS-G08.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
TSF
SOIL BEHAVIOR TYPE
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90043 89.87930
Date&Time	7/21/2014 10:26:49 AM	HOLE NUMBER	KAS-G09.14C	Elevation	

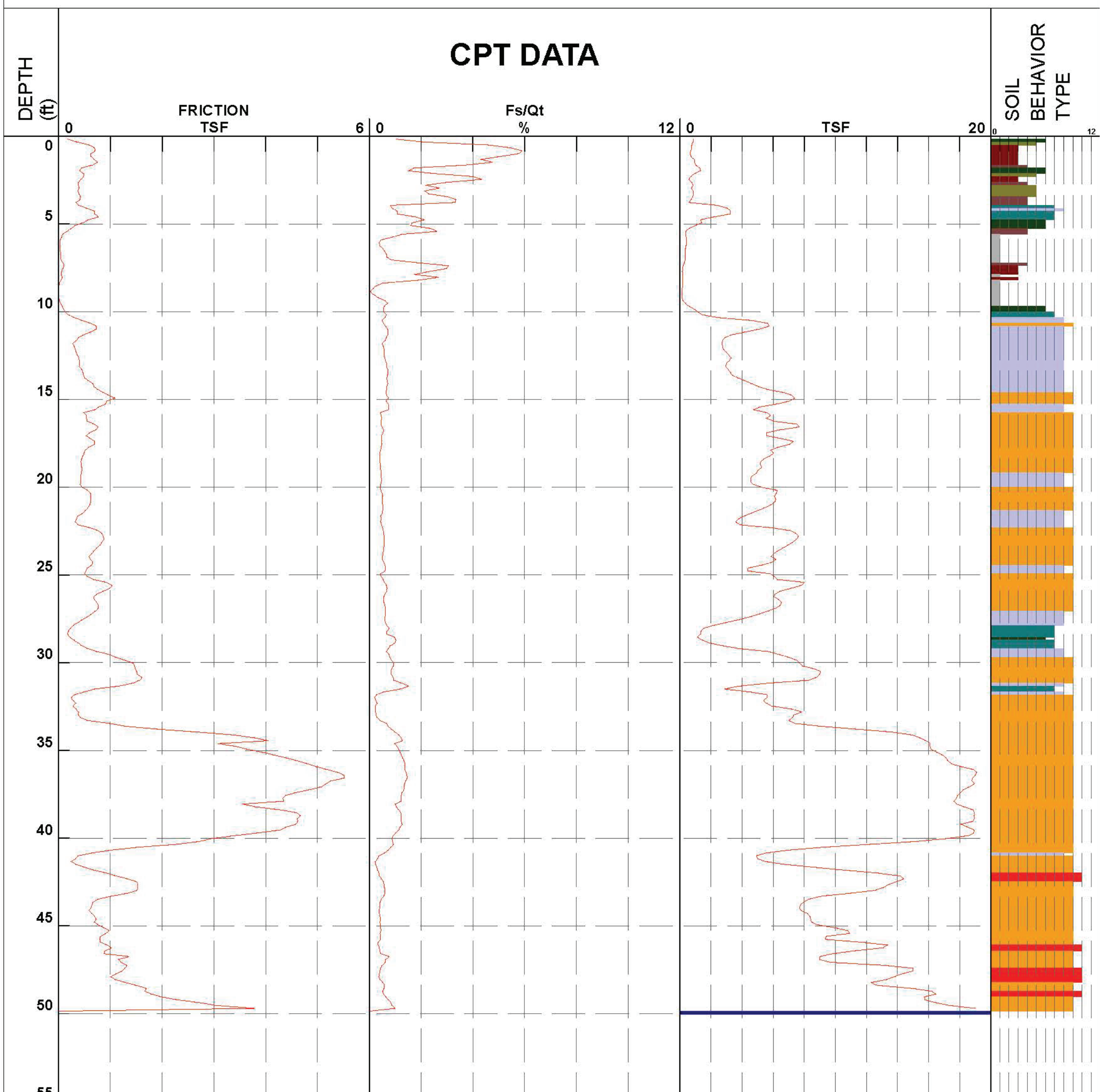


1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

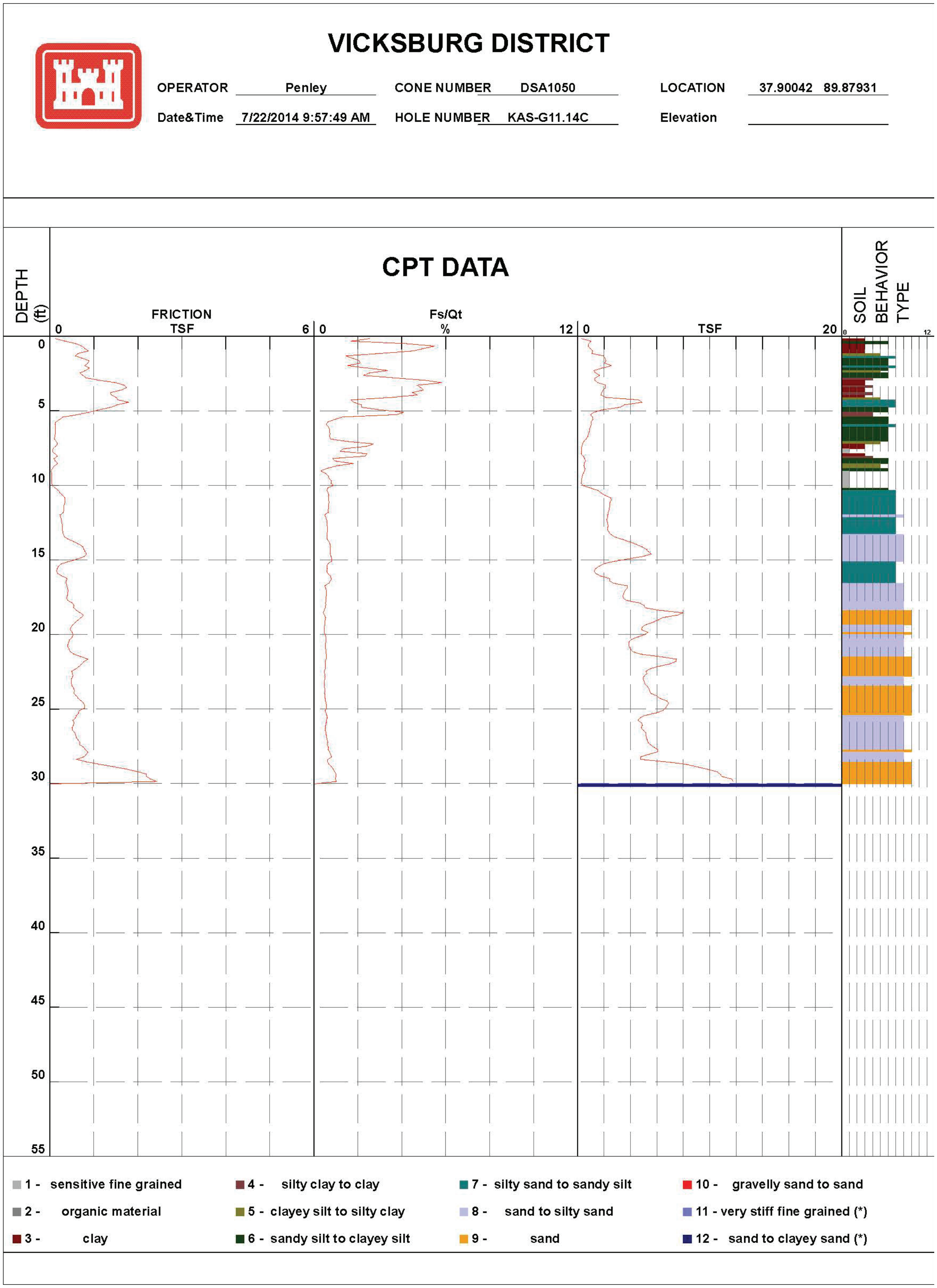
VICKSBURG DISTRICT

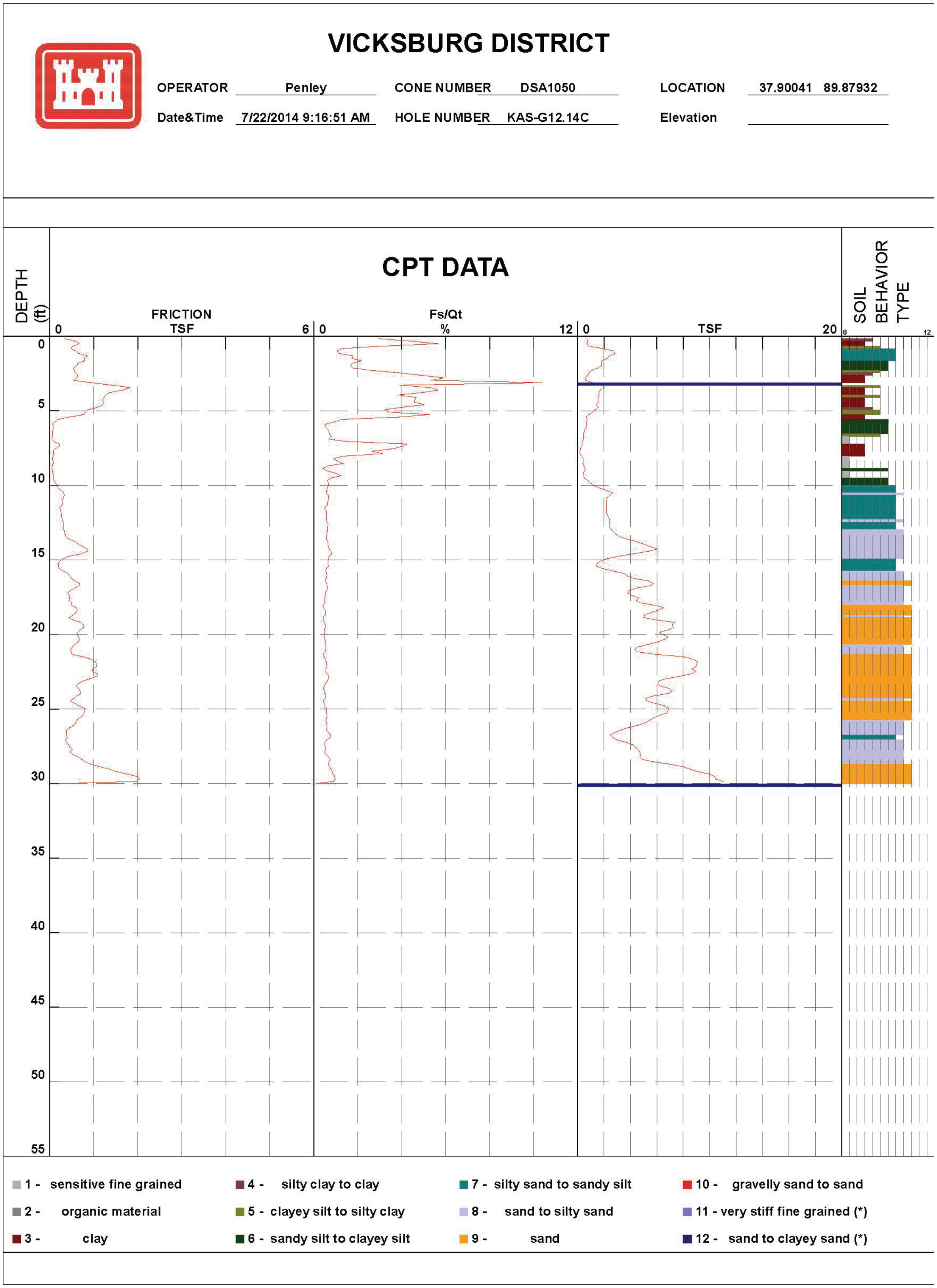
OPERATOR Penley CONE NUMBER DSA1050 LOCATION 37.90047 89.87924

Date&Time 7/21/2014 9:33:47 AM HOLE NUMBER KAS-G10.14C Elevation



■ 1 - sensitive fine grained
■ 2 - organic material
■ 3 - clay
■ 4 - silty clay to clay
■ 5 - clayey silt to silty clay
■ 6 - sandy silt to clayey silt
■ 7 - silty sand to sandy silt
■ 8 - sand to silty sand
■ 9 - sand
■ 10 - gravelly sand to sand
■ 11 - very stiff fine grained (*)
■ 12 - sand to clayey sand (*)

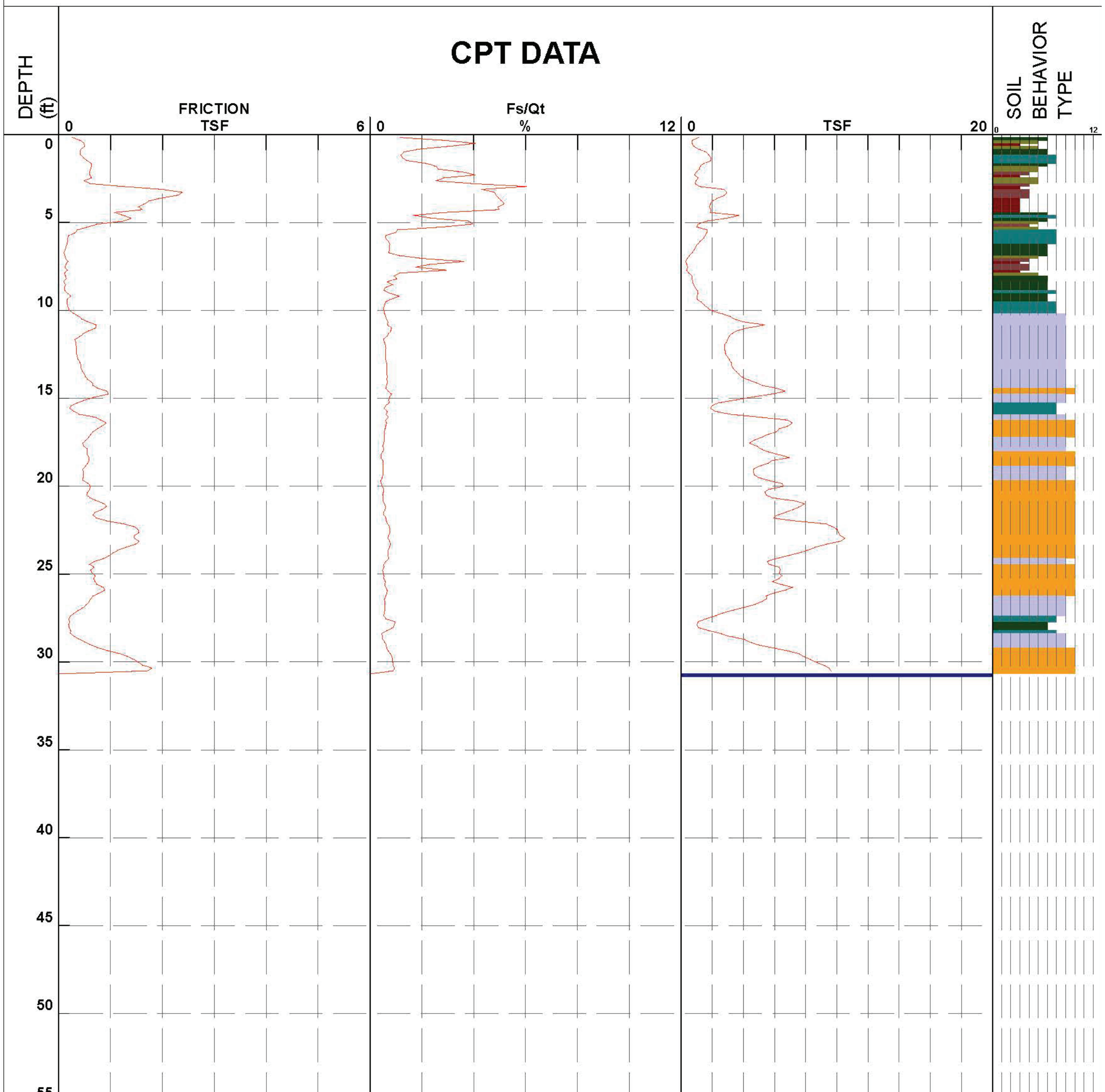

VICKSBURG DISTRICT
OPERATOR Penley
Date&Time 7/22/2014 9:57:49 AM
CONE NUMBER DSA1050
HOLE NUMBER KAS-G11.14C
LOCATION 37.90042 89.87931
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
0 6
Fs/Qt %
0 12
TSF
0 20
SOIL BEHAVIOR TYPE
0 12
0 5 10 15 20 25 30 35 40 45 50 55
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90041 89.87932
Date&Time 7/22/2014 9:16:51 AM
HOLE NUMBER KAS-G12.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
0
6
Fs/Qt %
0
12
0
TSF
20
SOIL BEHAVIOR TYPE
0
12
0
5
10
15
20
25
30
35
40
45
50
55
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR Penley | CONE NUMBER DSA1050 | LOCATION 37.90039 89.87928

Date&Time 7/22/2014 8:42:59 AM | HOLE NUMBER KAS-G13.14C | Elevation

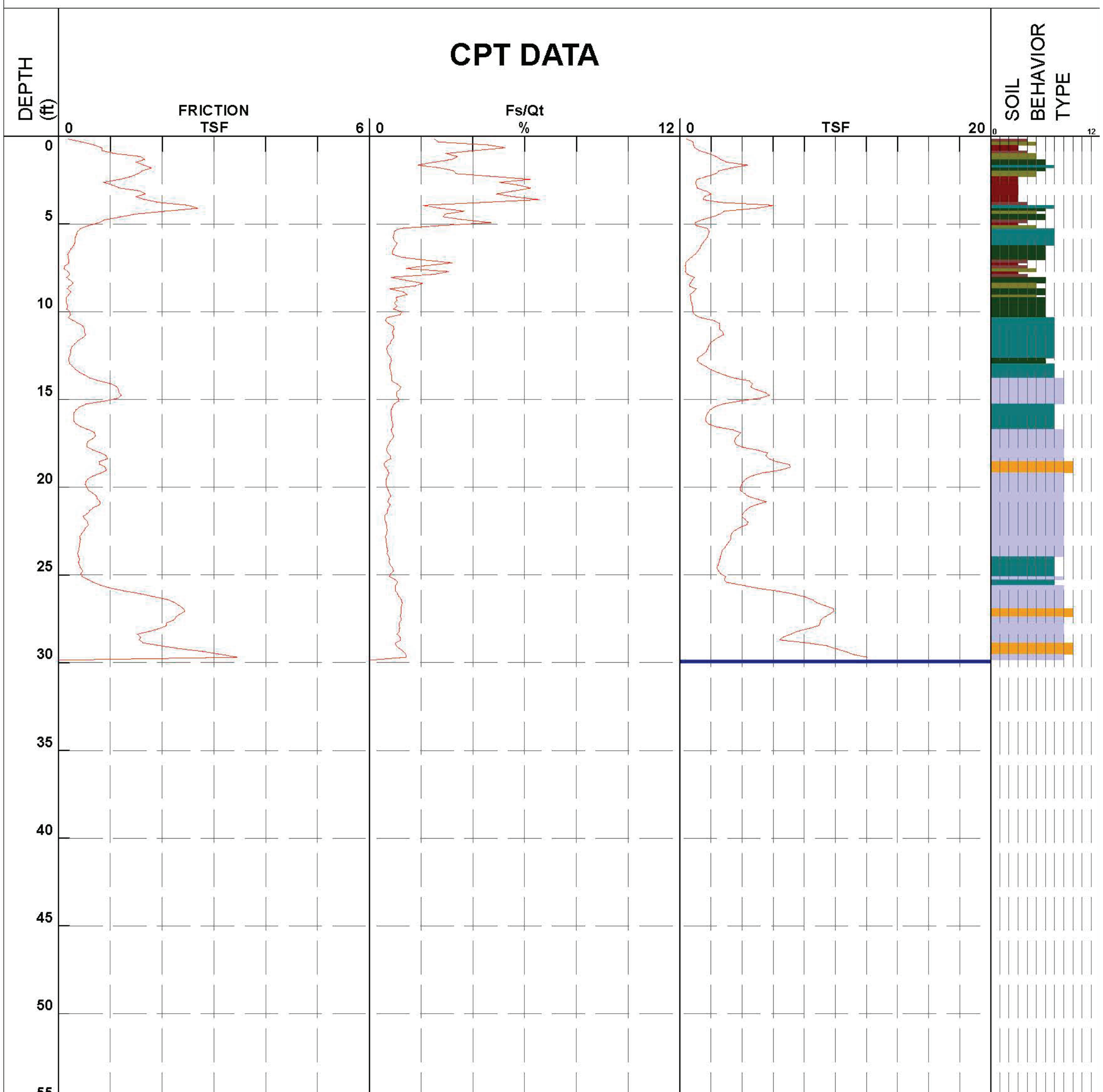


1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90034 89.87940
Date&Time	7/23/2014 9:21:54 AM	HOLE NUMBER	KAS-G15.14C	Elevation	

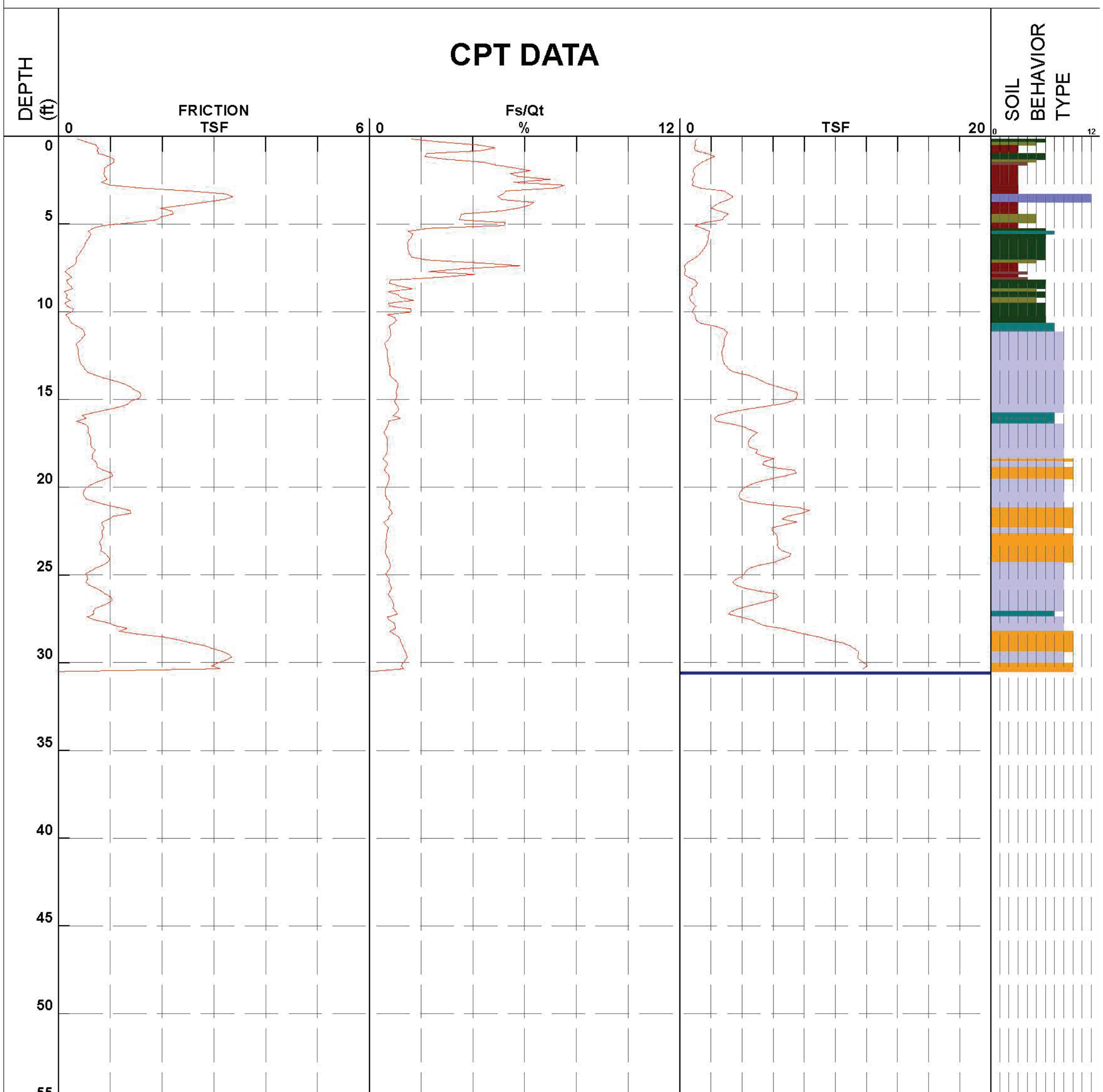
CPT DATA



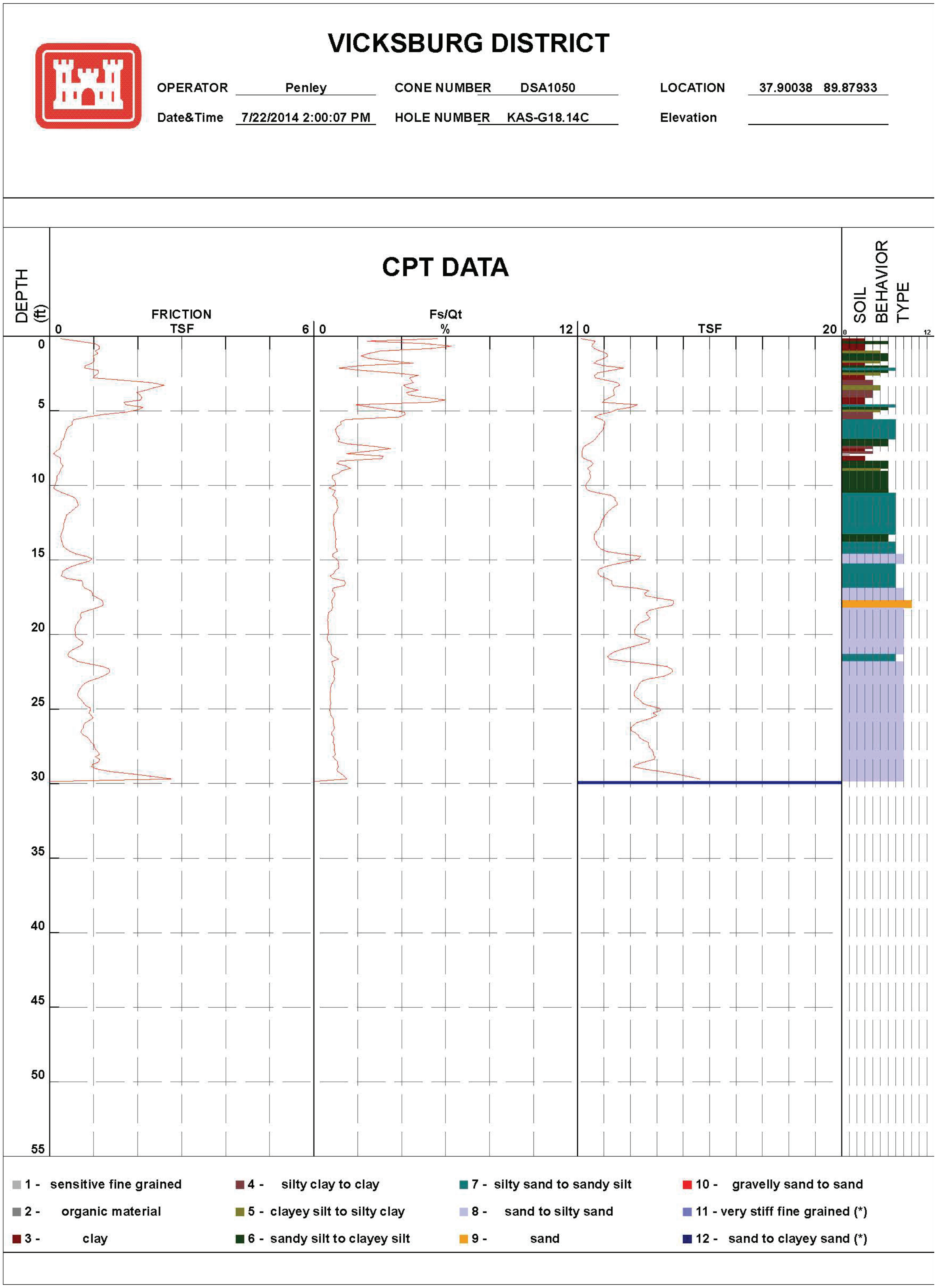
1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

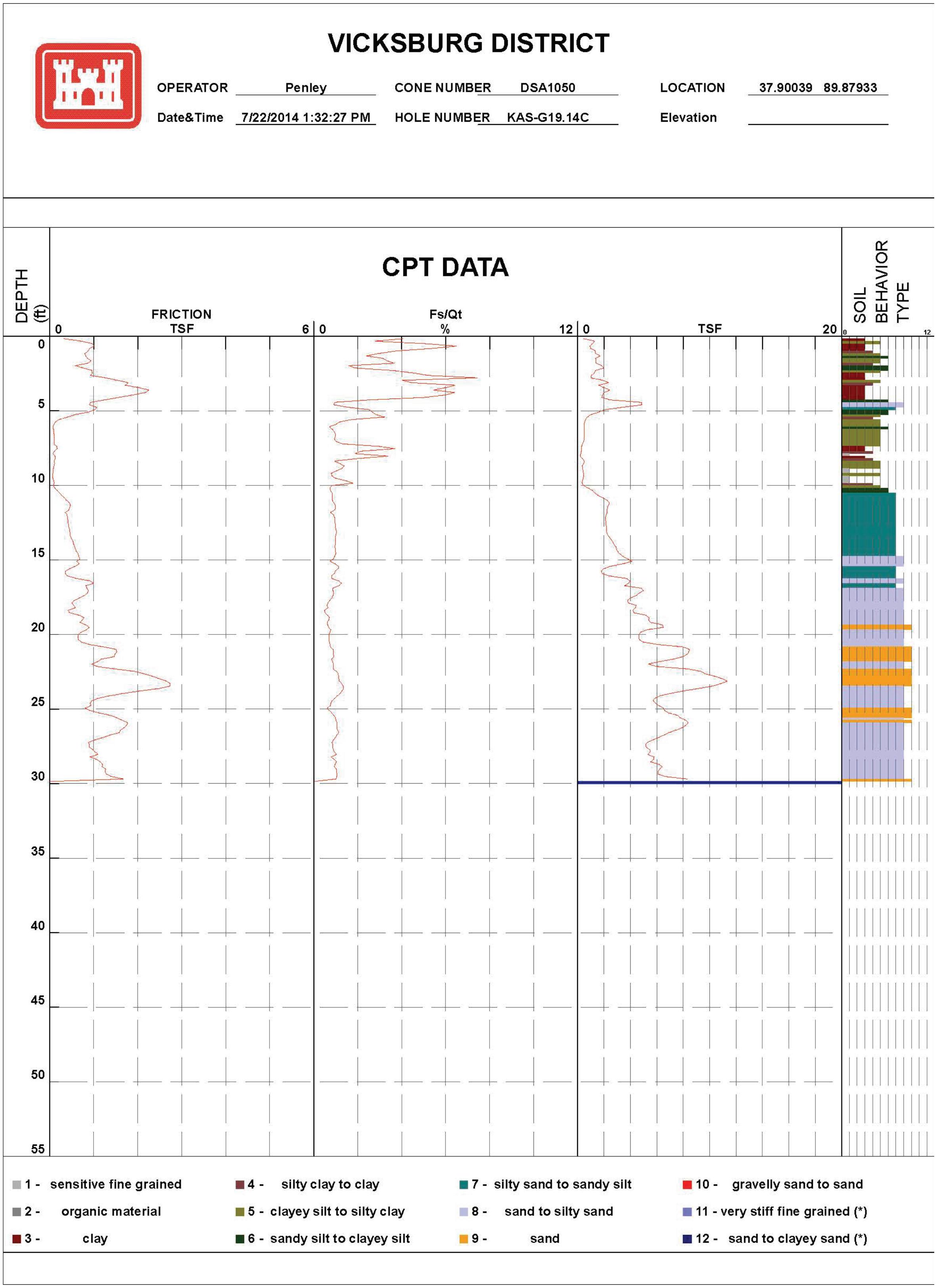
VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90037 89.87936
Date&Time	7/23/2014 8:38:18 AM	HOLE NUMBER	KAS-G17.14C	Elevation	



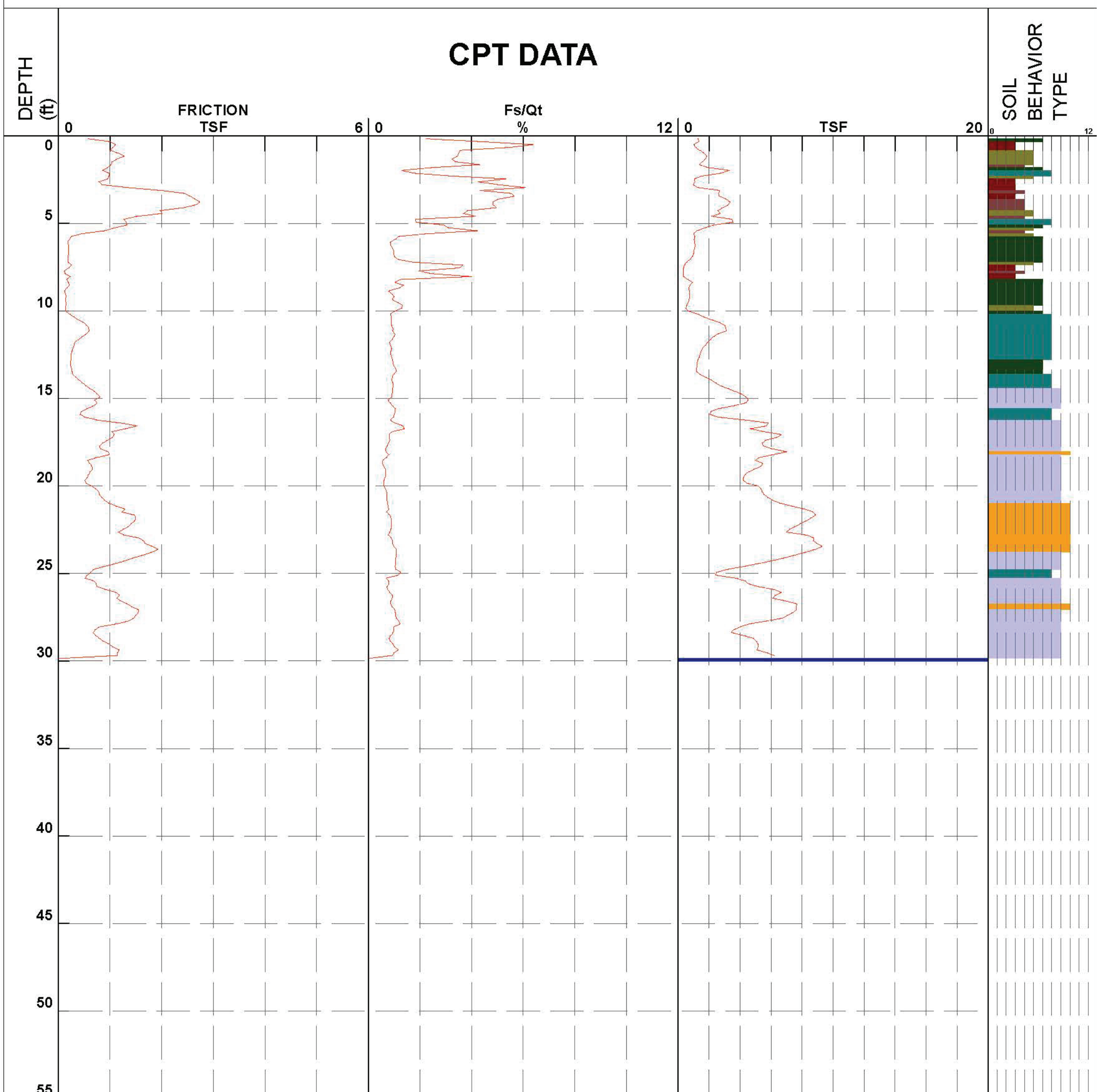
1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90038 89.87933
Date&Time 7/22/2014 2:00:07 PM
HOLE NUMBER KAS-G18.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
TSF
SOIL BEHAVIOR TYPE
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90039 89.87933
Date&Time 7/22/2014 1:32:27 PM
HOLE NUMBER KAS-G19.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
TSF
SOIL BEHAVIOR TYPE
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90039 89.87931
Date&Time	7/22/2014 1:05:27 PM	HOLE NUMBER	KAS-G20.14C	Elevation	

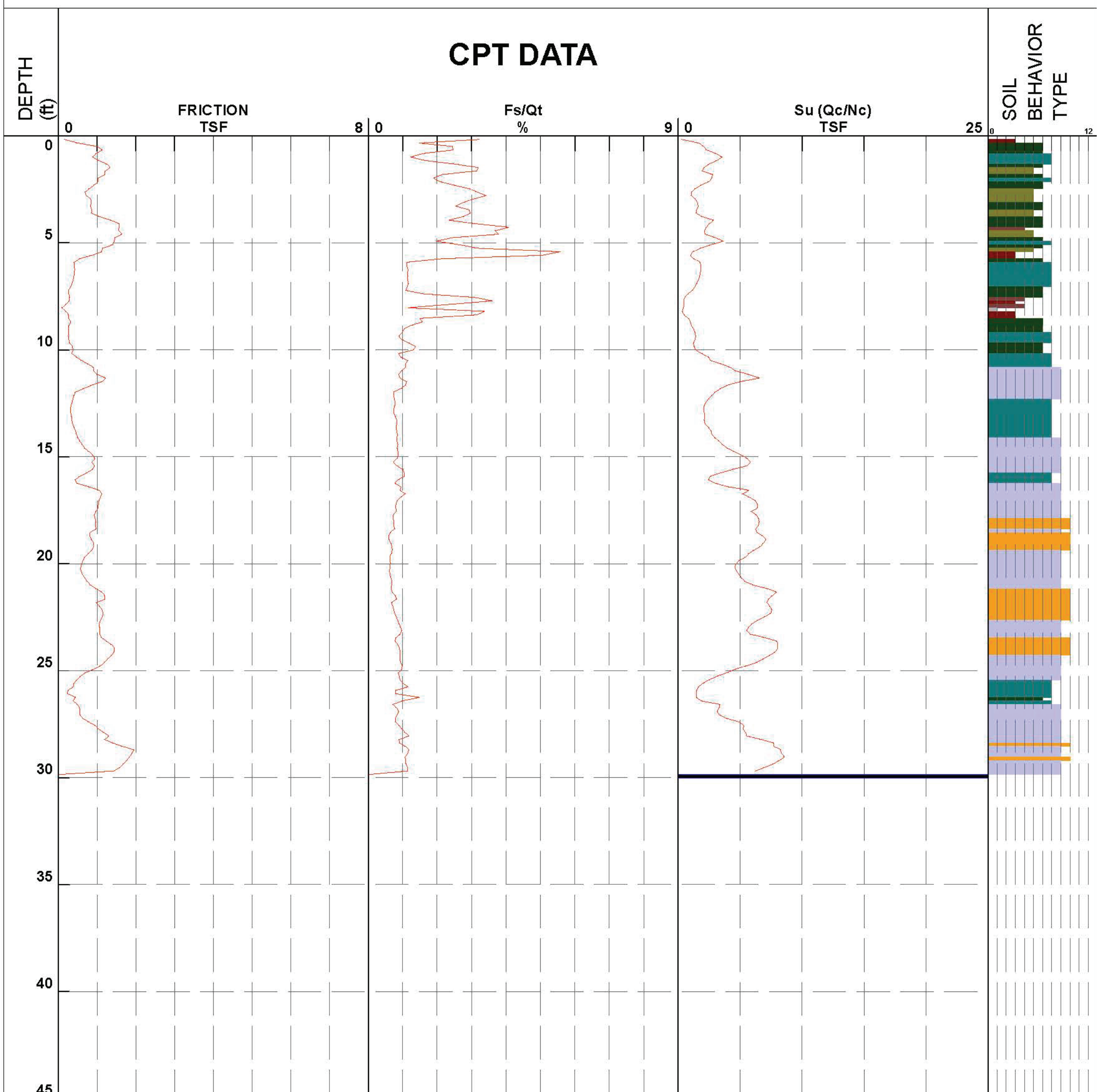


1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR Penley | CONE NUMBER DSA1050 | LOCATION 37.90042 89.87928

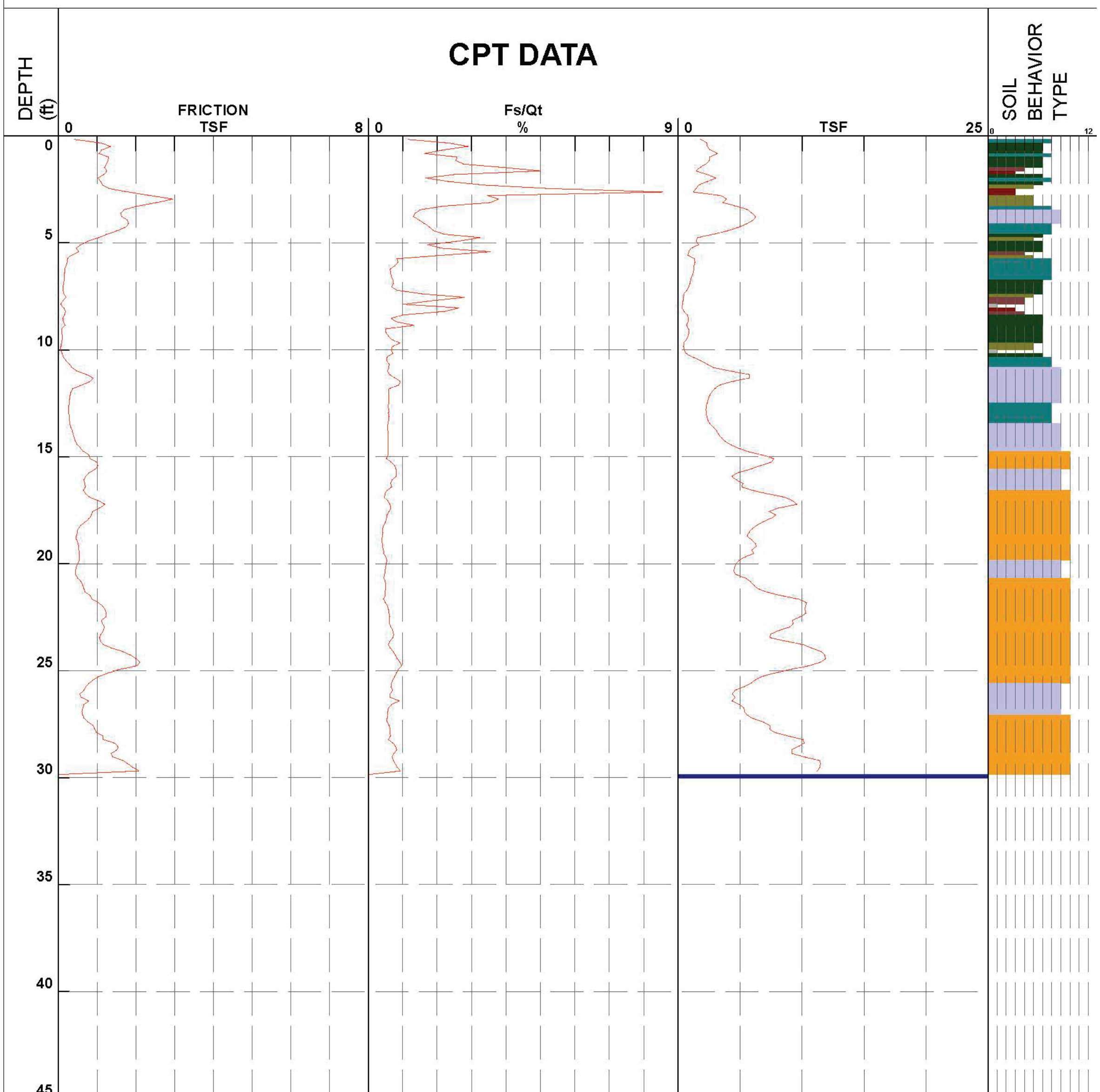
Date&Time 7/22/2014 11:17:26 AM | HOLE NUMBER KAS-G21.14C | Elevation



1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

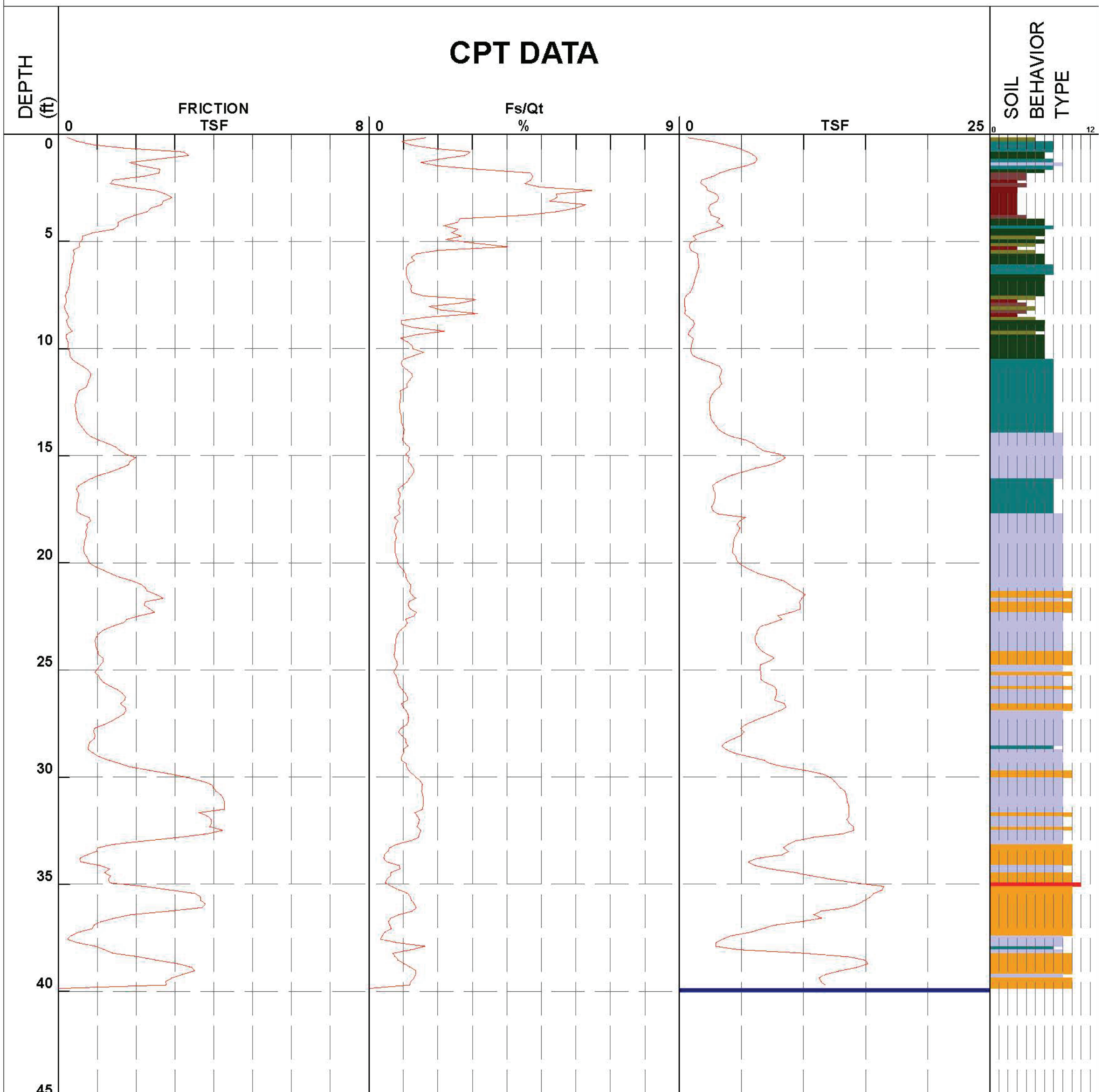
OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90044 89.87924
Date&Time	7/22/2014 10:33:31 AM	HOLE NUMBER	KAS-G22.14C	Elevation	



1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

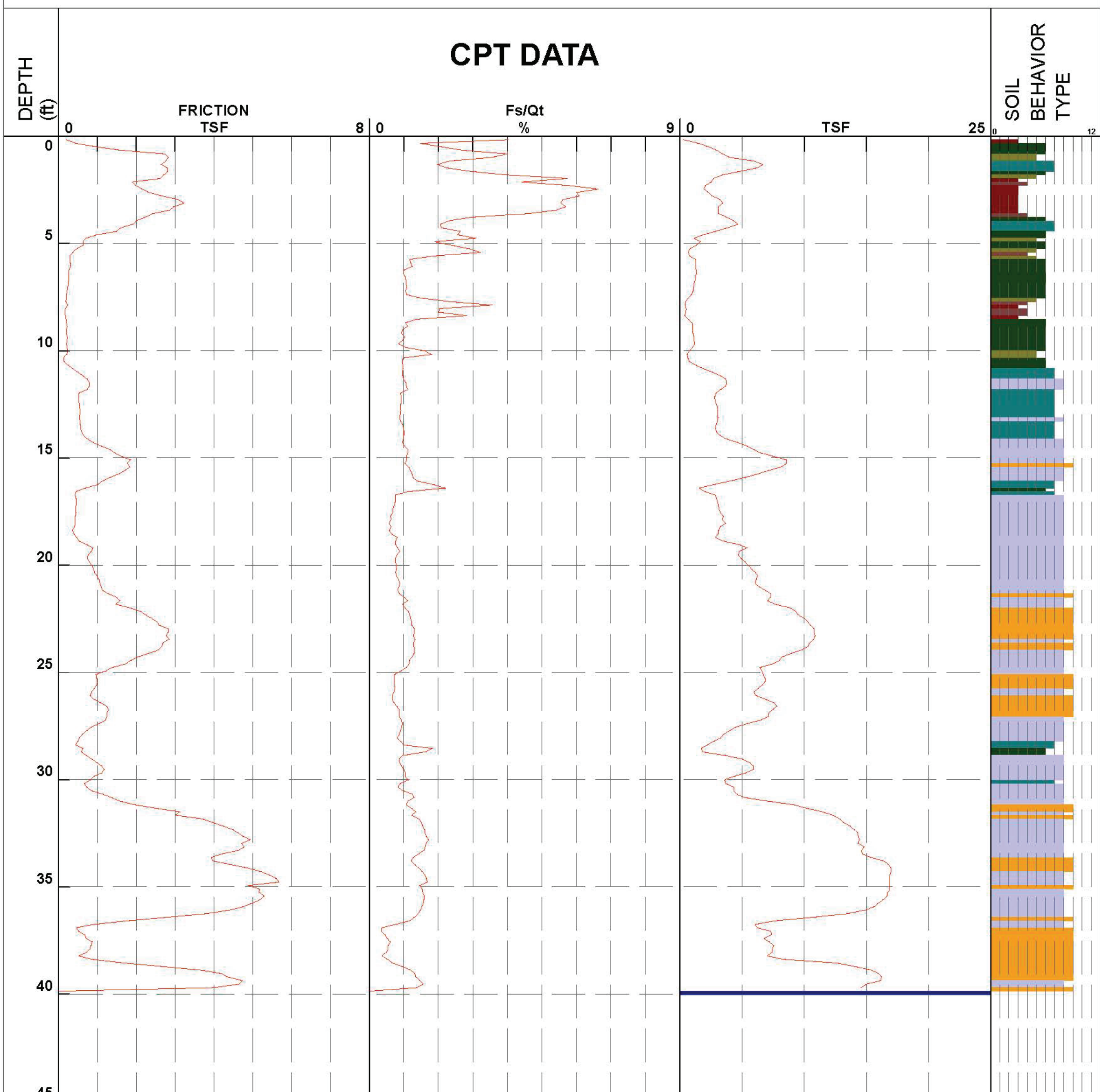
OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90034 89.87936
Date&Time	7/24/2014 12:51:35 PM	HOLE NUMBER	KAS-G24.14C	Elevation	



1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

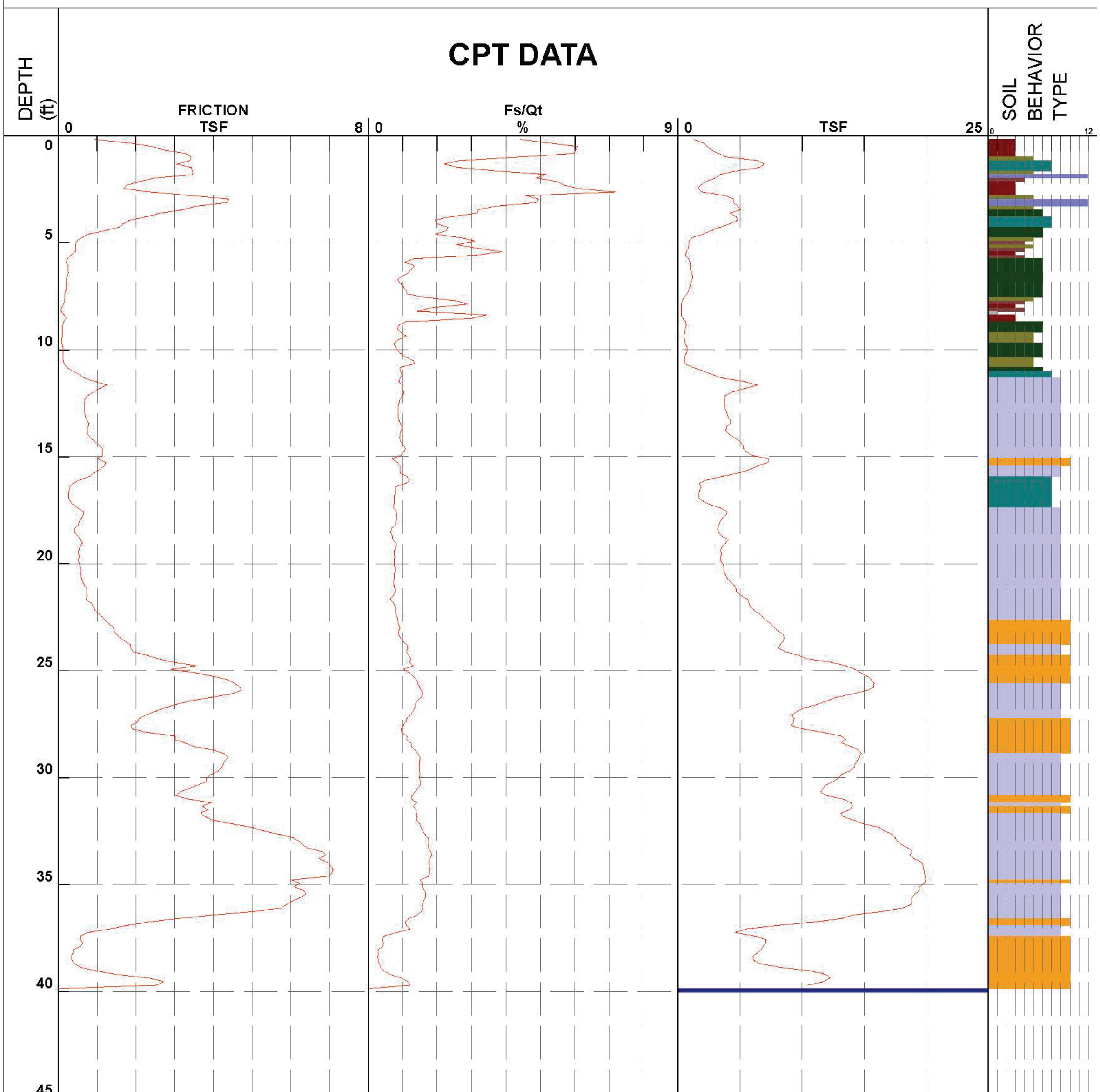
OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90036 89.87930
Date&Time	7/24/2014 11:20:59 AM	HOLE NUMBER	KAS-G25.14C	Elevation	



1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

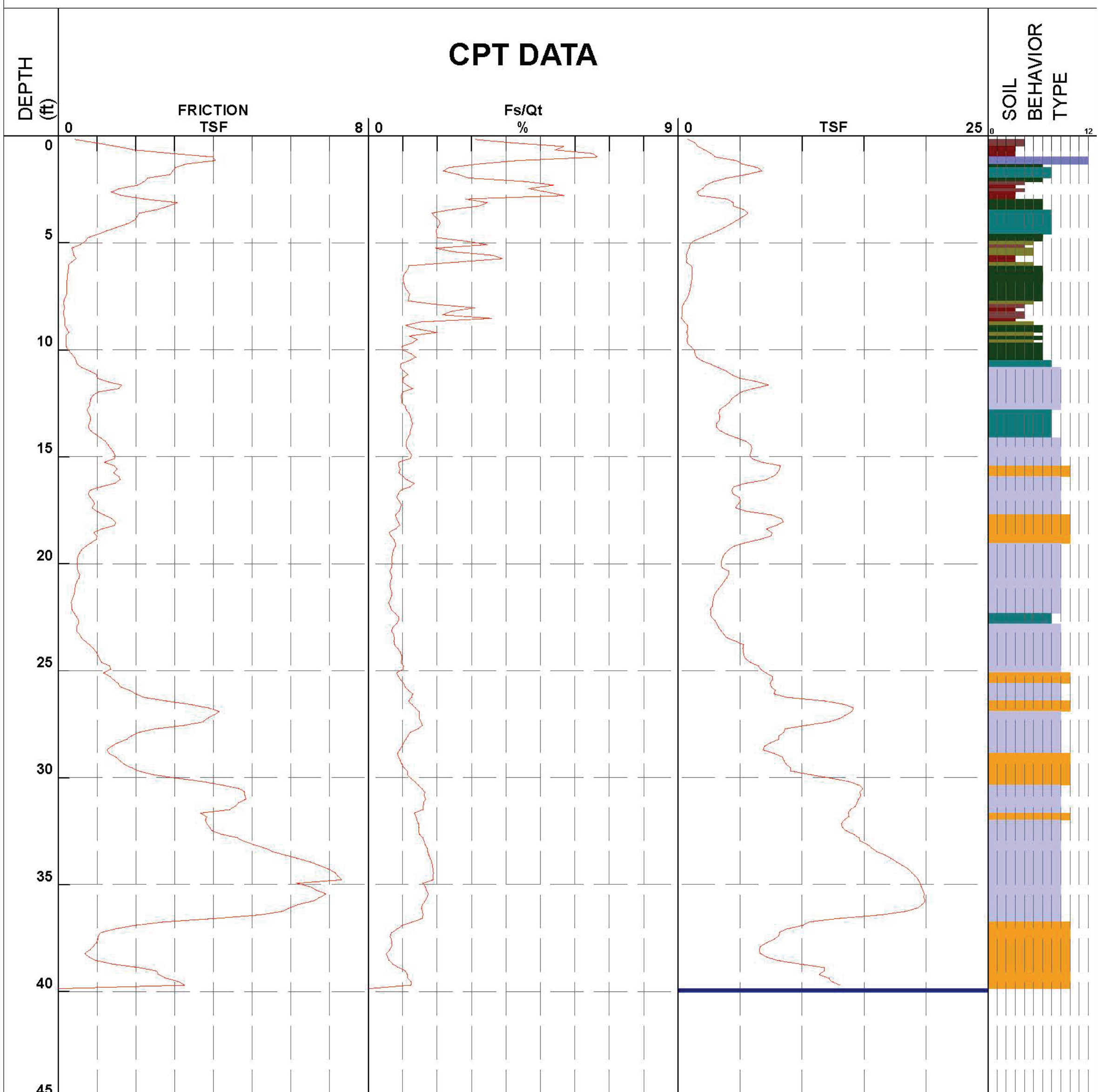
OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90039 89.87926
Date&Time	7/23/2014 10:39:14 AM	HOLE NUMBER	KAS-G26A.14C	Elevation	



1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)

VICKSBURG DISTRICT

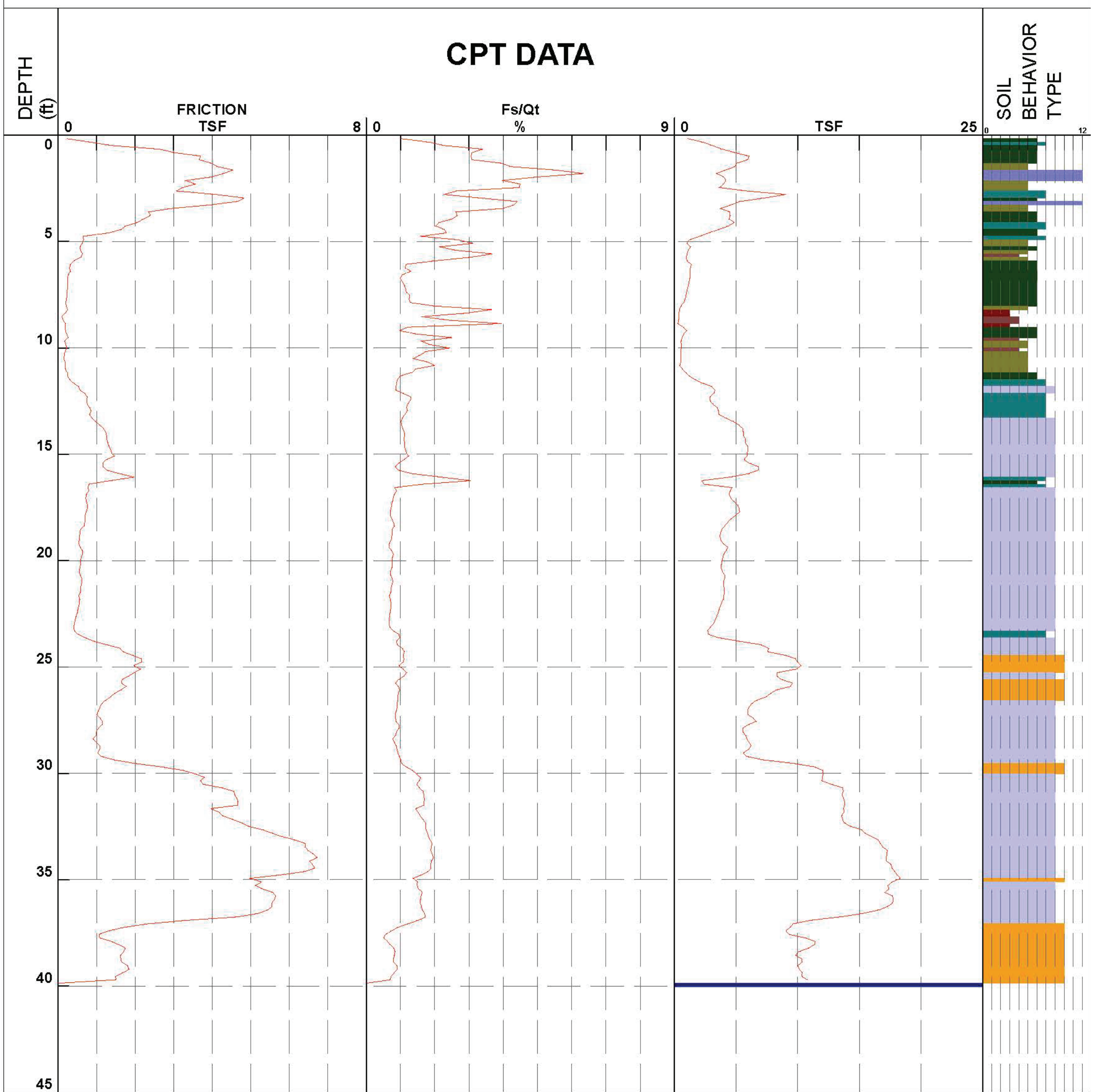
OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90043 89.87922
Date&Time	7/23/2014 10:01:12 AM	HOLE NUMBER	KAS-G27.14C	Elevation	



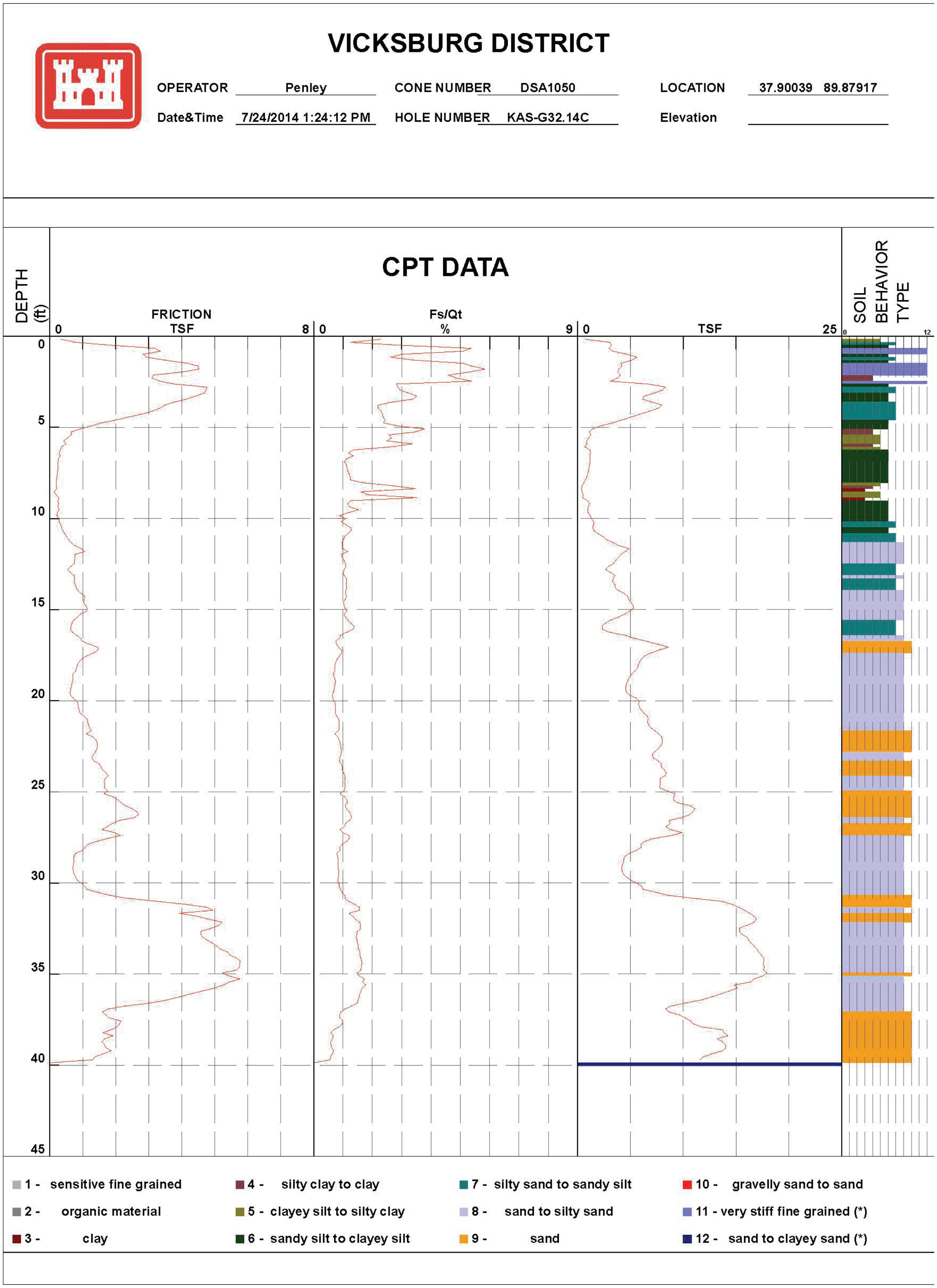
■ 1 - sensitive fine grained
■ 2 - organic material
■ 3 - clay
■ 4 - silty clay to clay
■ 5 - clayey silt to silty clay
■ 6 - sandy silt to clayey silt
■ 7 - silty sand to sandy silt
■ 8 - sand to silty sand
■ 9 - sand
■ 10 - gravelly sand to sand
■ 11 - very stiff fine grained (*)
■ 12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90035 89.87926
Date&Time	7/24/2014 2:00:15 PM	HOLE NUMBER	KAS-G30.14C	Elevation	



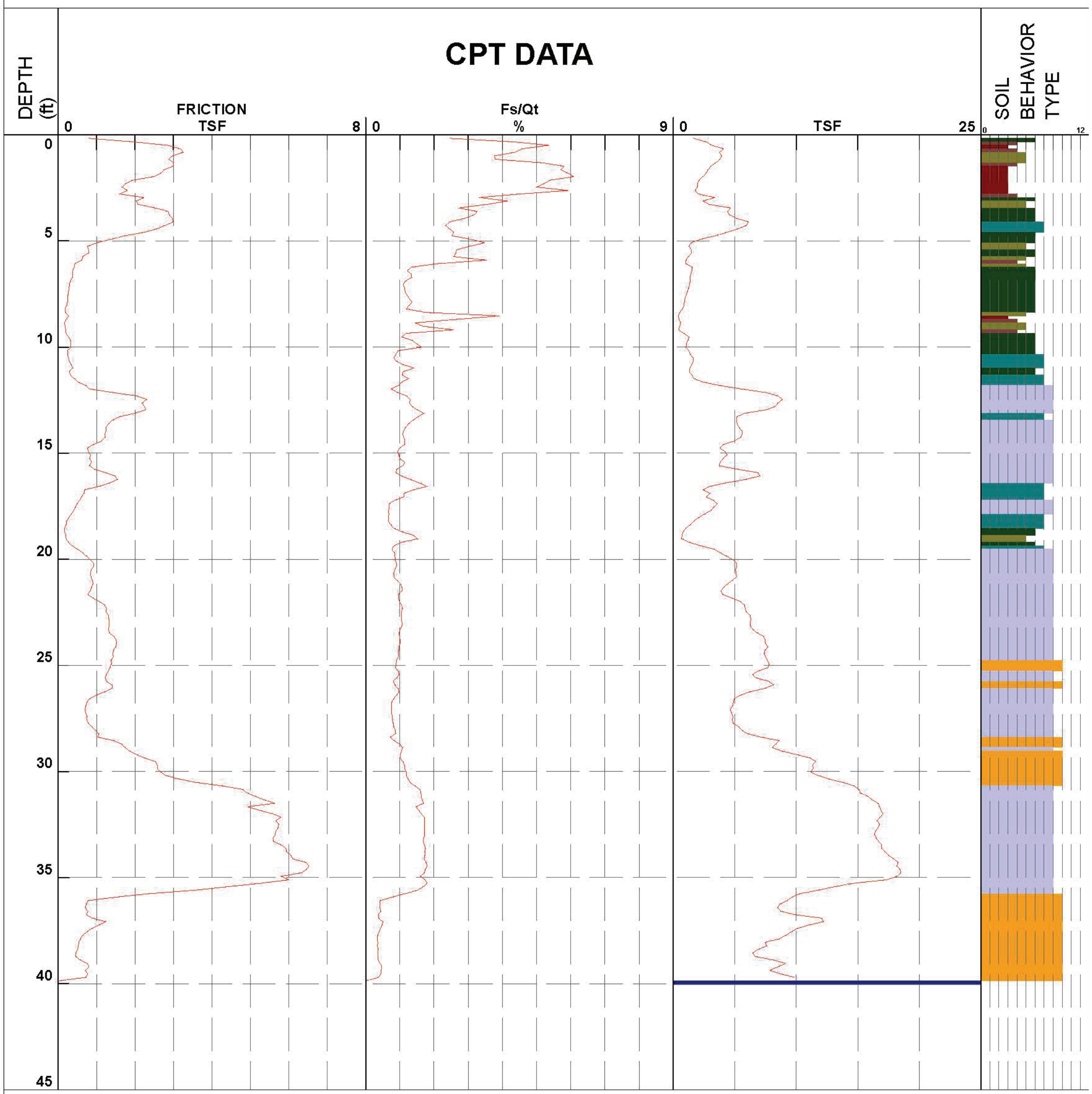
1 - sensitive fine grained	4 - silty clay to clay	7 - silty sand to sandy silt	10 - gravelly sand to sand
2 - organic material	5 - clayey silt to silty clay	8 - sand to silty sand	11 - very stiff fine grained (*)
3 - clay	6 - sandy silt to clayey silt	9 - sand	12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90039 89.87917
Date&Time 7/24/2014 1:24:12 PM
HOLE NUMBER KAS-G32.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
TSF
SOIL BEHAVIOR TYPE
0 5 10 15 20 25 30 35 40 45
0 8
0 9
0 25
0 12
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

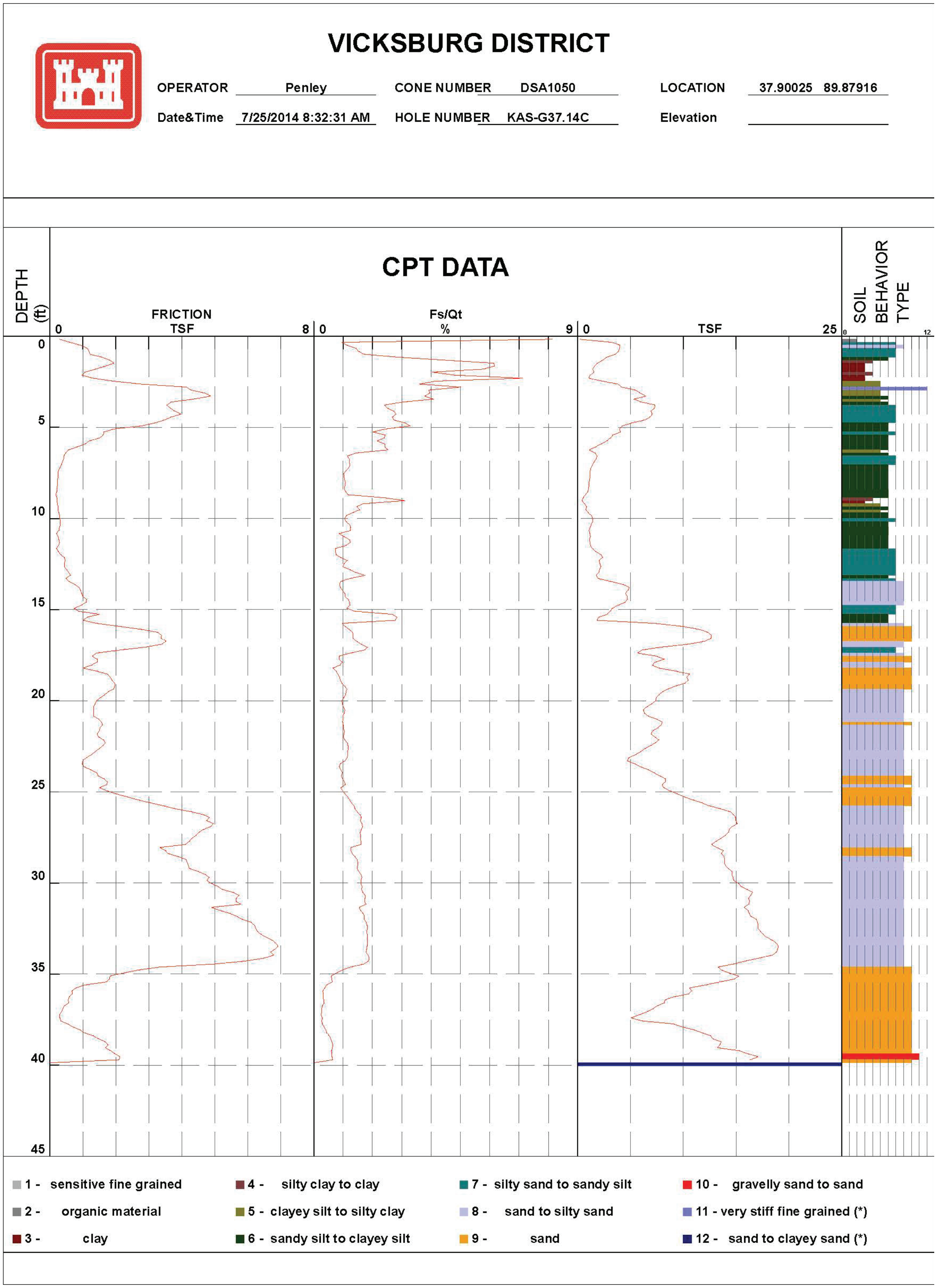
VICKSBURG DISTRICT

OPERATOR Penley | CONE NUMBER DSA1050 | LOCATION 37.90030 89.87922

Date&Time 7/24/2014 3:14:47 PM | HOLE NUMBER KAS-G34.14C | Elevation

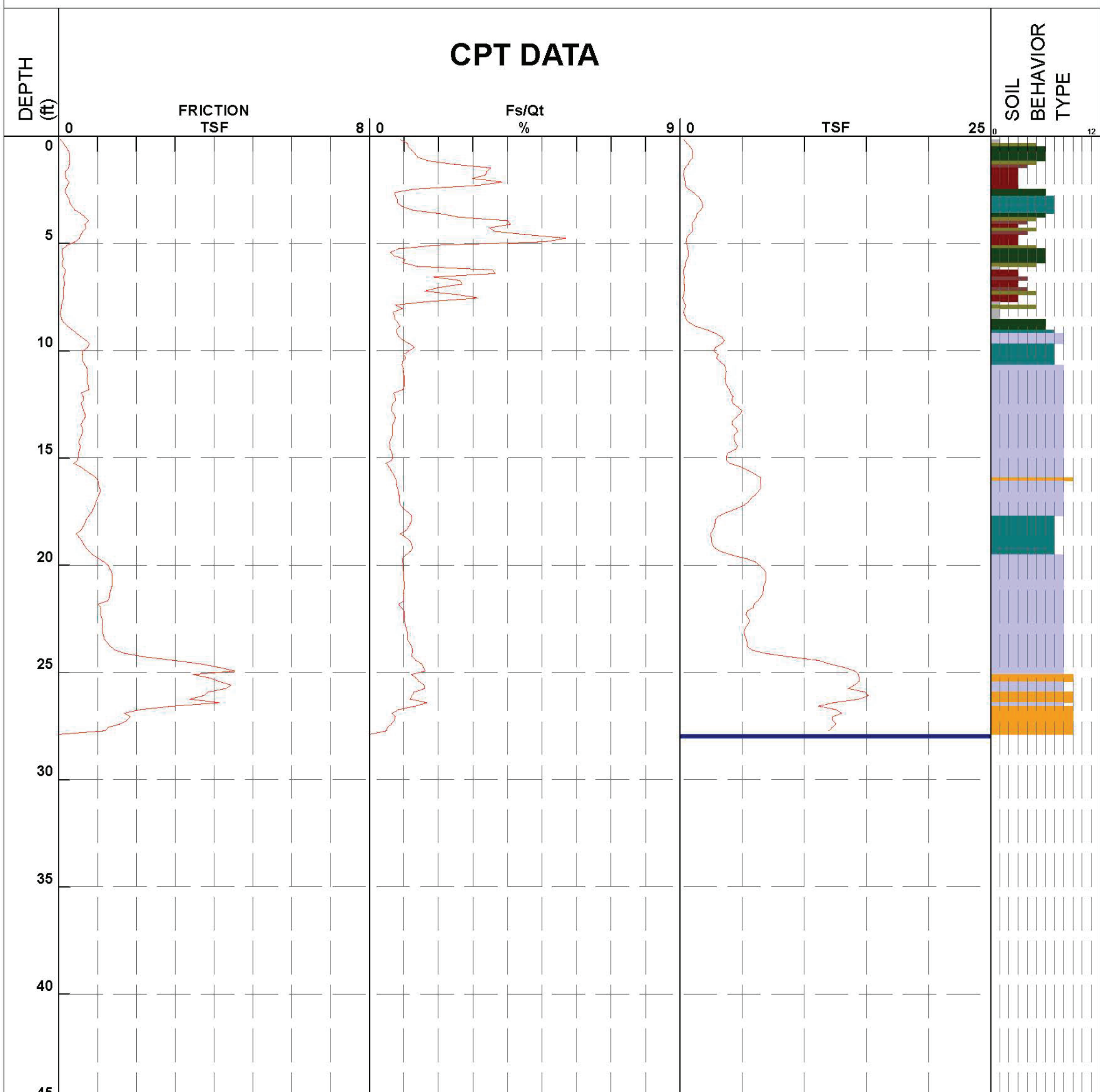


1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)


VICKSBURG DISTRICT
OPERATOR Penley
CONE NUMBER DSA1050
LOCATION 37.90025 89.87916
Date&Time 7/25/2014 8:32:31 AM
HOLE NUMBER KAS-G37.14C
Elevation
CPT DATA
DEPTH (ft)
FRICTION TSF
Fs/Qt %
TSF
SOIL BEHAVIOR TYPE
1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

VICKSBURG DISTRICT

OPERATOR	Penley	CONE NUMBER	DSA1050	LOCATION	37.90085 89.87882
Date&Time	7/22/2014 3:13:17 PM	HOLE NUMBER	KAS-SBC01.14C	Elevation	



1 - sensitive fine grained
2 - organic material
3 - clay
4 - silty clay to clay
5 - clayey silt to silty clay
6 - sandy silt to clayey silt
7 - silty sand to sandy silt
8 - sand to silty sand
9 - sand
10 - gravelly sand to sand
11 - very stiff fine grained (*)
12 - sand to clayey sand (*)

Appendix C: Boring Logs for Split-spoon Samples

Figure C1. Locations of sample borings.

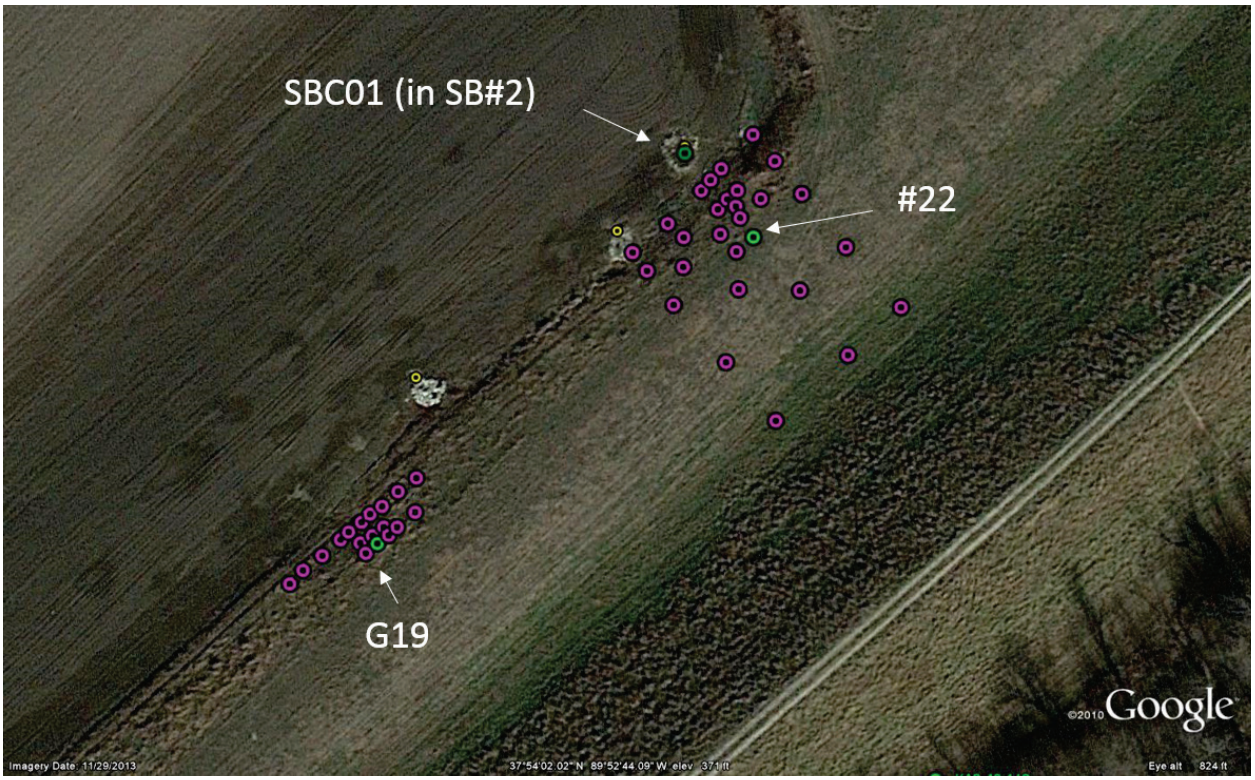
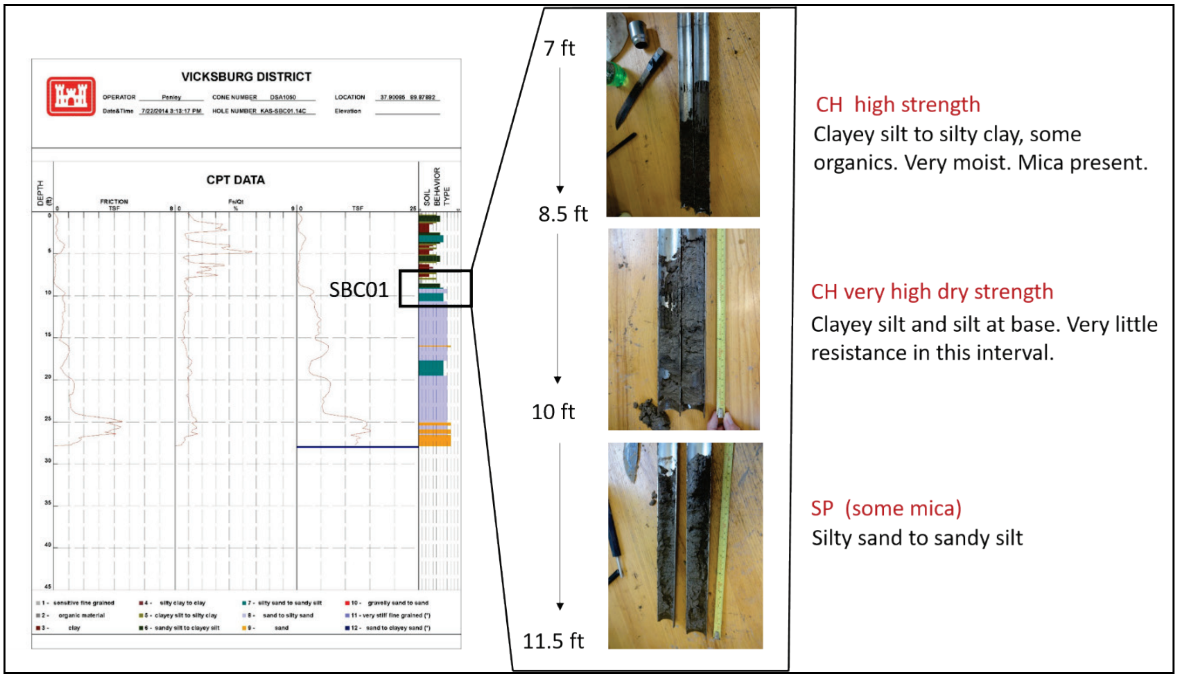
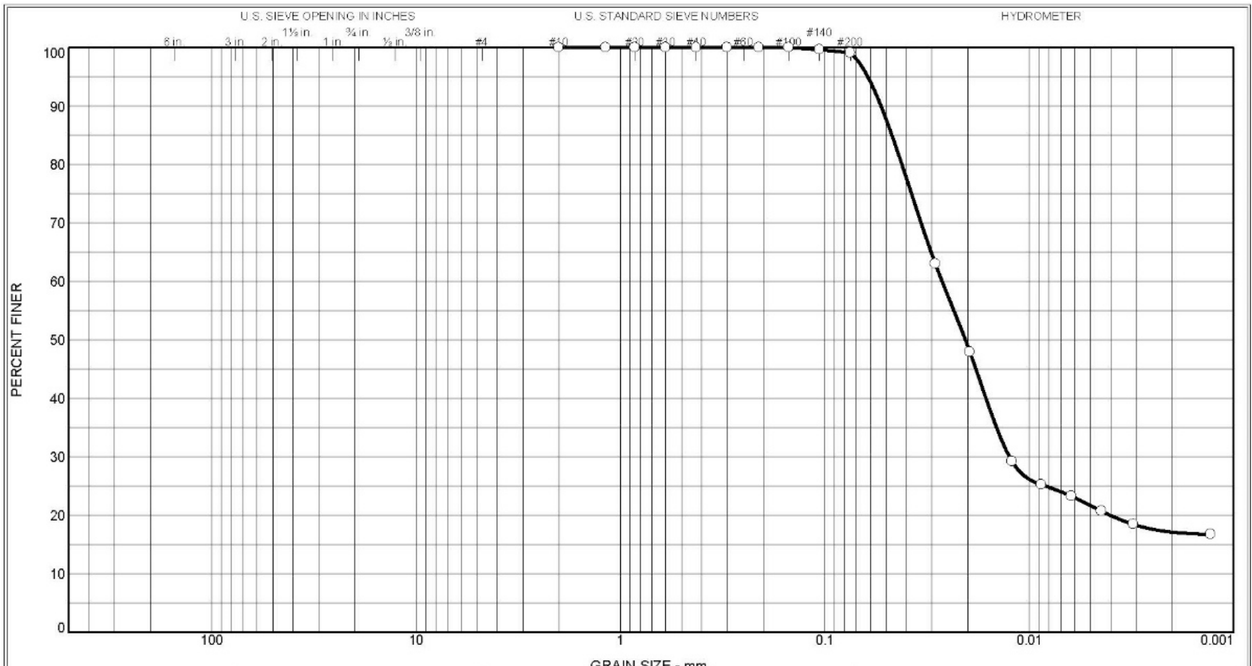


Figure C2. G19.



Appendix D: Soil Curves from Ejecta Samples from Split-spoon Samples

MD2815- G19 (7 - 8.5 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○		7-8.5	Silt (ML), Gray		35	26	9

Project Kaskaskia CPT

Area

Boring No. G19

Particle Size Distribution Report

Date: 11/9/2015

Corps of Engineers

ENG FORM 1 MAY 63 **2087**

Tested By: AT **Checked By:** TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: 22
Depth: 7.5-9
Material Description: Silt (ML), Gray
PL: NP
Tested by: AT **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
70.40	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.00	100.0
			#100	0.00	100.0
			#140	0.10	99.9
			#200	0.70	99.0

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =70.4
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.69 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 **-** 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.5	1.0331	1.0284	0.0134	32.6	7.7	0.0262	64.3
5.00	20.5	1.0275	1.0228	0.0134	27.0	9.2	0.0181	51.6
15.00	20.5	1.0218	1.0171	0.0134	21.3	10.7	0.0113	38.8
30.00	20.5	1.0190	1.0143	0.0134	18.5	11.4	0.0083	32.4
60.00	21.0	1.0171	1.0125	0.0133	16.6	11.9	0.0059	28.3
120.00	21.0	1.0154	1.0108	0.0133	14.9	12.4	0.0043	24.4
250.00	21.0	1.0141	1.0095	0.0133	13.6	12.7	0.0030	21.5
1440.00	21.0	1.0122	1.0076	0.0133	11.7	13.2	0.0013	17.2

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	72.8	26.2	99.0

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
			0.0023	0.0069	0.0119	0.0172	0.0233	0.0387	0.0441	0.0507	0.0602

Fineness Modulus
0.00

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

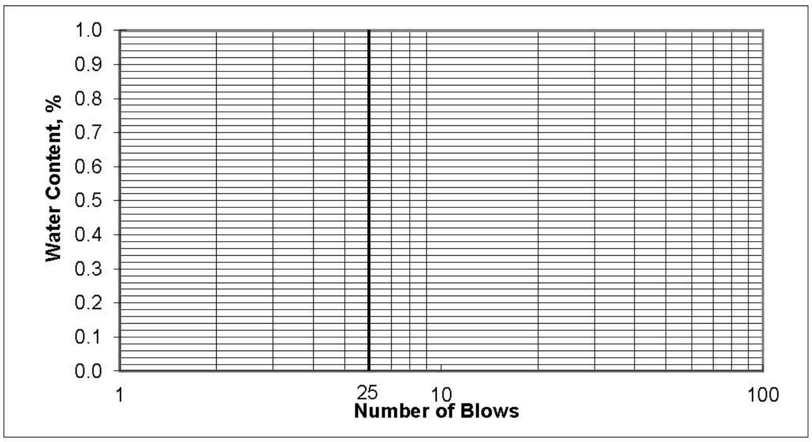
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. 22 SAMPLE NO. 7.5-9

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL

PL

PI

Symbol from plasticity chart: ML

Plastic LIMIT

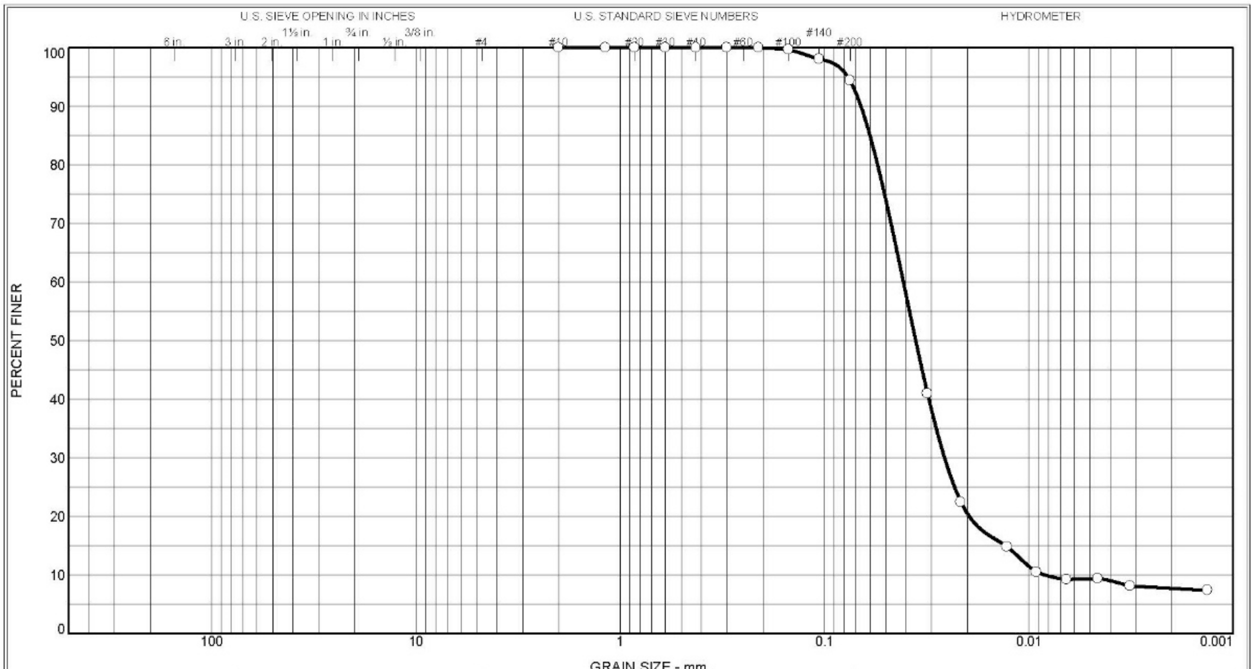
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silt (ML), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- G19 (8.5 – 10 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○		8.5-10	Silt (ML), Gray			NP	

Project Kaskaskia CPT

Area

Boring No. G19

Date: 10/28/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT **Checked By:** TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: G19
Depth: 8.5-10
Material Description: Silt (ML), Gray
PL: NP
Tested by: AT **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
62.70	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.00	100.0
			#100	0.20	99.7
			#140	1.20	98.1
			#200	3.50	94.4

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =62.7
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.69 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.5	1.0208	1.0161	0.0134	20.3	10.9	0.0313	41.0
5.00	20.5	1.0135	1.0088	0.0134	13.0	12.9	0.0215	22.4
15.00	20.5	1.0105	1.0058	0.0134	10.0	13.6	0.0128	14.8
30.00	20.5	1.0088	1.0041	0.0134	8.3	14.1	0.0092	10.5
60.00	20.5	1.0083	1.0036	0.0134	7.8	14.2	0.0065	9.2
120.00	21.0	1.0083	1.0037	0.0133	7.8	14.2	0.0046	9.4
250.00	21.0	1.0078	1.0032	0.0133	7.3	14.4	0.0032	8.1
1440.00	21.0	1.0075	1.0029	0.0133	7.0	14.4	0.0013	7.4

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	5.6	5.6	85.0	9.4	94.4

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
	0.0083	0.0130	0.0196	0.0259	0.0308	0.0358	0.0411	0.0549	0.0599	0.0662	0.0767

Fineness Modulus	C_u	C_c
0.00	4.94	1.96

CEERD-GEGB

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

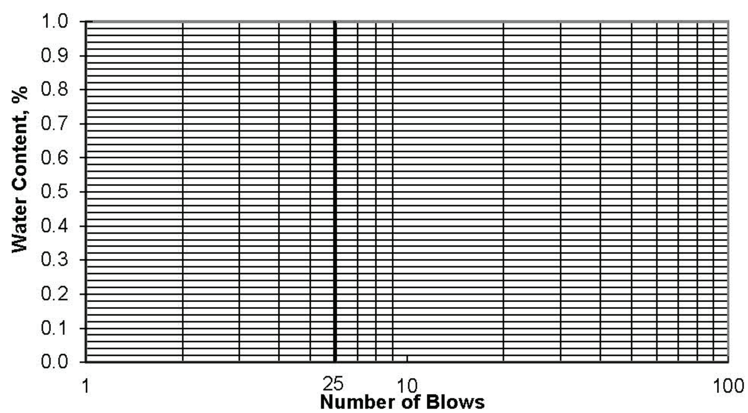
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. G19 SAMPLE NO. 8.5-10

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL
PL
PI

Symbol from plasticity chart: ML

Plastic LIMIT

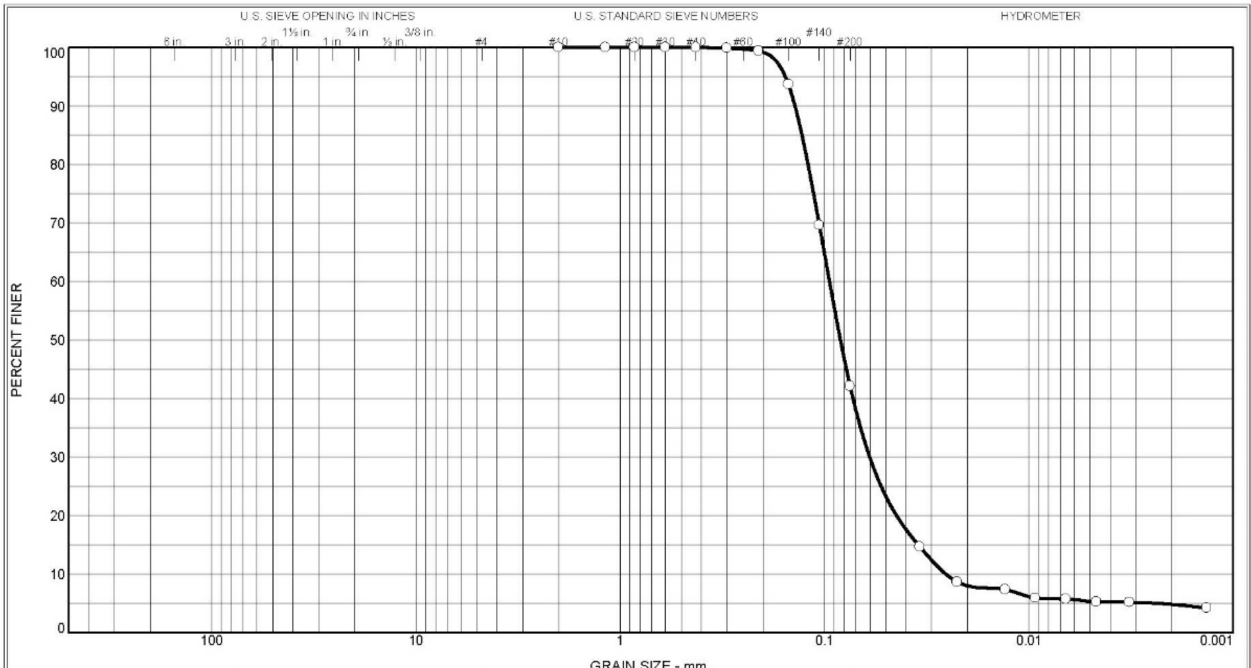
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silt (ML), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- G19 (10 - 11.5 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	10-11.5	Silty Sand (SM), Gray			NP	

Project Kaskaskia CPT

Area

Boring No. G19

Particle Size Distribution Report

Date: 10/28/2015

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT Checked By: TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: G19
Depth: 10-11.5
Material Description: Silty Sand (SM), Gray
PL: NP
Tested by: AT **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
98.50	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.10	99.9
			#70	0.60	99.4
			#100	6.20	93.7
			#140	29.90	69.6
			#200	57.00	42.1

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =98.5
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.67
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 **-** 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.5	1.0137	1.0090	0.0135	13.2	12.8	0.0341	14.7
5.00	20.5	1.0100	1.0053	0.0135	9.5	13.8	0.0224	8.7
15.00	20.5	1.0092	1.0045	0.0135	8.7	14.0	0.0130	7.4
30.00	20.5	1.0083	1.0036	0.0135	7.8	14.2	0.0093	5.9
60.00	20.5	1.0082	1.0035	0.0135	7.7	14.3	0.0066	5.7
120.00	20.5	1.0079	1.0032	0.0135	7.4	14.3	0.0047	5.3
250.00	21.0	1.0078	1.0032	0.0134	7.3	14.4	0.0032	5.2
1440.00	21.0	1.0072	1.0026	0.0134	6.7	14.5	0.0013	4.2

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	57.9	57.9	36.7	5.4	42.1

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
0.0023	0.0254	0.0347	0.0444	0.0601	0.0726	0.0836	0.0946	0.1204	0.1288	0.1393	0.1551

Fineness Modulus	C_u	C_c
0.06	3.72	1.50

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

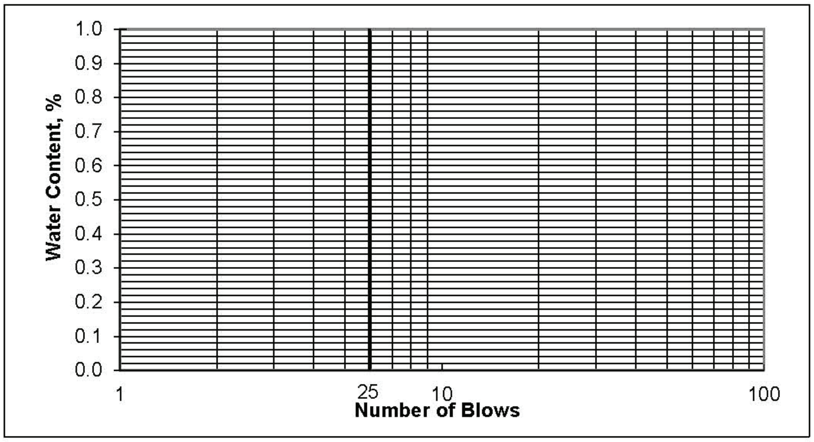
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. G19 SAMPLE NO. 10-11.5

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL

PL

PI

Symbol from plasticity chart

SM

Plastic LIMIT

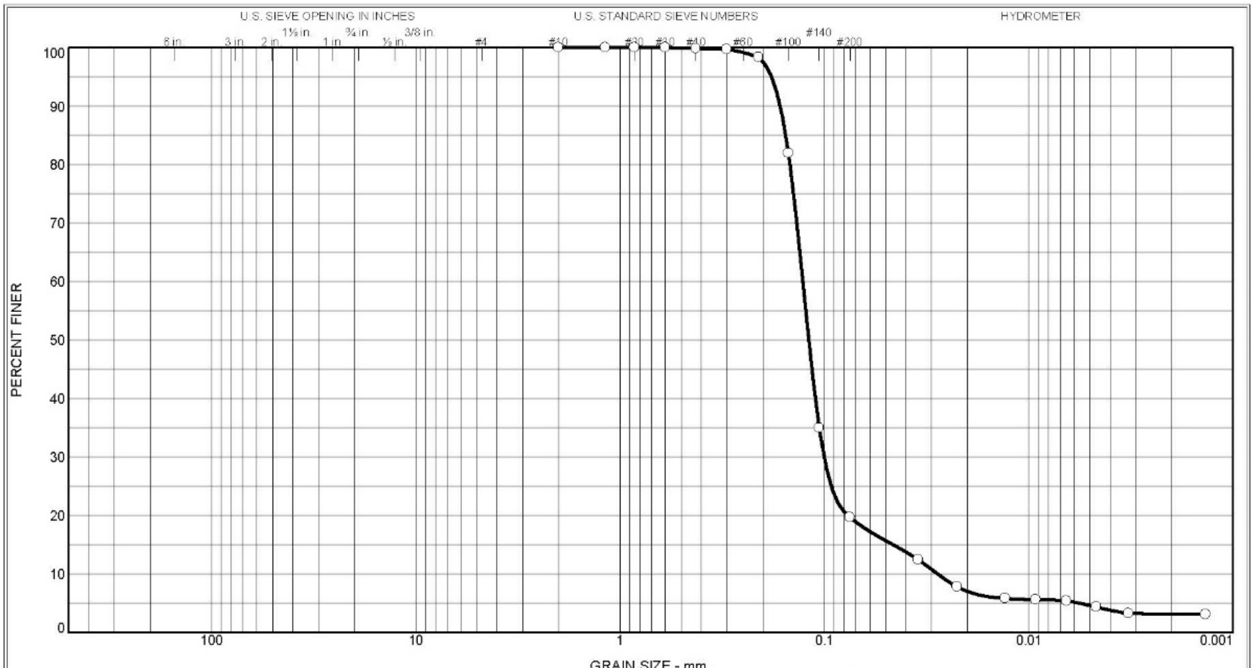
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silty Sand (SM), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- G22 (1.5 – 2 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	1.5-2	Silty Sand (SM), Gray			NP	
		Fines are classified visually.				

Project Kaskaskia CPT

Area

Boring No. 22

Particle Size Distribution Report

Date: 10/5/2015

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/WH Checked By: TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/5/2015

Project: Kaskaskia CPT
Location: 22
Depth: 1.5-2
Material Description: Silty Sand (SM), Gray
Fines are classified visually.
PL: NP
Tested by: AT/WH **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
72.60	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.10	99.9
			#50	0.20	99.7
			#70	1.20	98.3
			#100	13.10	82.0
			#140	47.20	35.0
			#200	58.30	19.7

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =72.6
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.67 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 x Rm

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	22.0	1.0101	1.0057	0.0132	9.6	13.8	0.0347	12.4
5.00	22.0	1.0080	1.0036	0.0132	7.5	14.3	0.0224	7.8
15.00	22.0	1.0071	1.0027	0.0132	6.6	14.5	0.0130	5.8
30.00	22.0	1.0070	1.0026	0.0132	6.5	14.6	0.0092	5.6
60.00	22.0	1.0069	1.0025	0.0132	6.4	14.6	0.0065	5.4
120.00	21.5	1.0065	1.0020	0.0133	6.0	14.7	0.0047	4.4
250.00	21.5	1.0060	1.0015	0.0133	5.5	14.8	0.0032	3.3
1440.00	21.0	1.0060	1.0014	0.0134	5.5	14.8	0.0014	3.1

CEERD-GEGB

Fractional Components

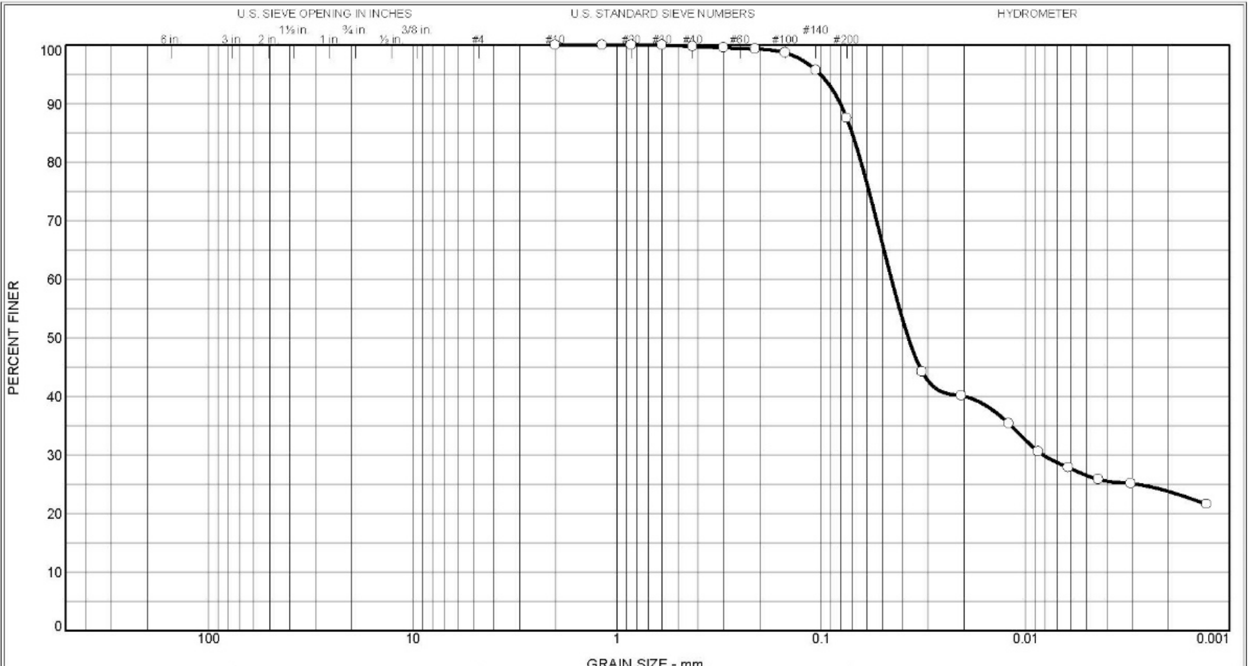
Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.1	80.2	80.3	15.1	4.6	19.7

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
0.0056	0.0278	0.0460	0.0768	0.1004	0.1107	0.1192	0.1275	0.1474	0.1546	0.1645	0.1812

Fineness Modulus	C_u	C_c
0.18	4.58	2.84

CEERD-GEGB

MD2815- G22 (2 - 2.3 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○		2-3	Clay (CL), Gray		35	18	17

Project Kaskaskia CPT

Area

Boring No. 22

Date: 10/28/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 **2087**

Tested By: AT/WH **Checked By:** TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: 22
Depth: 2-3
Material Description: Clay (CL), Gray
PL: 18 **LL:** 35
PI: 17
Tested by: AT/WH **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
46.60	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.10	99.8
			#50	0.20	99.6
			#70	0.30	99.4
			#100	0.60	98.7
			#140	2.00	95.7
			#200	5.80	87.6

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =46.6
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.70 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.5	1.0175	1.0130	0.0132	17.0	11.8	0.0321	44.2
5.00	21.5	1.0163	1.0118	0.0132	15.8	12.1	0.0205	40.1
15.00	21.5	1.0149	1.0104	0.0132	14.4	12.5	0.0120	35.4
30.00	21.5	1.0135	1.0090	0.0132	13.0	12.9	0.0086	30.6
60.00	21.5	1.0127	1.0082	0.0132	12.2	13.1	0.0062	27.9
120.00	21.5	1.0121	1.0076	0.0132	11.6	13.2	0.0044	25.8
250.00	21.5	1.0119	1.0074	0.0132	11.4	13.3	0.0030	25.1
1440.00	20.5	1.0110	1.0063	0.0134	10.5	13.5	0.0013	21.6

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.2	12.2	12.4	61.1	26.5	87.6

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
				0.0082	0.0197	0.0374	0.0452	0.0637	0.0705	0.0805	0.1009

Fineness Modulus
0.02

CEERD-GEGB

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

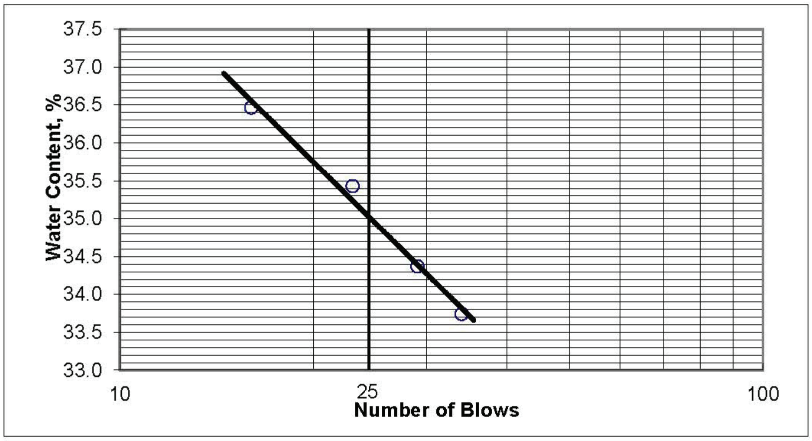
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. 22 SAMPLE NO. 2-3

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.	A10	553	63	68			
Tare Plus Wet Soil, g	38.36	35.81	37.05	31.62			
Tare Plus Dry Soil, g	32.59	30.61	32.15	27.27			
Water, g	5.77	5.20	4.90	4.35			
Tare, g	15.49	15.48	18.32	15.34			
Dry Soil, g	17.10	15.13	13.83	11.93			
Water content, %	33.7	34.4	35.4	36.5			
Number of Blows	34	29	23	16			



LL	35
PL	18
PI	17

Symbol from plasticity chart: CL

Plastic LIMIT

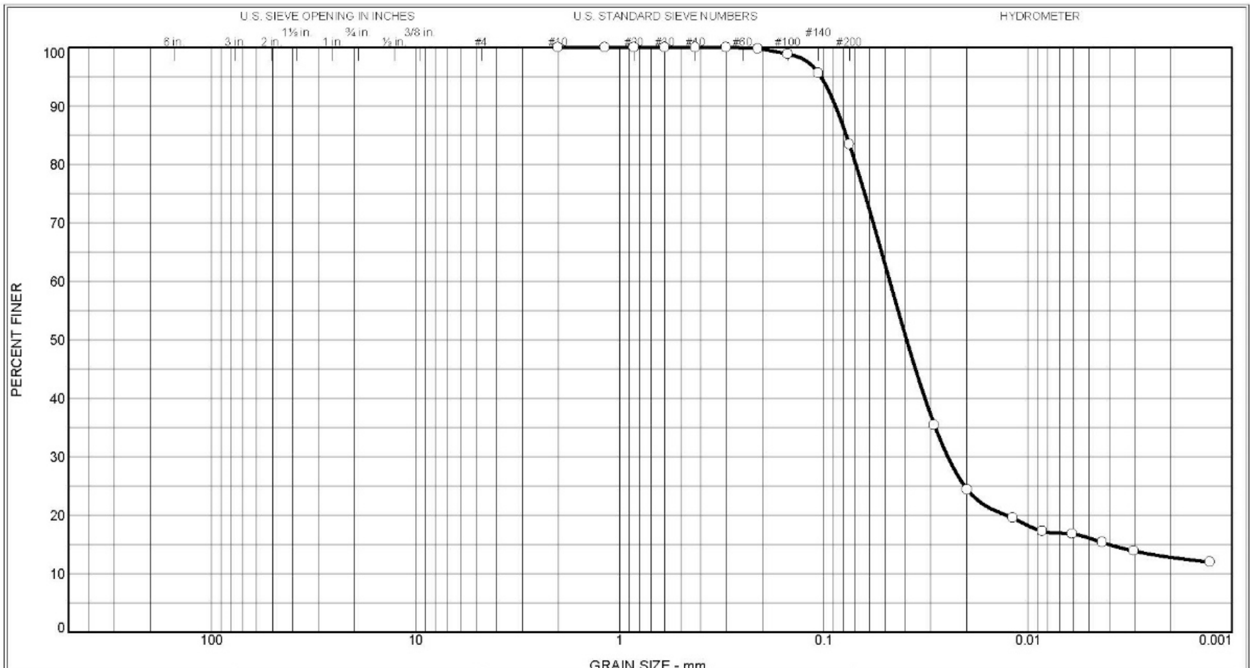
Run No.	1	2	3	4	5	6	7
Tare No.	A24	16					
Tare Plus Wet Soil, g	30.56	30.63					
Tare Plus Dry Soil, g	28.19	28.34					
Water, g	2.37	2.29					
Tare, g	15.30	15.84					
Dry Soil, g	12.89	12.50					
Water content, %	18.4	18.3					
Plastic Limit	18.4						

Remarks Clay (CL), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- G22 (3 - 4.5 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	3-4.5	Silt (ML) with Sand, Gray		NV	NP	NP

Project Kaskaskia CPT

Area

Boring No. 22

Date: 10/28/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/WH Checked By: TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: 22
Depth: 3-4.5
Material Description: Silt (ML) with Sand, Gray
PL: NP **LL:** NV
PI: NP
Tested by: AT/WH **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
98.40	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.20	99.8
			#100	1.10	98.9
			#140	4.30	95.6
			#200	16.30	83.4

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =98.4
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.68 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 x Rm

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	22.0	1.0263	1.0219	0.0132	25.8	9.5	0.0287	35.4
5.00	22.0	1.0195	1.0151	0.0132	19.0	11.3	0.0198	24.4
15.00	22.0	1.0165	1.0121	0.0132	16.0	12.1	0.0118	19.5
30.00	22.0	1.0151	1.0107	0.0132	14.6	12.4	0.0085	17.3
60.00	21.5	1.0149	1.0104	0.0133	14.4	12.5	0.0061	16.8
120.00	21.5	1.0140	1.0095	0.0133	13.5	12.7	0.0043	15.4
250.00	21.5	1.0131	1.0086	0.0133	12.6	13.0	0.0030	13.9
1440.00	21.0	1.0120	1.0074	0.0134	11.5	13.3	0.0013	12.0

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	16.6	16.6	67.3	16.1	83.4

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
		0.0040	0.0127	0.0247	0.0320	0.0393	0.0475	0.0697	0.0777	0.0877	0.1031

Fineness Modulus
0.01

CEERD-GEGB

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

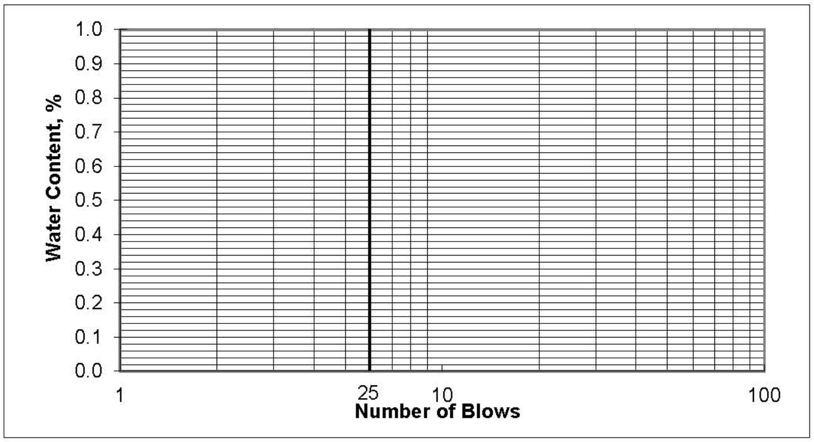
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. 22 SAMPLE NO. 3-4.5

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL

PL

PI

Symbol from plasticity chart

ML

Plastic LIMIT

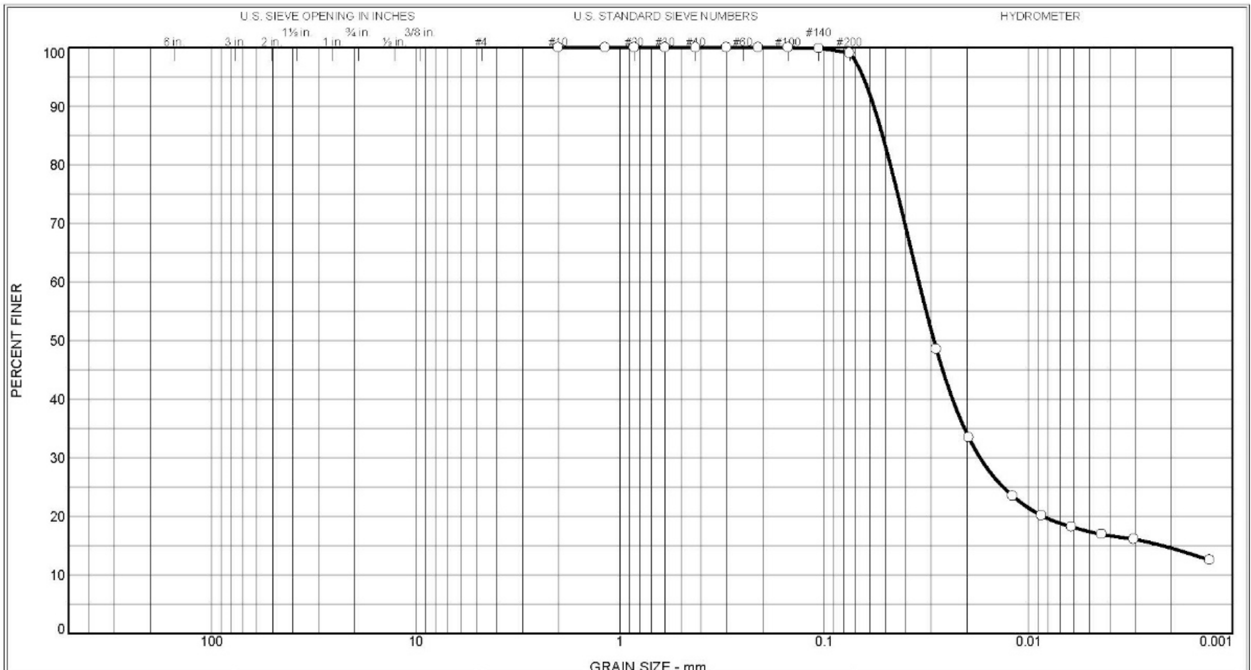
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silt (ML), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- G22 (4.5 – 6 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	4.5-6	Silt (ML), Gray			NP	

Project Kaskaskia CPT

Area

Boring No. 22

Date: 10/28/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/WH **Checked By:** TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: 22
Depth: 4.5-6
Material Description: Silt (ML), Gray
PL: NP
Tested by: AT/WH **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
74.90	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.00	100.0
			#100	0.00	100.0
			#140	0.10	99.9
			#200	0.70	99.1

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =74.9
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.69 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	22.0	1.0273	1.0229	0.0132	26.8	9.2	0.0282	48.6
5.00	22.0	1.0202	1.0158	0.0132	19.7	11.1	0.0196	33.5
15.00	22.0	1.0155	1.0111	0.0132	15.0	12.3	0.0119	23.5
30.00	21.5	1.0140	1.0095	0.0132	13.5	12.7	0.0086	20.1
60.00	21.5	1.0131	1.0086	0.0132	12.6	13.0	0.0062	18.2
120.00	21.5	1.0125	1.0080	0.0132	12.0	13.1	0.0044	17.0
250.00	21.5	1.0121	1.0076	0.0132	11.6	13.2	0.0030	16.1
1440.00	21.0	1.0105	1.0059	0.0133	10.0	13.6	0.0013	12.6

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.9	81.7	17.4	99.1

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
		0.0022	0.0085	0.0172	0.0235	0.0290	0.0344	0.0474	0.0518	0.0571	0.0644

Fineness Modulus
0.00

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

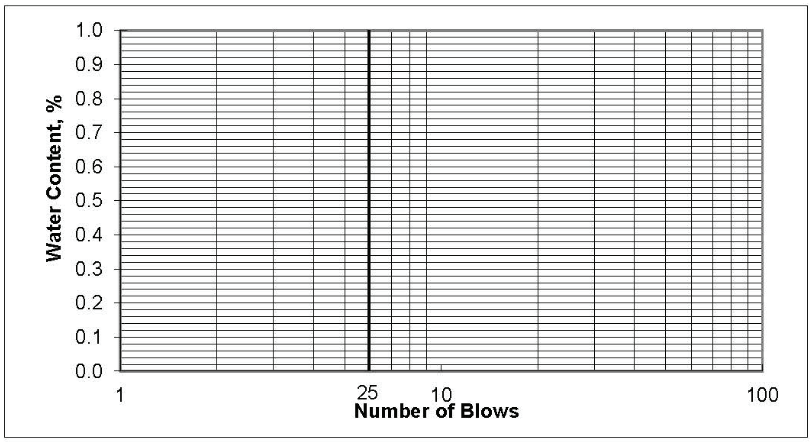
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. 22 SAMPLE NO. 4.5-6

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL

PL

PI

Symbol from plasticity chart

ML

Plastic LIMIT

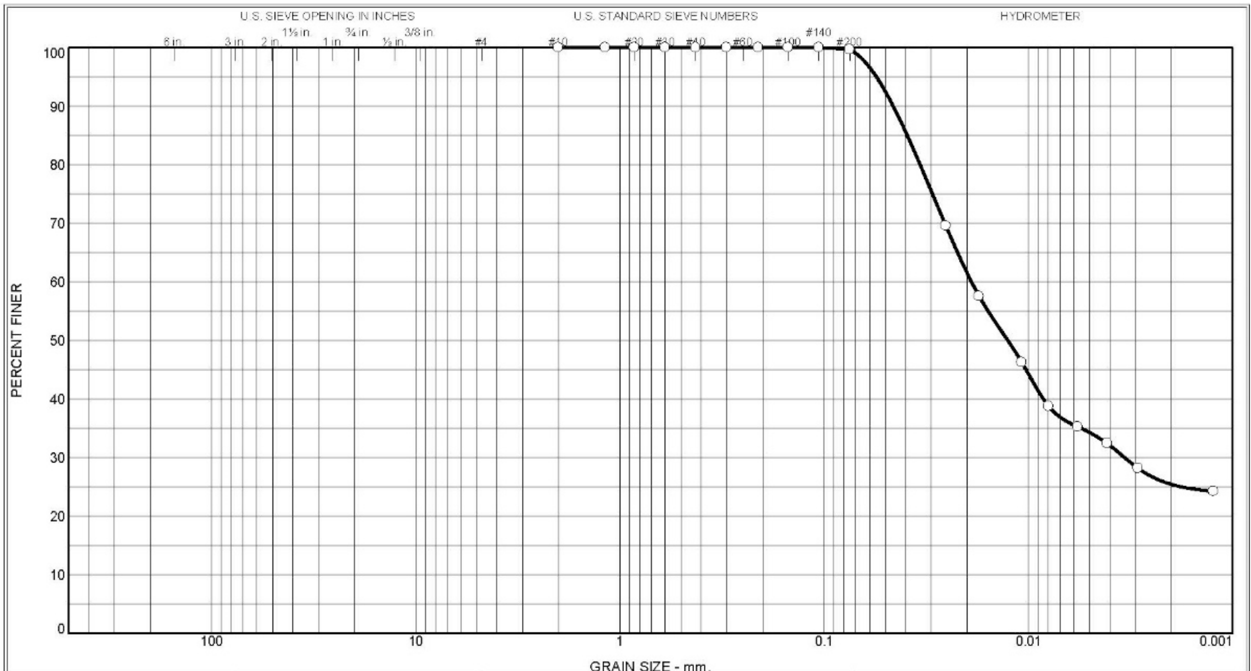
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silt (ML), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- G22 (6 – 7 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	6-7.5	Clay (CL), Gray		37	24	13

Project Kaskaskia CPT

Area

Boring No. 22

Date: 11/9/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/WH Checked By: TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

11/9/2015

Project: Kaskaskia CPT
Location: 22
Depth: 6-7.5
Material Description: Clay (CL), Gray
PL: 24 **LL:** 37
PI: 13
Tested by: AT/WH **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
67.60	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.00	100.0
			#100	0.00	100.0
			#140	0.00	100.0
			#200	0.20	99.7

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =67.6
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.69 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	22.0	1.0340	1.0296	0.0132	33.5	7.4	0.0254	69.6
5.00	22.0	1.0289	1.0245	0.0132	28.4	8.8	0.0174	57.6
15.00	22.0	1.0241	1.0197	0.0132	23.6	10.1	0.0108	46.3
30.00	21.5	1.0210	1.0165	0.0132	20.5	10.9	0.0080	38.8
60.00	21.5	1.0195	1.0150	0.0132	19.0	11.3	0.0057	35.3
120.00	21.5	1.0183	1.0138	0.0132	17.8	11.6	0.0041	32.4
250.00	21.5	1.0165	1.0120	0.0132	16.0	12.1	0.0029	28.2
1440.00	21.0	1.0149	1.0103	0.0133	14.4	12.5	0.0012	24.3

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	65.4	34.3	99.7

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
				0.0034	0.0084	0.0126	0.0190	0.0339	0.0392	0.0459	0.0554

Fineness Modulus
0.00

CEERD-GEGB

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

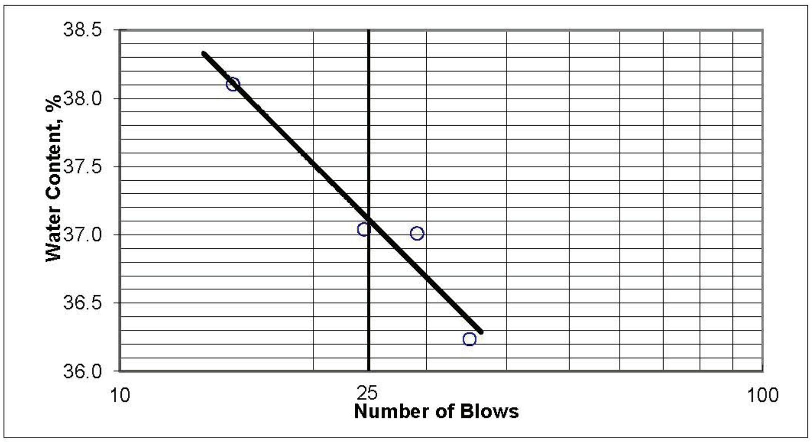
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. 22 SAMPLE NO. 6-7.5

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.	9A	K-15	310	344			
Tare Plus Wet Soil, g	37.66	35.76	34.78	36.05			
Tare Plus Dry Soil, g	32.54	30.76	29.65	30.51			
Water, g	5.12	5.00	5.13	5.54			
Tare, g	18.41	17.25	15.80	15.97			
Dry Soil, g	14.13	13.51	13.85	14.54			
Water content, %	36.2	37.0	37.0	38.1			
Number of Blows	35	29	24	15			



LL	37
PL	24
PI	13

Symbol from plasticity chart: CL

Plastic LIMIT

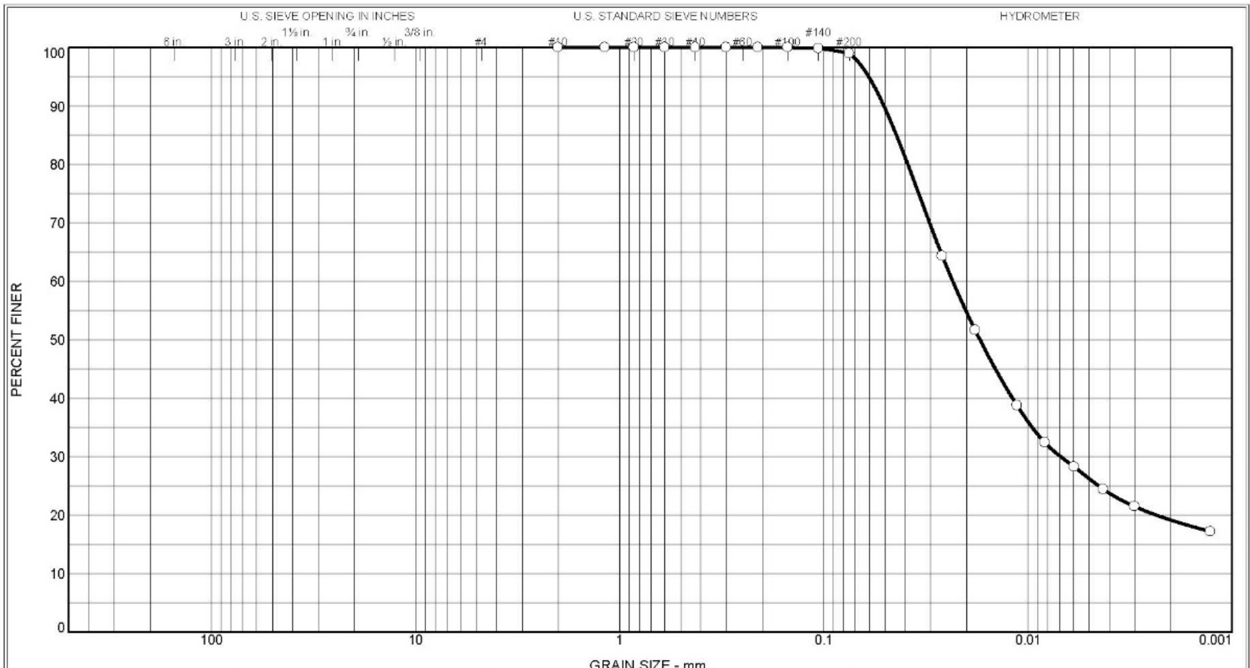
Run No.	1	2	3	4	5	6	7
Tare No.	3	42					
Tare Plus Wet Soil, g	52.86	52.06					
Tare Plus Dry Soil, g	49.53	48.96					
Water, g	3.33	3.10					
Tare, g	35.91	36.32					
Dry Soil, g	13.62	12.64					
Water content, %	24.4	24.5					
Plastic Limit	24.5						

Remarks Clay (CL), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- G22 (7.5 – 9 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	7.5-9	Silt (ML), Gray			NP	

Project: Kaskaskia CPT

Area

Boring No.: 22

Date: 10/28/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT **Checked By:** TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: 22
Depth: 7.5-9
Material Description: Silt (ML), Gray
PL: NP
Tested by: AT **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
70.40	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.00	100.0
			#100	0.00	100.0
			#140	0.10	99.9
			#200	0.70	99.0

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =70.4
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.69 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.5	1.0331	1.0284	0.0134	32.6	7.7	0.0262	64.3
5.00	20.5	1.0275	1.0228	0.0134	27.0	9.2	0.0181	51.6
15.00	20.5	1.0218	1.0171	0.0134	21.3	10.7	0.0113	38.8
30.00	20.5	1.0190	1.0143	0.0134	18.5	11.4	0.0083	32.4
60.00	21.0	1.0171	1.0125	0.0133	16.6	11.9	0.0059	28.3
120.00	21.0	1.0154	1.0108	0.0133	14.9	12.4	0.0043	24.4
250.00	21.0	1.0141	1.0095	0.0133	13.6	12.7	0.0030	21.5
1440.00	21.0	1.0122	1.0076	0.0133	11.7	13.2	0.0013	17.2

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	72.8	26.2	99.0

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
			0.0023	0.0069	0.0119	0.0172	0.0233	0.0387	0.0441	0.0507	0.0602

Fineness Modulus
0.00

CEERD-GEGB

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

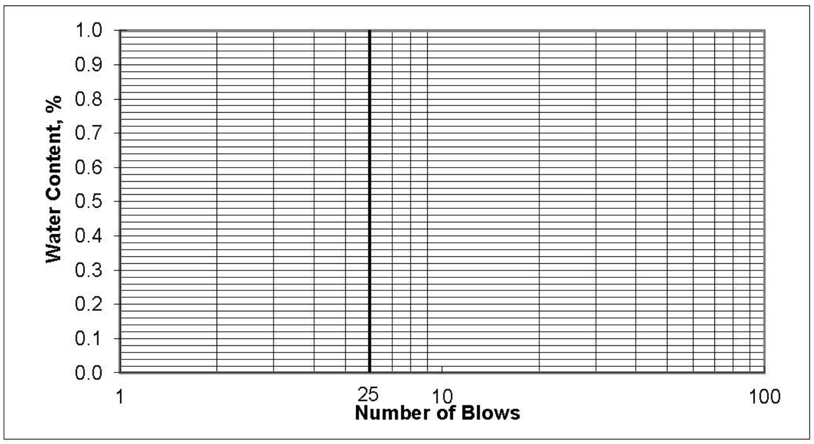
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. 22 SAMPLE NO. 7.5-9

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL

PL

PI

Symbol from plasticity chart

ML

Plastic LIMIT

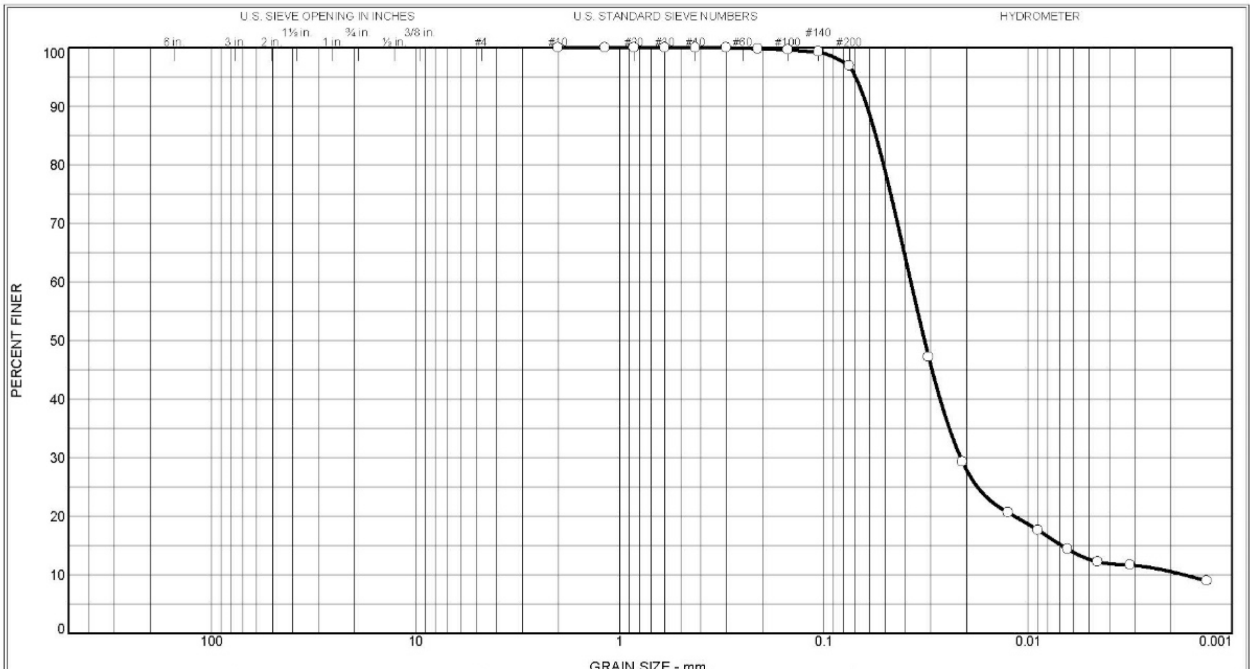
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silt (ML), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- G22 (9 – 10 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	9-10.5	Silt (ML), Gray		NV	NP	NP

Project Kaskaskia CPT

Area

Boring No. 22

Date: 10/28/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 **2087**

Tested By: AT **Checked By:** TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: 22
Depth: 9-10.5
Material Description: Silt (ML), Gray
PL: NP **LL:** NV
PI: NP
Tested by: AT **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
58.70	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.10	99.8
			#100	0.20	99.7
			#140	0.40	99.3
			#200	1.80	96.9

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =58.7
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.69 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 x Rm

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.0	1.0220	1.0174	0.0133	21.5	10.6	0.0307	47.2
5.00	21.0	1.0154	1.0108	0.0133	14.9	12.4	0.0209	29.3
15.00	21.0	1.0122	1.0076	0.0133	11.7	13.2	0.0125	20.6
30.00	21.0	1.0111	1.0065	0.0133	10.6	13.5	0.0089	17.6
60.00	21.0	1.0099	1.0053	0.0133	9.4	13.8	0.0064	14.4
120.00	21.0	1.0091	1.0045	0.0133	8.6	14.0	0.0046	12.2
250.00	21.0	1.0089	1.0043	0.0133	8.4	14.1	0.0032	11.7
1440.00	21.0	1.0079	1.0033	0.0133	7.4	14.3	0.0013	9.0

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	3.1	3.1	84.3	12.6	96.9

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
	0.0017	0.0068	0.0116	0.0214	0.0270	0.0321	0.0375	0.0510	0.0556	0.0615	0.0698

Fineness Modulus	C_u	C_c
0.00	21.87	7.11

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

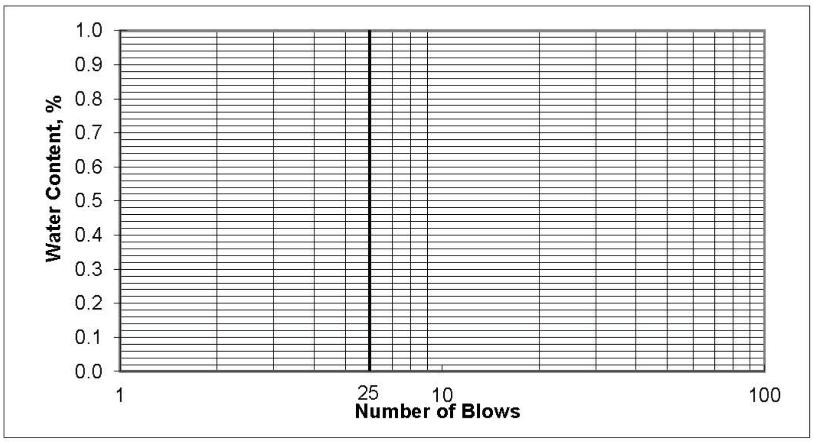
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. 22 SAMPLE NO. 9-10.5

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL

PL

PI

Symbol from plasticity chart

ML

Plastic LIMIT

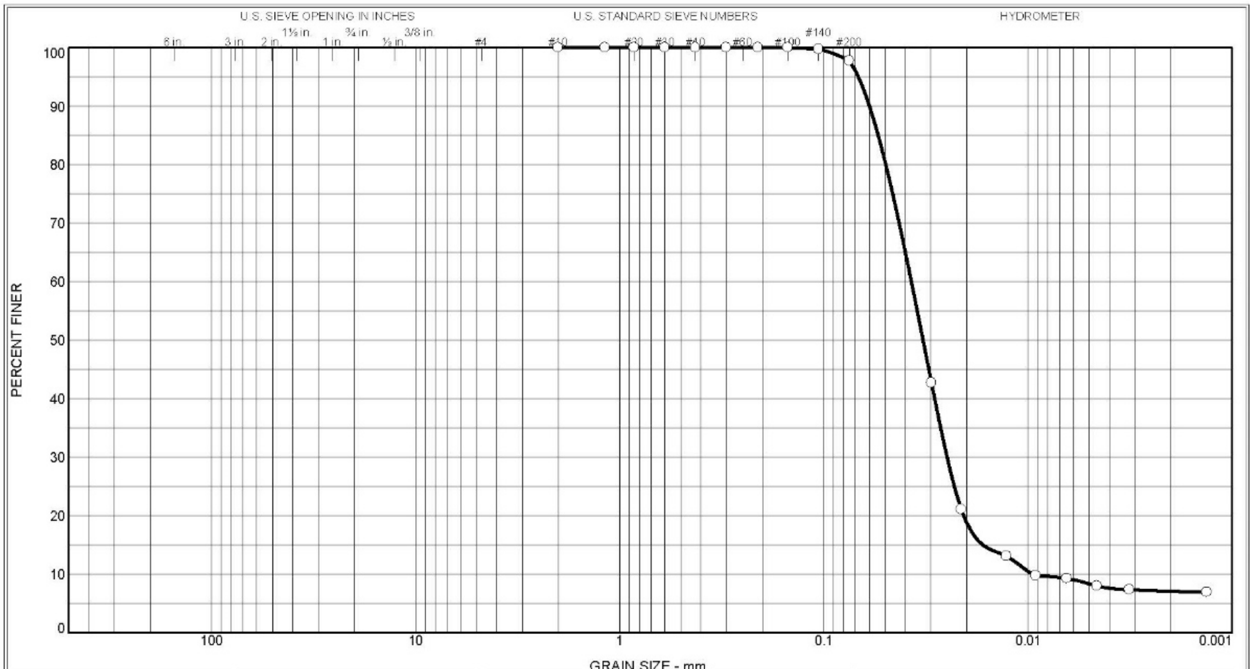
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silt (ML), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- G22 (10.5 – 12 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	10.5-12	Silt (ML), Gray			NP	

Project Kaskaskia CPT

Area

Boring No. 22

Particle Size Distribution Report

Date: 10/28/2015

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT Checked By: TRJ

GRAIN SIZE DISTRIBUTION TEST DATA 10/28/2015

Project: Kaskaskia CPT
Location: 22
Depth: 10.5-12
Material Description: Silt (ML), Gray
PL: NP
Tested by: AT **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
75.80	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.00	100.0
			#100	0.00	100.0
			#140	0.20	99.7
			#200	1.70	97.8

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =75.8
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.69 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.5	1.0250	1.0203	0.0134	24.5	9.8	0.0297	42.7
5.00	20.5	1.0147	1.0100	0.0134	14.2	12.5	0.0212	21.1
15.00	20.5	1.0109	1.0062	0.0134	10.4	13.5	0.0127	13.1
30.00	20.5	1.0093	1.0046	0.0134	8.8	14.0	0.0091	9.7
60.00	21.0	1.0090	1.0044	0.0133	8.5	14.0	0.0064	9.3
120.00	21.0	1.0084	1.0038	0.0133	7.9	14.2	0.0046	8.0
250.00	21.0	1.0081	1.0035	0.0133	7.6	14.3	0.0032	7.4
1440.00	21.0	1.0079	1.0033	0.0133	7.4	14.3	0.0013	6.9

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	2.2	2.2	89.4	8.4	97.8

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
	0.0095	0.0167	0.0207	0.0249	0.0286	0.0327	0.0372	0.0497	0.0541	0.0597	0.0677

Fineness Modulus	C_u	C_c
0.00	3.93	1.76

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

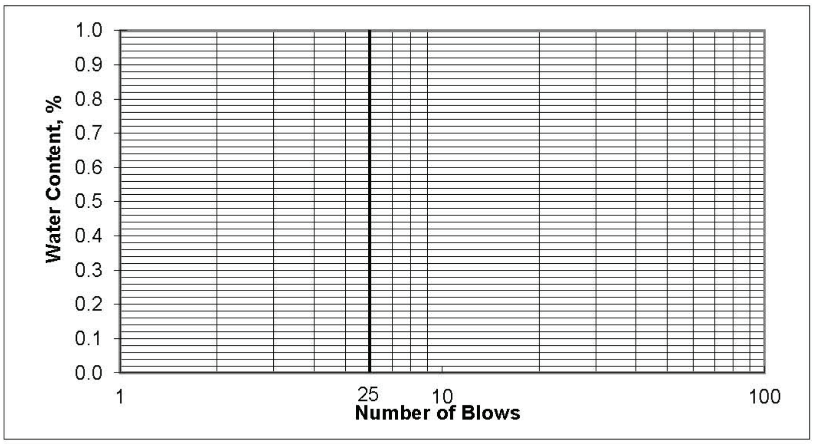
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. 22 SAMPLE NO. 10.5-12

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL

PL

PI

Symbol from plasticity chart

ML

Plastic LIMIT

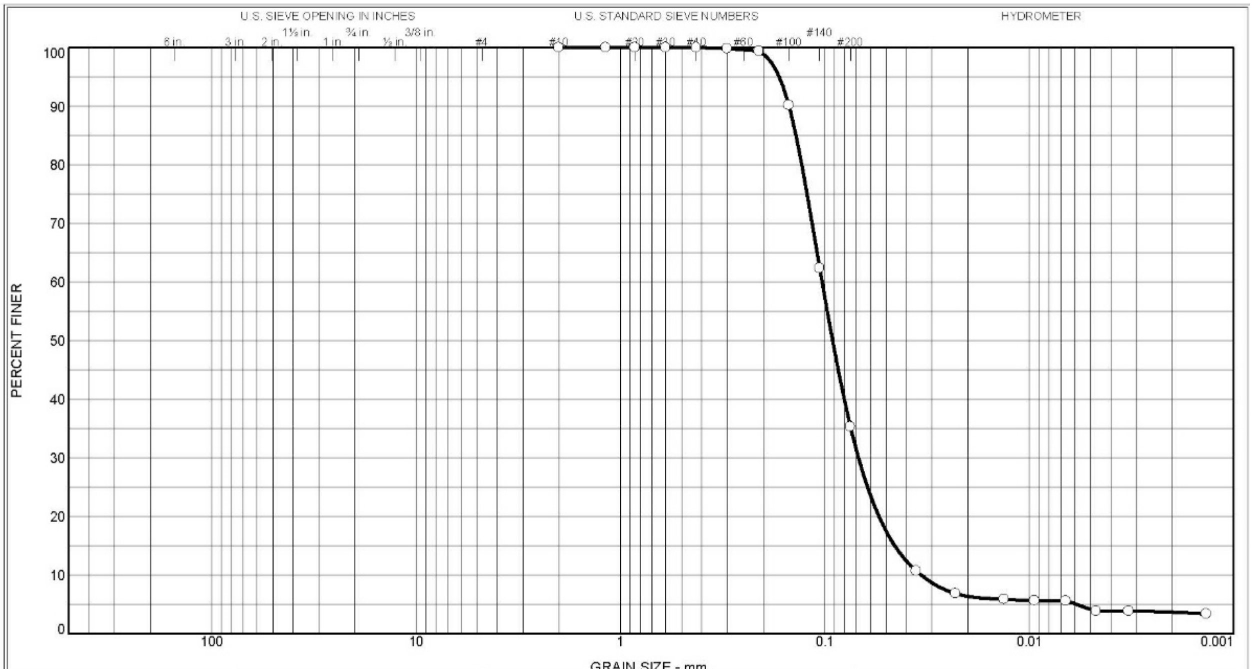
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silt (ML), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- G22 (12 - 13.5 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○		12-13.5	Silty Sand (SM), Gray			NP	

Project Kaskaskia CPT

Area

Boring No. 22

Particle Size Distribution Report

Date: 10/28/2015

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT Checked By: TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: 22
Depth: 12-13.5
Material Description: Silty Sand (SM), Gray
PL: NP
Tested by: AT **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
66.20	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.10	99.8
			#70	0.40	99.4
			#100	6.50	90.2
			#140	24.90	62.4
			#200	42.80	35.3

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =66.2
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.67 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.5	1.0091	1.0044	0.0135	8.6	14.0	0.0357	10.7
5.00	20.5	1.0075	1.0028	0.0135	7.0	14.4	0.0229	6.9
15.00	20.5	1.0071	1.0024	0.0135	6.6	14.5	0.0133	5.9
30.00	20.5	1.0070	1.0023	0.0135	6.5	14.6	0.0094	5.7
60.00	21.0	1.0069	1.0023	0.0134	6.4	14.6	0.0066	5.6
120.00	21.0	1.0062	1.0016	0.0134	5.7	14.8	0.0047	3.9
250.00	21.0	1.0062	1.0016	0.0134	5.7	14.8	0.0033	3.9
1440.00	21.0	1.0060	1.0014	0.0134	5.5	14.8	0.0014	3.4

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	64.7	64.7	31.2	4.1	35.3

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
0.0058	0.0337	0.0455	0.0544	0.0684	0.0804	0.0917	0.1032	0.1297	0.1384	0.1495	0.1670

Fineness Modulus	C_u	C_c
0.10	3.06	1.35

CEERD-GEGB

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

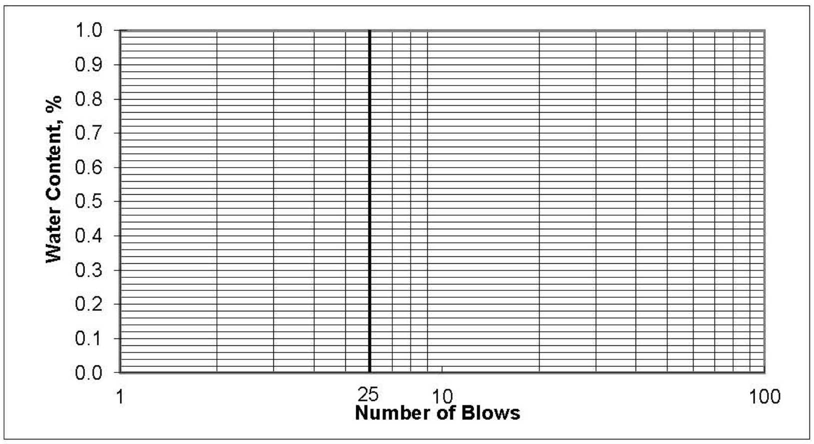
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. 22 SAMPLE NO. 12-13.5

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL

PL

PI

Symbol from plasticity chart

SM

Plastic LIMIT

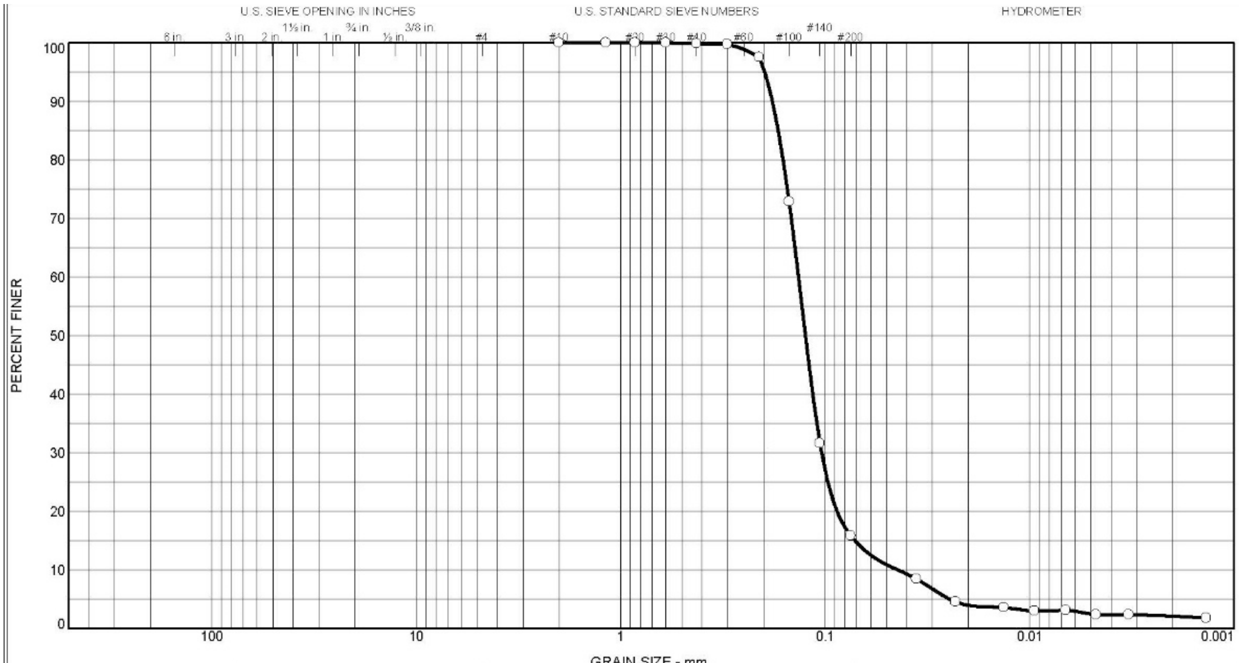
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silty Sand (SM), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- G22 (12 - 13.5 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○		13.5-15	Silty Sand (SM), Gray			NP	

Particle Size Distribution Report

Project Kaskaskia CPT

Area

Boring No. 22

Date: 10/28/2015

Corps of Engineers

ENG FORM 1 MAY 63 **2087**

Tested By: AT **Checked By:** TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: 22
Depth: 13.5-15
Material Description: Silty Sand (SM), Gray
PL: NP
Tested by: AT **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
81.90	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.10	99.9
			#50	0.20	99.8
			#70	2.00	97.6
			#100	22.20	72.9
			#140	56.00	31.6
			#200	68.90	15.9

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =81.9
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.67 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	20.5	1.0090	1.0043	0.0135	8.5	14.0	0.0357	8.5
5.00	20.5	1.0070	1.0023	0.0135	6.5	14.6	0.0230	4.6
15.00	20.5	1.0065	1.0018	0.0135	6.0	14.7	0.0133	3.6
30.00	20.5	1.0062	1.0015	0.0135	5.7	14.8	0.0095	3.0
60.00	21.0	1.0062	1.0016	0.0134	5.7	14.8	0.0067	3.1
120.00	21.0	1.0058	1.0012	0.0134	5.3	14.9	0.0047	2.4
250.00	21.0	1.0058	1.0012	0.0134	5.3	14.9	0.0033	2.4
1440.00	21.0	1.0055	1.0009	0.0134	5.0	15.0	0.0014	1.8

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.1	84.0	84.1	13.4	2.5	15.9

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
0.0245	0.0440	0.0715	0.0876	0.1040	0.1150	0.1248	0.1350	0.1605	0.1696	0.1810	0.1972

Fineness Modulus	C_u	C_c
0.27	3.07	1.82

CEERD-GEGB

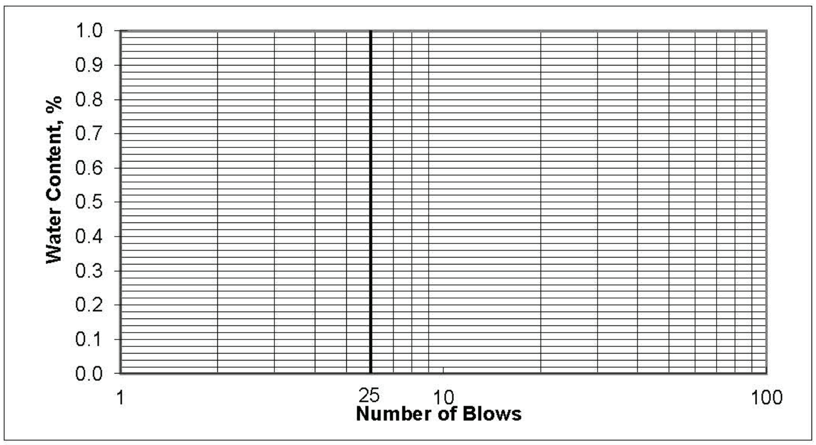
LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

WORK ORDER NO.	MD2815	DATE	10/26/2015
PROJECT	Kaskaskia CPT		
BORING NO.	22	SAMPLE NO.	13.5-15

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL	
PL	
PI	
Symbol from plasticity chart	SM

Plastic LIMIT

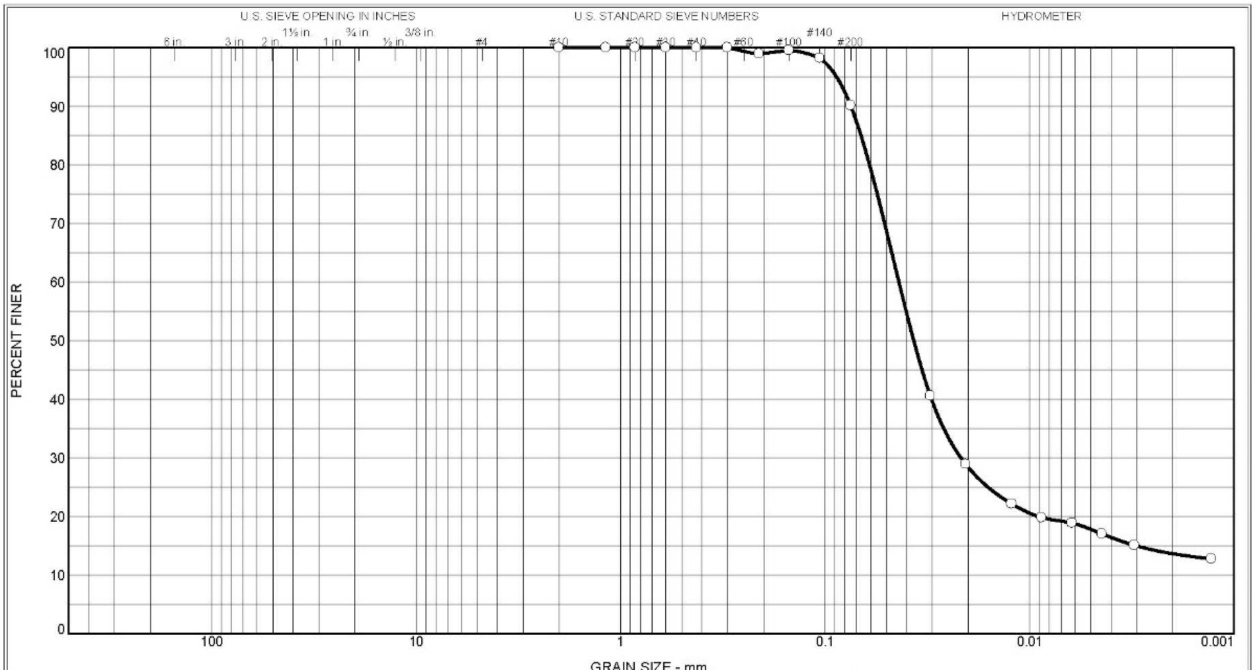
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silty Sand (SM), Gray

Technician	AT	Computed By	AT	Checked By	TRJ

Revised 5/21/09

MD2815- C01 (1 - 1.25 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○		1-2.5	Clay (CL), Gray		39	22	17

Project Kaskaskia CPT

Area

Boring No. SB-C01

Date: 11/9/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT Checked By: TRJ

GRAIN SIZE DISTRIBUTION TEST DATA **11/9/2015**

Project: Kaskaskia CPT
Location: SB-C01
Depth: 1-2.5
Material Description: Clay (CL), Gray
PL: 22 **LL:** 39
PI: 17
Tested by: AT **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
68.10	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.70	99.0
			#100	0.30	99.6
			#140	1.20	98.2
			#200	6.70	90.2

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =68.1
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.70 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.0	1.0220	1.0174	0.0133	21.5	10.6	0.0306	40.6
5.00	21.0	1.0170	1.0124	0.0133	16.5	11.9	0.0205	28.9
15.00	21.0	1.0141	1.0095	0.0133	13.6	12.7	0.0122	22.2
30.00	21.0	1.0131	1.0085	0.0133	12.6	13.0	0.0087	19.8
60.00	21.0	1.0127	1.0081	0.0133	12.2	13.1	0.0062	18.9
120.00	21.0	1.0119	1.0073	0.0133	11.4	13.3	0.0044	17.0
250.00	21.5	1.0110	1.0065	0.0132	10.5	13.5	0.0031	15.1
1440.00	21.5	1.0100	1.0055	0.0132	9.5	13.8	0.0013	12.8

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	9.8	9.8	72.4	17.8	90.2

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
		0.0030	0.0090	0.0216	0.0302	0.0368	0.0435	0.0606	0.0667	0.0747	0.0877

Fineness Modulus
0.00

CEERD-GEGB

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

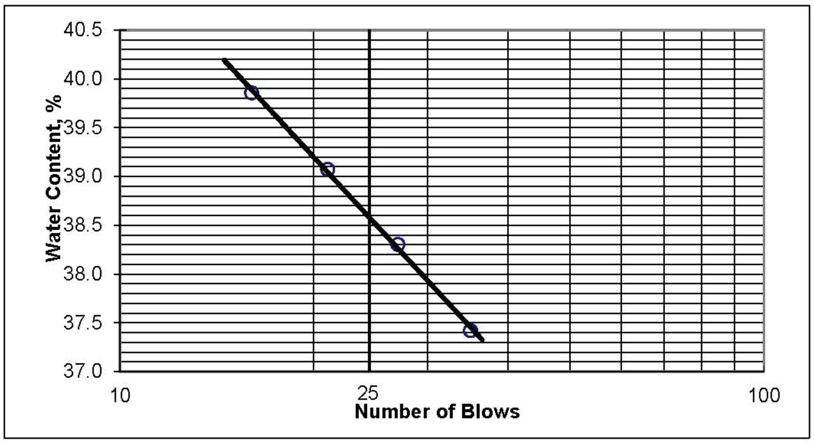
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. SB-C01 SAMPLE NO. 1-2.5

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.	1135C	442	31	556			
Tare Plus Wet Soil, g	55.18	32.92	34.78	34.87			
Tare Plus Dry Soil, g	49.93	28.09	29.31	29.33			
Water, g	5.25	4.83	5.47	5.54			
Tare, g	35.90	15.48	15.31	15.43			
Dry Soil, g	14.03	12.61	14.00	13.90			
Water content, %	37.4	38.3	39.1	39.9			
Number of Blows	35	27	21	16			



LL	39
PL	22
PI	17

Symbol from plasticity chart

CL

Plastic LIMIT

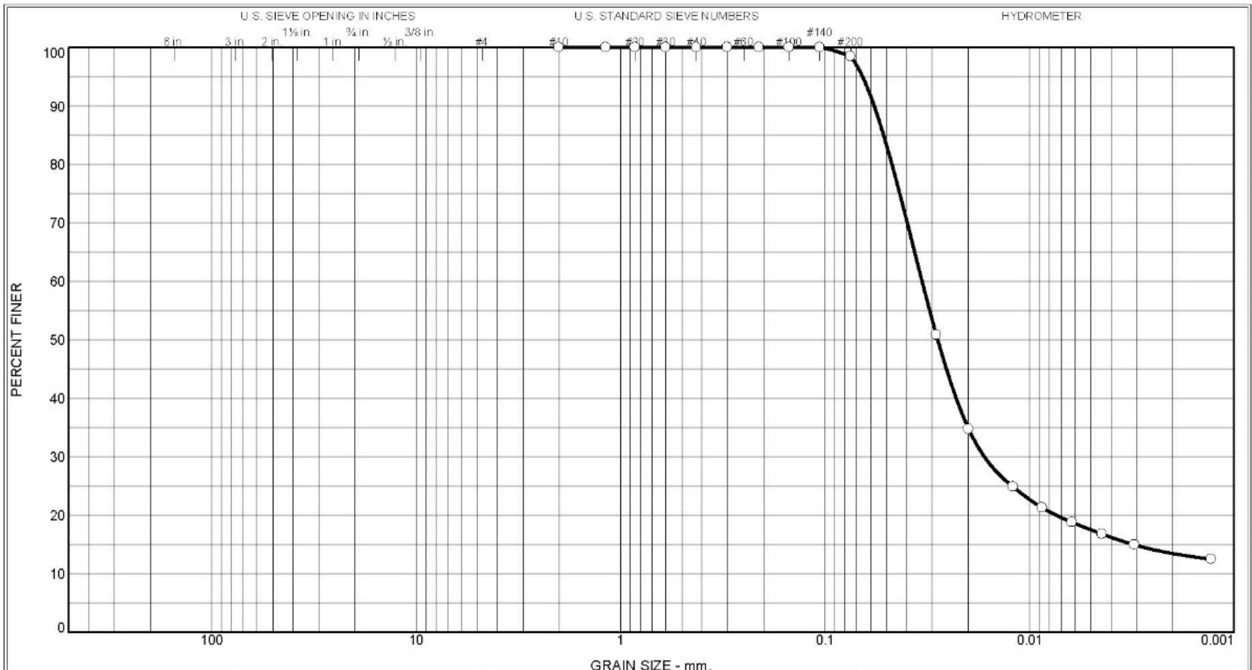
Run No.	1	2	3	4	5	6	7
Tare No.	A32	A34					
Tare Plus Wet Soil, g	31.10	28.39					
Tare Plus Dry Soil, g	28.28	26.11					
Water, g	2.82	2.28					
Tare, g	15.51	15.59					
Dry Soil, g	12.77	10.52					
Water content, %	22.1	21.7					
Plastic Limit	21.9						

Remarks Clay (CL), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- C01 (2.5 - 4 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	2.5-4	Clay (CL), Gray		33	23	10

Project Kaskaskia CPT

Area

Boring No. SB-C01

Date: 11/9/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/WH Checked By: TRJ

GRAIN SIZE DISTRIBUTION TEST DATA 11/9/2015

Project: Kaskaskia CPT
Location: SB-C01
Depth: 2.5-4
Material Description: Clay (CL), Gray
PL: 23 **LL:** 33
PI: 10
Tested by: AT/WH **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
71.10	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.00	100.0
			#100	0.00	100.0
			#140	0.00	100.0
			#200	1.10	98.5

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =71.1
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.69 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 x Rm

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.0	1.0273	1.0227	0.0133	26.8	9.2	0.0286	50.8
5.00	21.0	1.0201	1.0155	0.0133	19.6	11.1	0.0199	34.7
15.00	21.0	1.0157	1.0111	0.0133	15.2	12.3	0.0120	24.9
30.00	21.0	1.0141	1.0095	0.0133	13.6	12.7	0.0087	21.3
60.00	21.0	1.0130	1.0084	0.0133	12.5	13.0	0.0062	18.8
120.00	21.0	1.0121	1.0075	0.0133	11.6	13.2	0.0044	16.8
250.00	21.5	1.0112	1.0067	0.0132	10.7	13.5	0.0031	15.0
1440.00	21.5	1.0101	1.0056	0.0132	9.6	13.8	0.0013	12.5

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	1.5	1.5	81.0	17.5	98.5

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
		0.0031	0.0074	0.0166	0.0229	0.0281	0.0335	0.0471	0.0517	0.0575	0.0655

Fineness Modulus
0.00

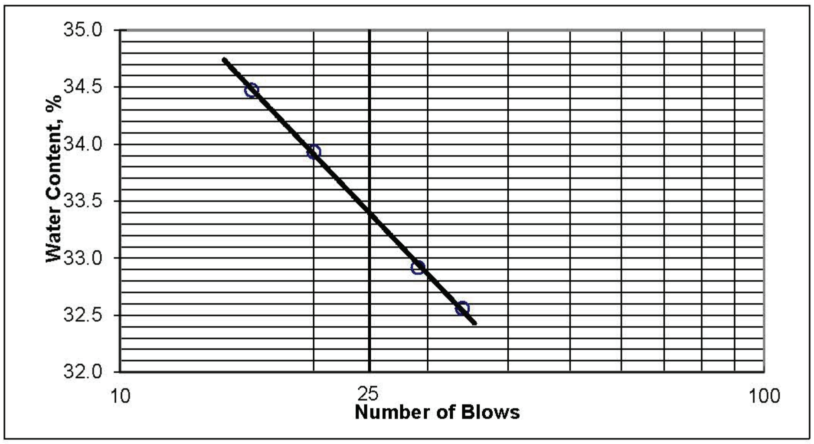
LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

WORK ORDER NO.	MD2815	DATE	10/26/2015
PROJECT	Kaskaskia CPT		
BORING NO.	SB-C01	SAMPLE NO.	2.5-4

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.	A-00	A3	A5	A12			
Tare Plus Wet Soil, g	30.09	32.53	31.20	36.73			
Tare Plus Dry Soil, g	26.45	28.31	27.23	31.29			
Water, g	3.64	4.22	3.97	5.44			
Tare, g	15.27	15.49	15.53	15.51			
Dry Soil, g	11.18	12.82	11.70	15.78			
Water content, %	32.6	32.9	33.9	34.5			
Number of Blows	34	29	20	16			



LL	33
PL	23
PI	10

Symbol from plasticity chart: CL

Plastic LIMIT

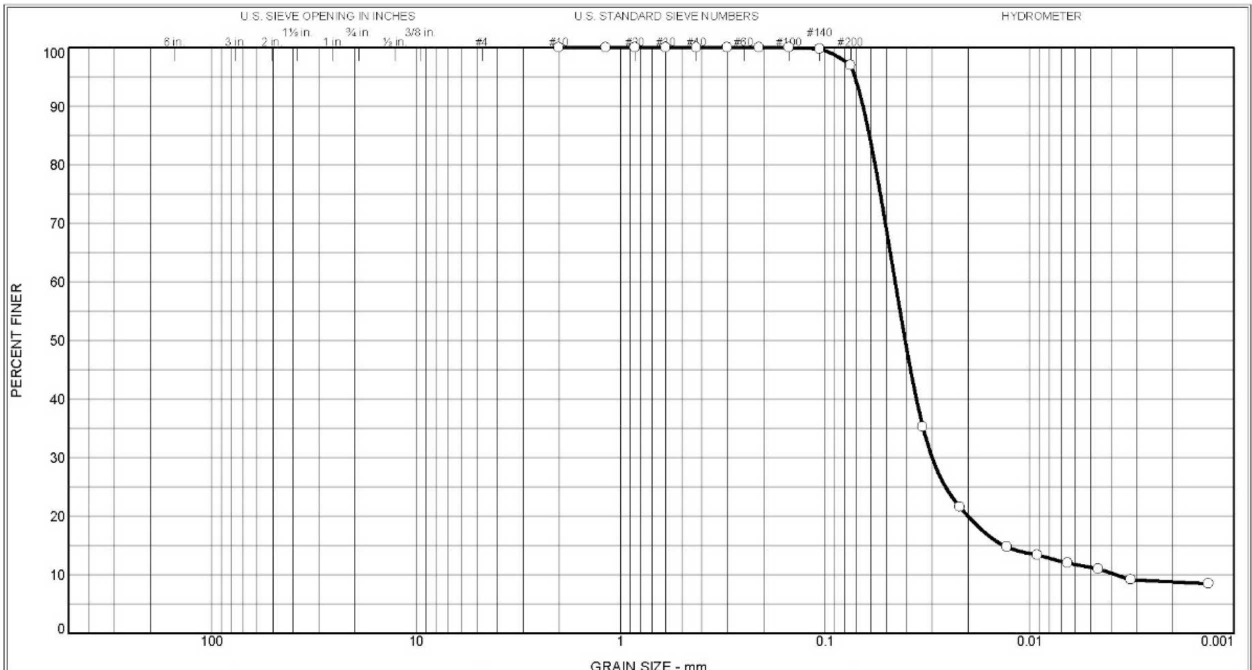
Run No.	1	2	3	4	5	6	7
Tare No.	A18	A19					
Tare Plus Wet Soil, g	30.80	33.02					
Tare Plus Dry Soil, g	27.92	29.76					
Water, g	2.88	3.26					
Tare, g	15.30	15.49					
Dry Soil, g	12.62	14.27					
Water content, %	22.8	22.8					
Plastic Limit	22.8						

Remarks: Clay (CL), Gray

Technician: AT Computed By: AT Checked By: TRJ

Revised 5/21/09

MD2815- C01 (4 - 4.5 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○		4-5.5	Clay (CL), Gray		36	22	14

Project Kaskaskia CPT

Area

Boring No. SB-C01

Date: 11/9/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/WH **Checked By:** TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

11/9/2015

Project: Kaskaskia CPT
Location: SB-C01
Depth: 4-5.5
Material Description: Clay (CL), Gray
PL: 22 **LL:** 36
PI: 14
Tested by: AT/WH **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
46.50	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.00	100.0
			#100	0.00	100.0
			#140	0.10	99.8
			#200	1.40	97.0

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =46.5
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.69 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 x Rm

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.0	1.0149	1.0103	0.0133	14.4	12.5	0.0333	35.3
5.00	21.0	1.0109	1.0063	0.0133	10.4	13.5	0.0219	21.6
15.00	21.0	1.0089	1.0043	0.0133	8.4	14.1	0.0129	14.7
30.00	21.0	1.0085	1.0039	0.0133	8.0	14.2	0.0092	13.4
60.00	21.0	1.0081	1.0035	0.0133	7.6	14.3	0.0065	12.0
120.00	21.0	1.0078	1.0032	0.0133	7.3	14.4	0.0046	11.0
250.00	21.5	1.0072	1.0027	0.0132	6.7	14.5	0.0032	9.2
1440.00	21.5	1.0070	1.0025	0.0132	6.5	14.6	0.0013	8.5

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	3.0	3.0	85.7	11.3	97.0

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
	0.0038	0.0134	0.0200	0.0300	0.0358	0.0406	0.0454	0.0569	0.0607	0.0652	0.0714

Fineness Modulus	C_u	C_c
0.00	12.05	5.24

CEERD-GEGB

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

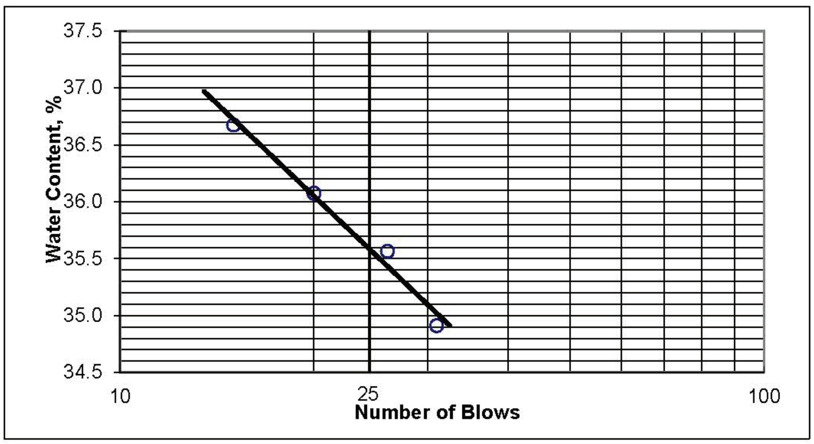
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. SB-C01 SAMPLE NO. 4-5.5

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.	A20	A21	A22	A23			
Tare Plus Wet Soil, g	37.47	34.45	37.85	36.93			
Tare Plus Dry Soil, g	31.79	29.46	31.84	31.15			
Water, g	5.68	4.99	6.01	5.78			
Tare, g	15.52	15.43	15.18	15.39			
Dry Soil, g	16.27	14.03	16.66	15.76			
Water content, %	34.9	35.6	36.1	36.7			
Number of Blows	31	26	20	15			



LL	36
PL	22
PI	14

Symbol from plasticity chart: CL

Plastic LIMIT

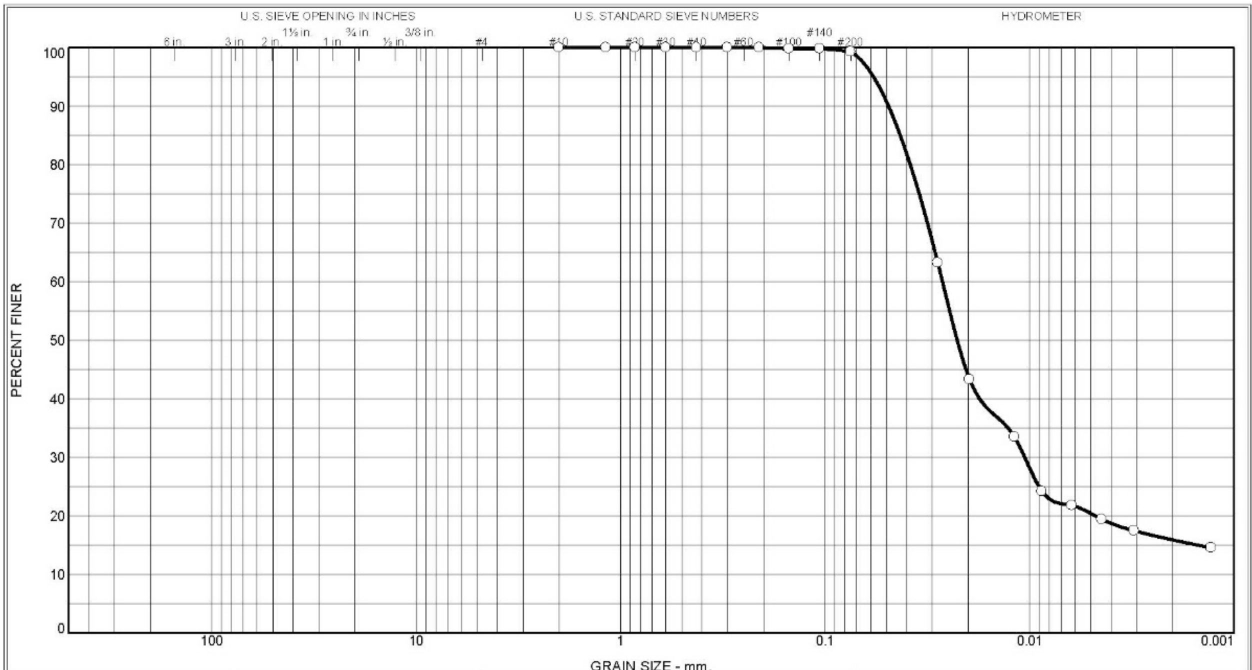
Run No.	1	2	3	4	5	6	7
Tare No.	A26	A29					
Tare Plus Wet Soil, g	29.00	31.86					
Tare Plus Dry Soil, g	26.51	28.87					
Water, g	2.49	2.99					
Tare, g	15.44	15.58					
Dry Soil, g	11.07	13.29					
Water content, %	22.5	22.5					
Plastic Limit	22.5						

Remarks Clay (CL), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- C01 (5.5 - 7 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

	Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○		5.5-7	Silt (ML), Gray			NP	

Project Kaskaskia CPT

Area

Boring No. SB-C01

Date: 10/28/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 **2087**

Tested By: AT/WH **Checked By:** TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: SB-C01
Depth: 5.5-7
Material Description: Silt (ML), Gray
PL: NP
Tested by: AT/WH **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
59.90	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.00	100.0
			#100	0.10	99.8
			#140	0.10	99.8
			#200	0.40	99.3

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =59.9
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.69 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.0	1.0284	1.0238	0.0133	27.9	8.9	0.0281	63.3
5.00	21.0	1.0209	1.0163	0.0133	20.4	10.9	0.0197	43.3
15.00	21.0	1.0172	1.0126	0.0133	16.7	11.9	0.0119	33.5
30.00	21.0	1.0137	1.0091	0.0133	13.2	12.8	0.0087	24.2
60.00	21.0	1.0128	1.0082	0.0133	12.3	13.0	0.0062	21.8
120.00	21.0	1.0119	1.0073	0.0133	11.4	13.3	0.0044	19.4
250.00	21.5	1.0111	1.0066	0.0132	10.6	13.5	0.0031	17.5
1440.00	21.5	1.0100	1.0055	0.0132	9.5	13.8	0.0013	14.6

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.7	78.9	20.4	99.3

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
		0.0015	0.0048	0.0106	0.0176	0.0226	0.0267	0.0383	0.0429	0.0489	0.0579

Fineness Modulus
0.00

CEERD-GEGB

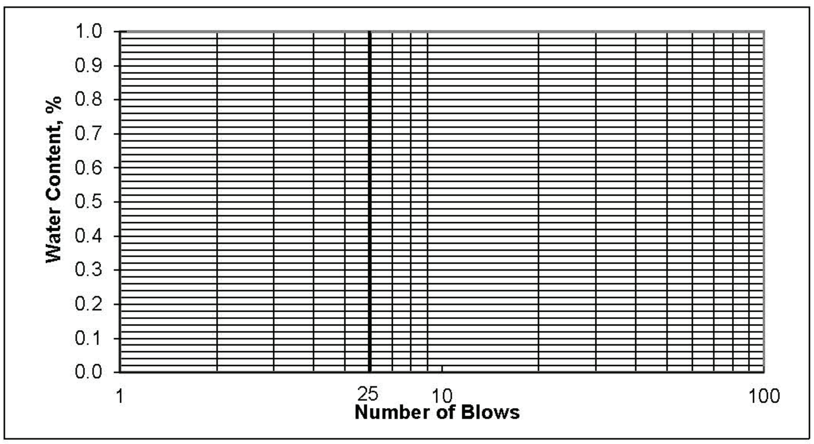
LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

WORK ORDER NO.	MD2815	DATE	10/26/2015
PROJECT	Kaskaskia CPT		
BORING NO.	SB-C01	SAMPLE NO.	5.5-7

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL

PL

PI

Symbol from plasticity chart: ML

Plastic LIMIT

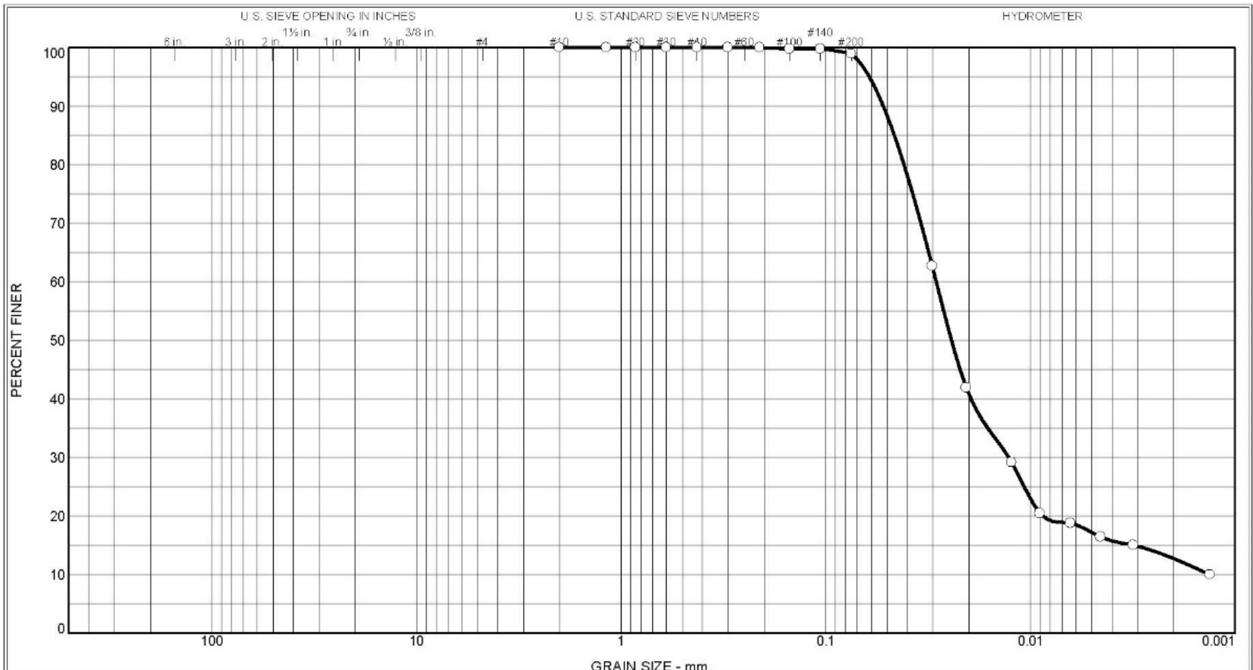
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks: Non-Plastic Silt(ML), Gray

Technician: AT Computed By: AT Checked By: TRJ

Revised 5/21/09

MD2815- C01 (7 - 8.5 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	7-8.5	Silt (ML), Gray			NP	

Particle Size Distribution Report

Project Kaskaskia CPT

Area

Boring No. SB-C01

Date: 10/28/2015

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/WH **Checked By:** TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: SB-C01
Depth: 7-8.5
Material Description: Silt (ML), Gray
PL: NP
Tested by: AT/WH **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
47.50	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.00	100.0
			#100	0.10	99.8
			#140	0.10	99.8
			#200	0.50	98.9

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =47.5
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.69 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.0	1.0233	1.0187	0.0133	22.8	10.3	0.0302	62.7
5.00	21.0	1.0171	1.0125	0.0133	16.6	11.9	0.0205	41.9
15.00	21.0	1.0133	1.0087	0.0133	12.8	12.9	0.0124	29.2
30.00	21.0	1.0107	1.0061	0.0133	10.2	13.6	0.0090	20.5
60.00	21.0	1.0102	1.0056	0.0133	9.7	13.7	0.0064	18.8
120.00	21.0	1.0095	1.0049	0.0133	9.0	13.9	0.0045	16.4
250.00	21.5	1.0090	1.0045	0.0132	8.5	14.0	0.0031	15.0
1440.00	21.5	1.0075	1.0030	0.0132	7.0	14.4	0.0013	10.0

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	1.1	1.1	81.7	17.2	98.9

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
	0.0013	0.0031	0.0087	0.0128	0.0195	0.0243	0.0288	0.0415	0.0462	0.0523	0.0612

Fineness Modulus	C_u	C_c
0.00	21.69	4.25

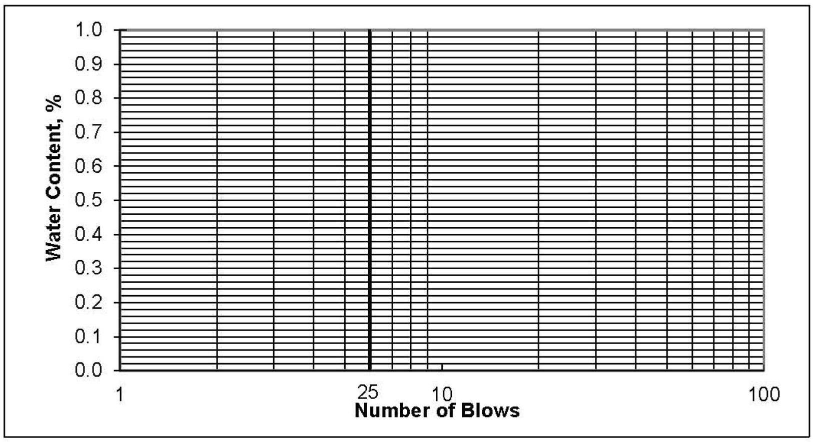
LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

WORK ORDER NO.	MD2815	DATE	10/26/2015
PROJECT	Kaskaskia CPT		
BORING NO.	SB-C01	SAMPLE NO.	7-8.5

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL	
PL	
PI	
Symbol from plasticity chart	ML

Plastic LIMIT

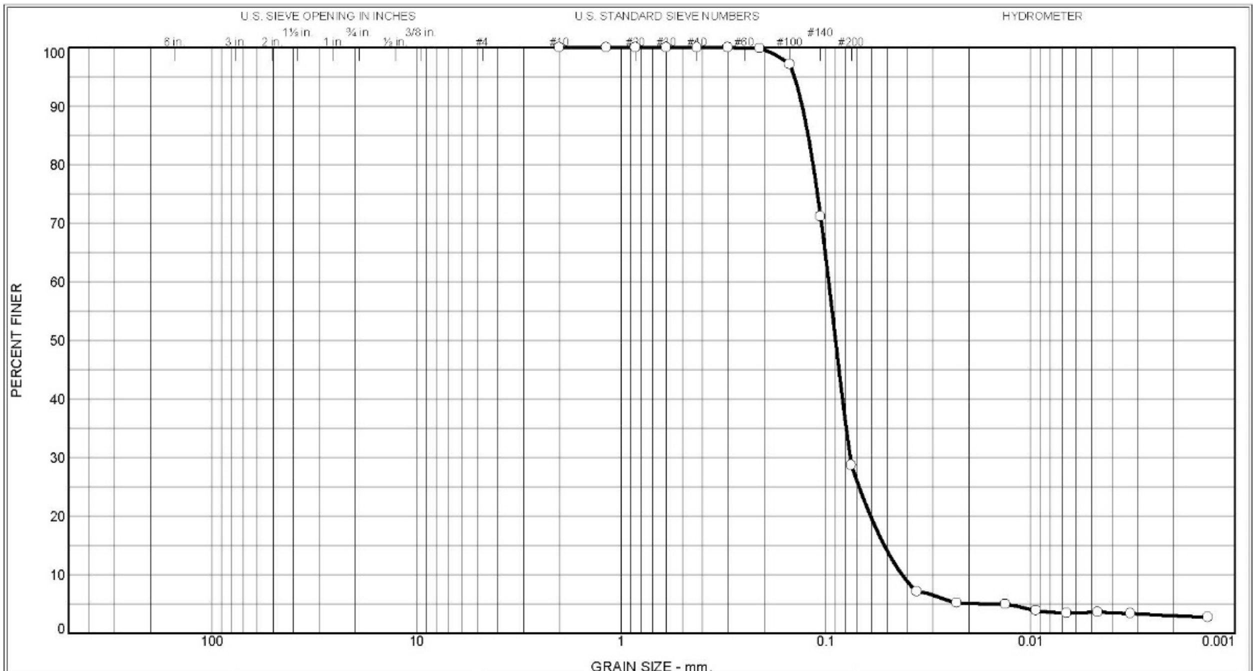
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silt(ML), Gray

Technician	AT	Computed By	AT	Checked By	TRJ

Revised 5/21/09

MD2815- C01 (8.5 – 10 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	8.5-10	Silty Sand (SM), Gray			NP	

Project Kaskaskia CPT

Area

Boring No. SB-C01

Particle Size Distribution Report

Date: 10/28/2015

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/WH Checked By: TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: SB-C01
Depth: 8.5-10
Material Description: Silty Sand (SM), Gray
PL: NP
Tested by: AT/WH **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
74.20	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.00	100.0
			#70	0.10	99.9
			#100	2.10	97.2
			#140	21.40	71.2
			#200	52.90	28.7

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =74.2
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.67 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.0	1.0079	1.0033	0.0134	7.4	14.3	0.0359	7.1
5.00	21.0	1.0070	1.0024	0.0134	6.5	14.6	0.0229	5.2
15.00	21.0	1.0069	1.0023	0.0134	6.4	14.6	0.0132	5.0
30.00	21.0	1.0064	1.0018	0.0134	5.9	14.7	0.0094	3.9
60.00	21.0	1.0062	1.0016	0.0134	5.7	14.8	0.0067	3.5
120.00	21.5	1.0062	1.0017	0.0133	5.7	14.8	0.0047	3.6
250.00	21.5	1.0061	1.0016	0.0133	5.6	14.8	0.0032	3.4
1440.00	21.5	1.0058	1.0013	0.0133	5.3	14.9	0.0014	2.8

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	71.3	71.3	25.1	3.6	28.7

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
0.0142	0.0424	0.0518	0.0604	0.0760	0.0829	0.0896	0.0968	0.1153	0.1219	0.1303	0.1421

Fineness Modulus	C_u	C_c
0.03	2.28	1.41

CEERD-GEGB

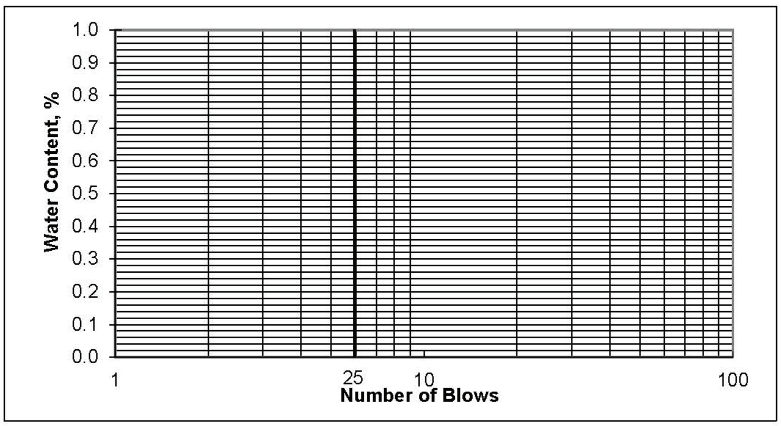
LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

WORK ORDER NO.	MD2815	DATE	10/26/2015
PROJECT	Kaskaskia CPT		
BORING NO.	SB-C01	SAMPLE NO.	8.5-10

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL	
PL	
PI	
Symbol from plasticity chart	SM

Plastic LIMIT

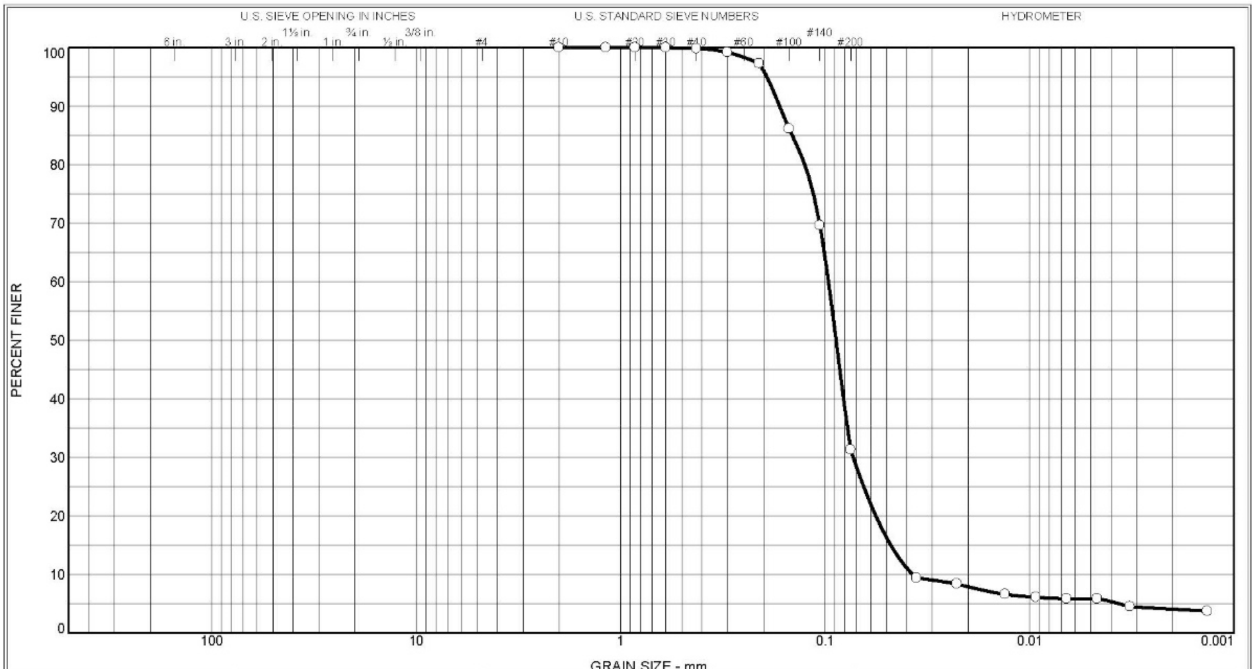
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silty Sand (SM), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- C01 (10 - 11.5 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	10-11.5	Silty Sand (SM), Gray			NP	

Project Kaskaskia CPT

Area

Boring No. SB-C01

Date: 10/28/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 2087

Tested By: AT/WH

Checked By: TRJ

GRAIN SIZE DISTRIBUTION TEST DATA **10/28/2015**

Project: Kaskaskia CPT
Location: SB-C01
Depth: 10-11.5
Material Description: Silty Sand (SM), Gray
PL: NP
Tested by: AT/WH **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
62.90	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.10	99.8
			#50	0.50	99.2
			#70	1.70	97.3
			#100	8.70	86.2
			#140	19.10	69.6
			#200	43.20	31.3

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =62.9
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.68 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.0	1.0083	1.0037	0.0134	7.8	14.2	0.0356	9.4
5.00	21.0	1.0079	1.0033	0.0134	7.4	14.3	0.0226	8.4
15.00	21.0	1.0072	1.0026	0.0134	6.7	14.5	0.0131	6.6
30.00	21.0	1.0070	1.0024	0.0134	6.5	14.6	0.0093	6.1
60.00	21.0	1.0069	1.0023	0.0134	6.4	14.6	0.0066	5.9
120.00	21.0	1.0069	1.0023	0.0134	6.4	14.6	0.0047	5.9
250.00	21.5	1.0063	1.0018	0.0133	5.8	14.8	0.0032	4.5
1440.00	21.5	1.0060	1.0015	0.0133	5.5	14.8	0.0013	3.7

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.2	68.5	68.7	25.4	5.9	31.3

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
0.0036	0.0372	0.0477	0.0565	0.0729	0.0813	0.0884	0.0963	0.1256	0.1448	0.1668	0.1923

Fineness Modulus	C_u	C_c
0.15	2.59	1.48

CEERD-GEGB

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

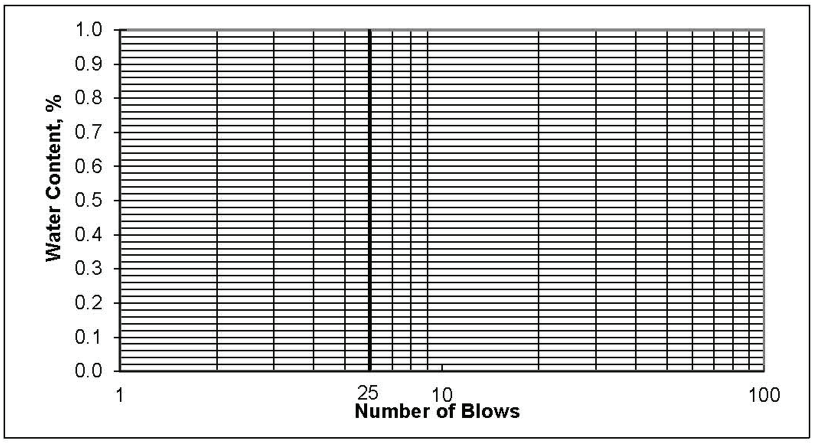
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. SB-C01 SAMPLE NO. 10-11.5

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL

PL

PI

Symbol from plasticity chart: SM

Plastic LIMIT

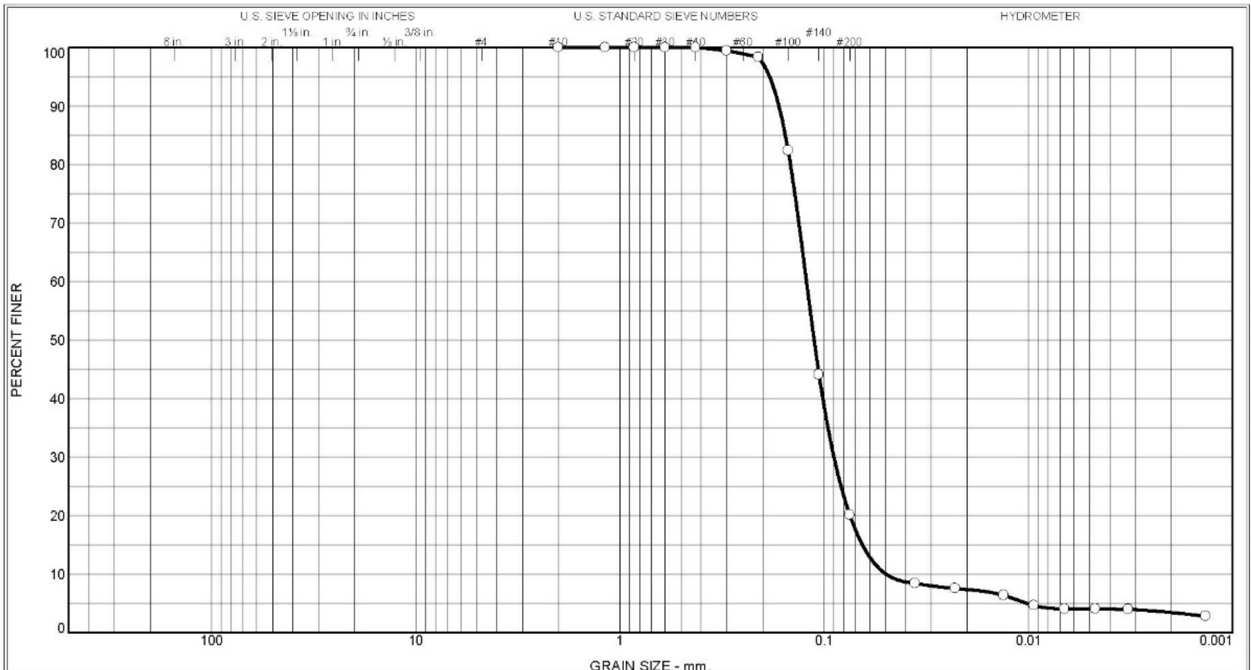
Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silty Sand (SM), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

MD2815- C01 (11.5 – 13 ft):



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay

Sample No.	Elev or Depth	Classification	Nat w%	LL	PL	PI
○	11.5-13	Silty Sand (SM), Gray			NP	

Project Kaskaskia CPT

Area

Boring No. SB-C01

Date: 10/28/2015

Particle Size Distribution Report

Corps of Engineers

ENG FORM 1 MAY 63 **2087**

Tested By: AT/WH **Checked By:** TRJ

GRAIN SIZE DISTRIBUTION TEST DATA

10/28/2015

Project: Kaskaskia CPT
Location: SB-C01
Depth: 11.5-13
Material Description: Silty Sand (SM), Gray
PL: NP
Tested by: AT/WH **Checked by:** TRJ

Sieve Test Data

Dry Sample and Tare (grams)	Tare (grams)	Cumulative Pan Tare Weight (grams)	Sieve Opening Size	Cumulative Weight Retained (grams)	Percent Finer
55.10	0.00	0.00	#10	0.00	100.0
			#16	0.00	100.0
			#20	0.00	100.0
			#30	0.00	100.0
			#40	0.00	100.0
			#50	0.30	99.5
			#70	0.90	98.4
			#100	9.70	82.4
			#140	30.80	44.1
			#200	44.00	20.1

Hydrometer Test Data

Hydrometer test uses material passing #10
Percent passing #10 based upon complete sample = 100.0
Weight of hydrometer sample =55.1
Automatic temperature correction
Composite correction (fluid density and meniscus height) at 20 deg. C = -4.7
Meniscus correction only = -0.5
Specific gravity of solids = 2.68 est
Hydrometer type = 151H
Hydrometer effective depth equation: L = 16.294964 - 0.2645 **x Rm**

Elapsed Time (min.)	Temp. (deg. C.)	Actual Reading	Corrected Reading	K	Rm	Eff. Depth	Diameter (mm.)	Percent Finer
2.00	21.0	1.0075	1.0029	0.0134	7.0	14.4	0.0359	8.4
5.00	21.0	1.0072	1.0026	0.0134	6.7	14.5	0.0228	7.6
15.00	21.0	1.0068	1.0022	0.0134	6.3	14.6	0.0132	6.4
30.00	21.0	1.0062	1.0016	0.0134	5.7	14.8	0.0094	4.7
60.00	21.0	1.0060	1.0014	0.0134	5.5	14.8	0.0066	4.1
120.00	21.0	1.0060	1.0014	0.0134	5.5	14.8	0.0047	4.1
250.00	21.5	1.0059	1.0014	0.0133	5.4	14.9	0.0032	4.0
1440.00	21.5	1.0055	1.0010	0.0133	5.0	15.0	0.0014	2.8

CEERD-GEGB

Fractional Components

Cobbles	Gravel			Sand				Fines		
	Coarse	Fine	Total	Coarse	Medium	Fine	Total	Silt	Clay	Total
0.0	0.0	0.0	0.0	0.0	0.0	79.9	79.9	16.0	4.1	20.1

D_5	D_{10}	D_{15}	D_{20}	D_{30}	D_{40}	D_{50}	D_{60}	D_{80}	D_{85}	D_{90}	D_{95}
0.0101	0.0497	0.0650	0.0747	0.0897	0.1016	0.1120	0.1221	0.1462	0.1547	0.1663	0.1845

Fineness Modulus	C_u	C_c
0.18	2.46	1.33

CEERD-GEGB

LIQUID LIMIT, PLASTIC LIMIT, AND PLASTICITY INDEX OF SOILS

ASTM D 4318

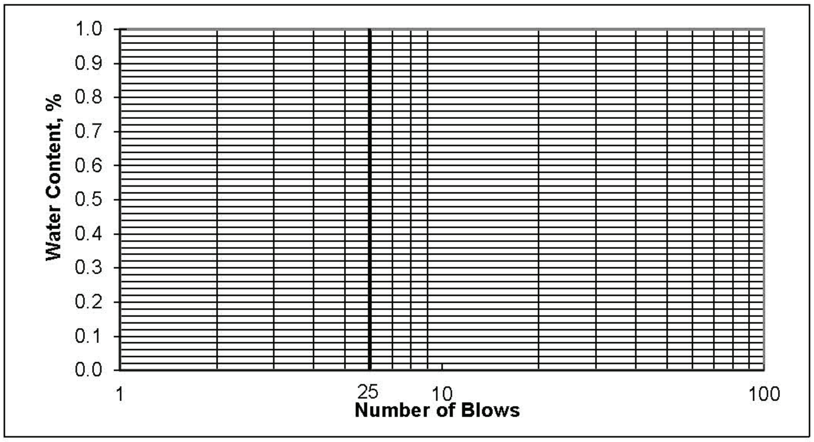
WORK ORDER NO. MD2815 DATE 10/26/2015

PROJECT Kaskaskia CPT

BORING NO. SB-C01 SAMPLE NO. 11.5-13

LIQUID LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Number of Blows							



LL
PL
PI

Symbol from plasticity chart: SM

Plastic LIMIT

Run No.	1	2	3	4	5	6	7
Tare No.							
Tare Plus Wet Soil, g							
Tare Plus Dry Soil, g							
Water, g							
Tare, g							
Dry Soil, g							
Water content, %							
Plastic Limit							

Remarks Non-Plastic Silty Sand (SM), Gray

Technician AT Computed By AT Checked By TRJ

Revised 5/21/09

Appendix E: ERT Survey Results

Figure E1. Close-up of the six ERT surveys conducted in the vicinity of boil #2.

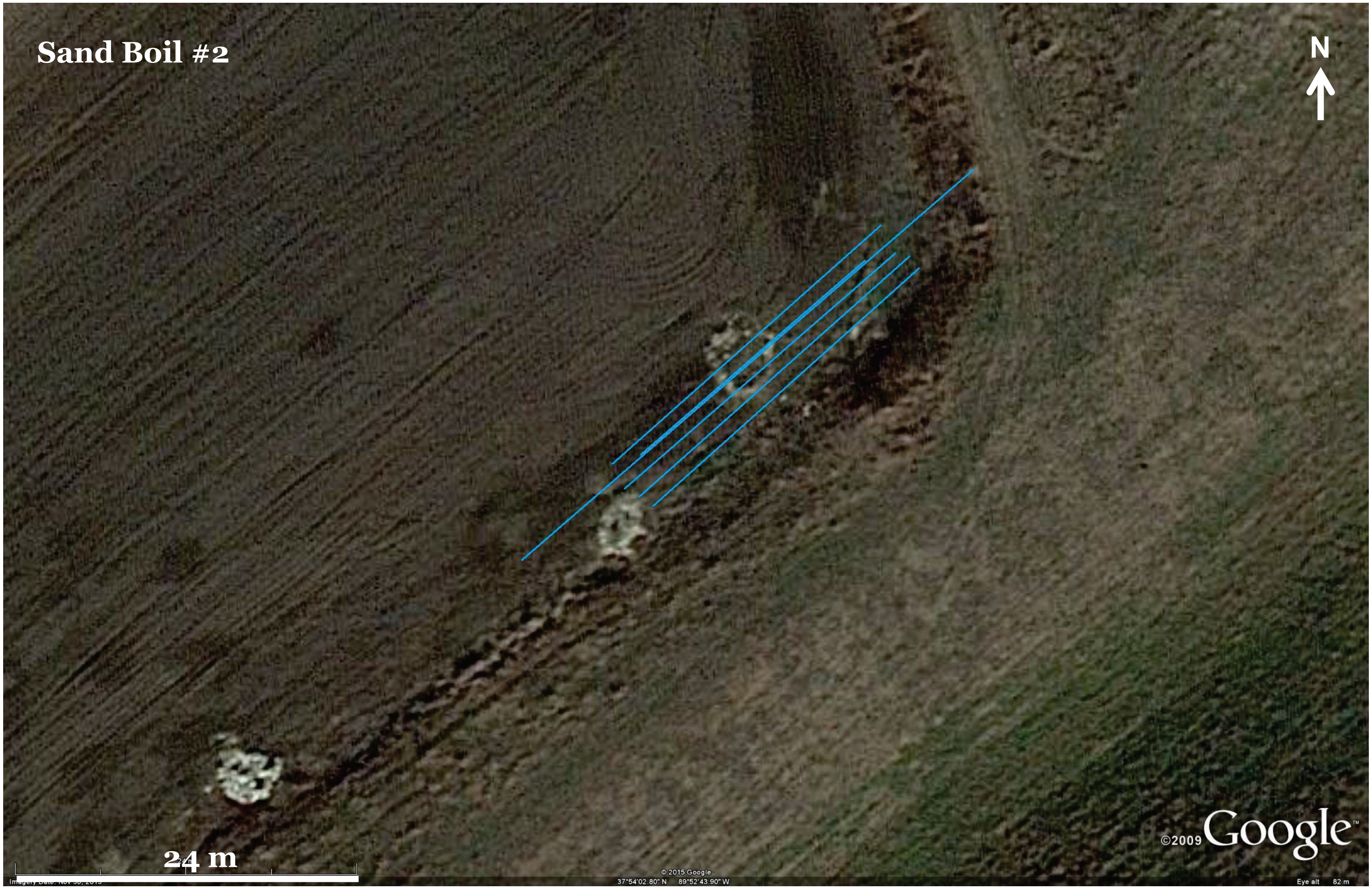


Figure E2. ERT File K1407241.

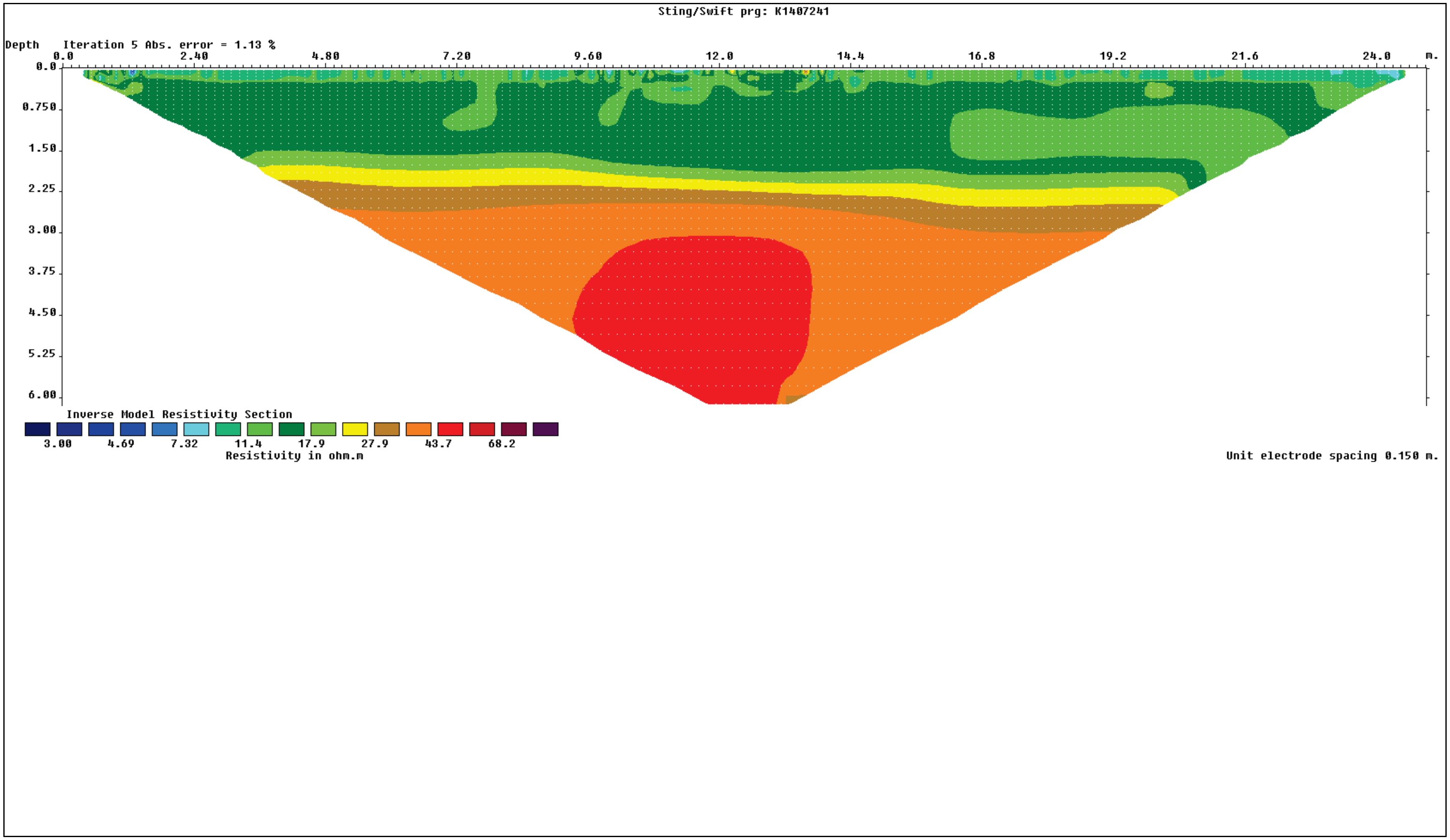


Figure E3. ERT File K1407231.

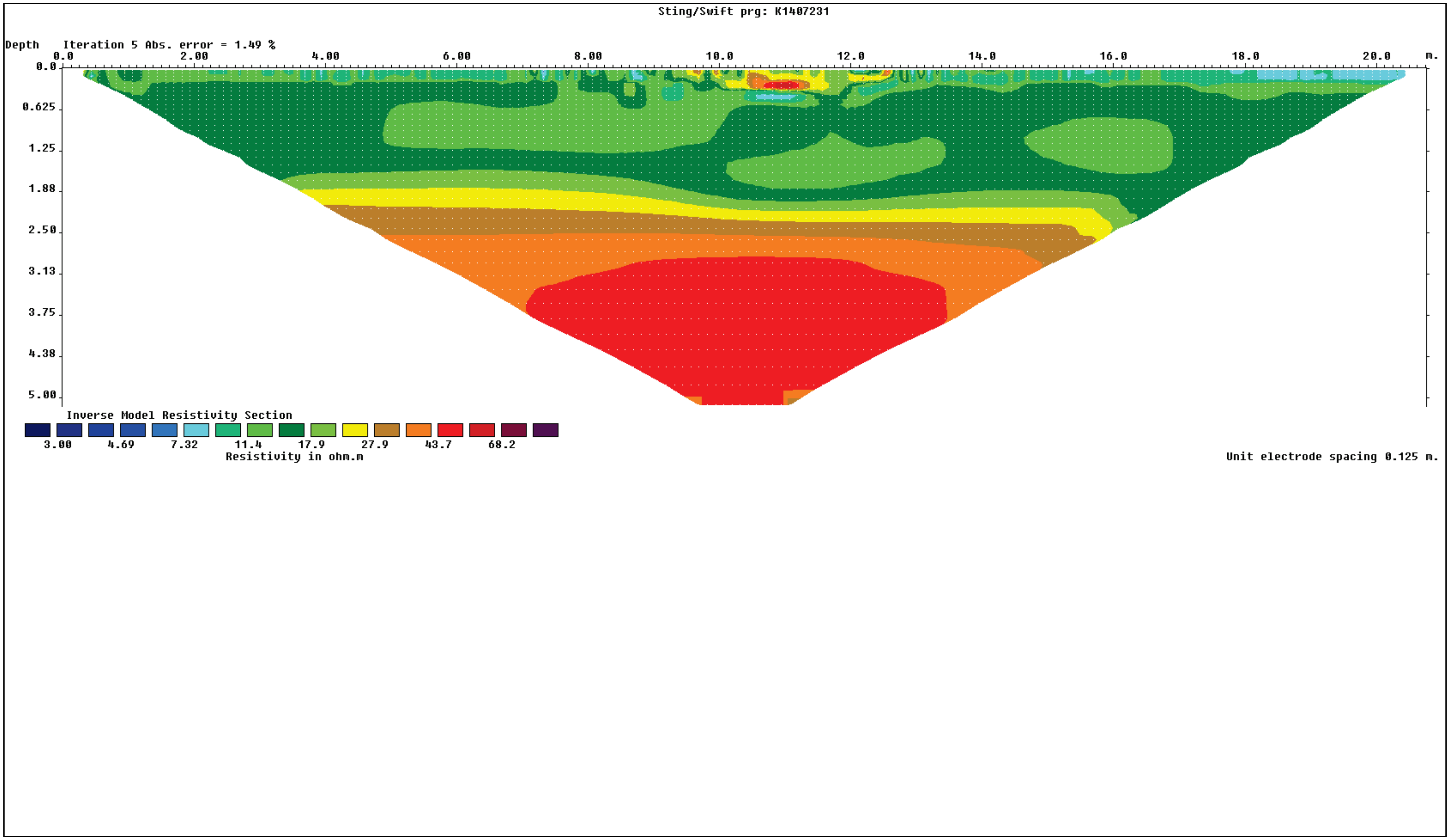


Figure E4. ERT File KA140722.

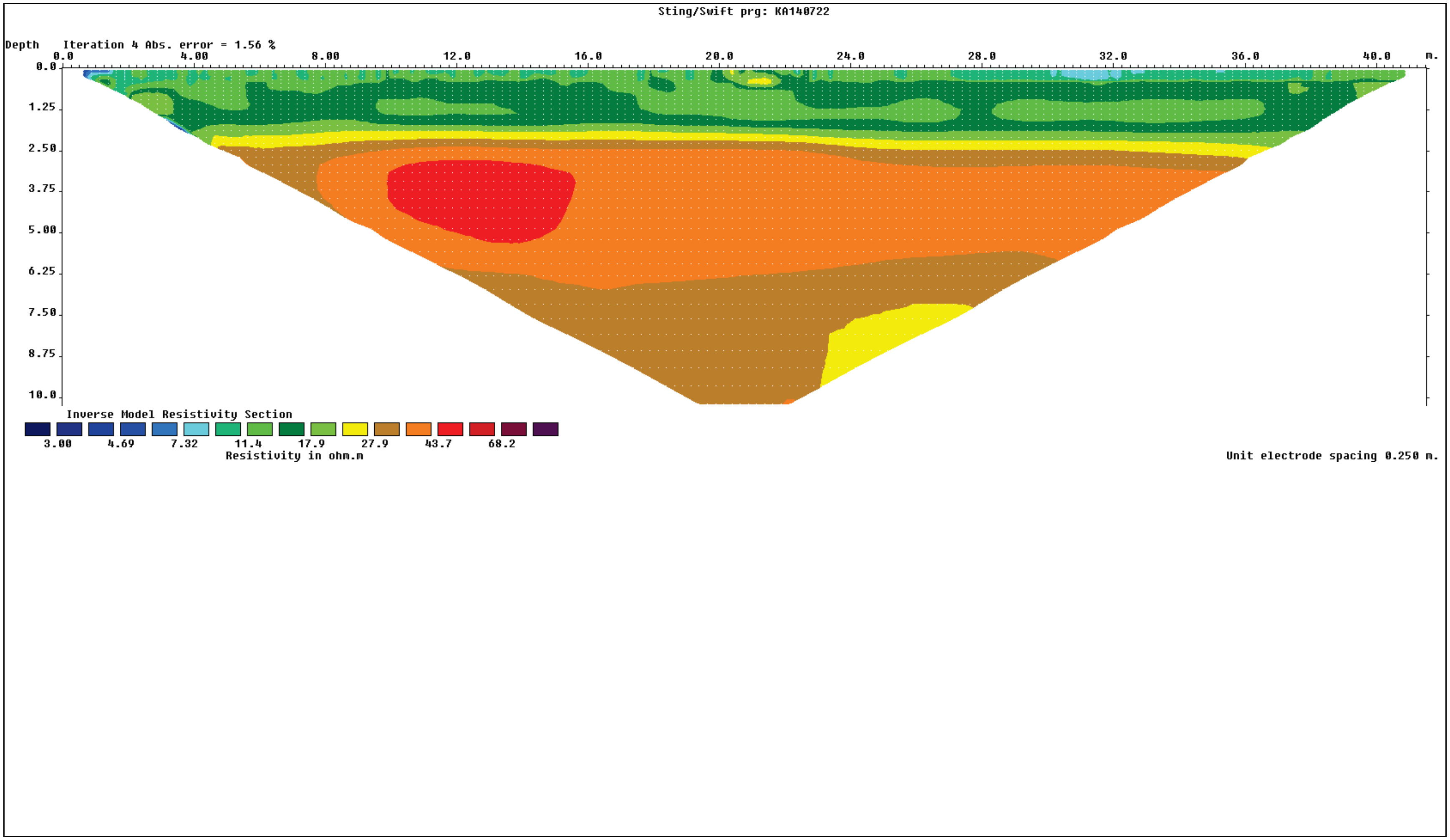


Figure E5. ERT File K1407232.

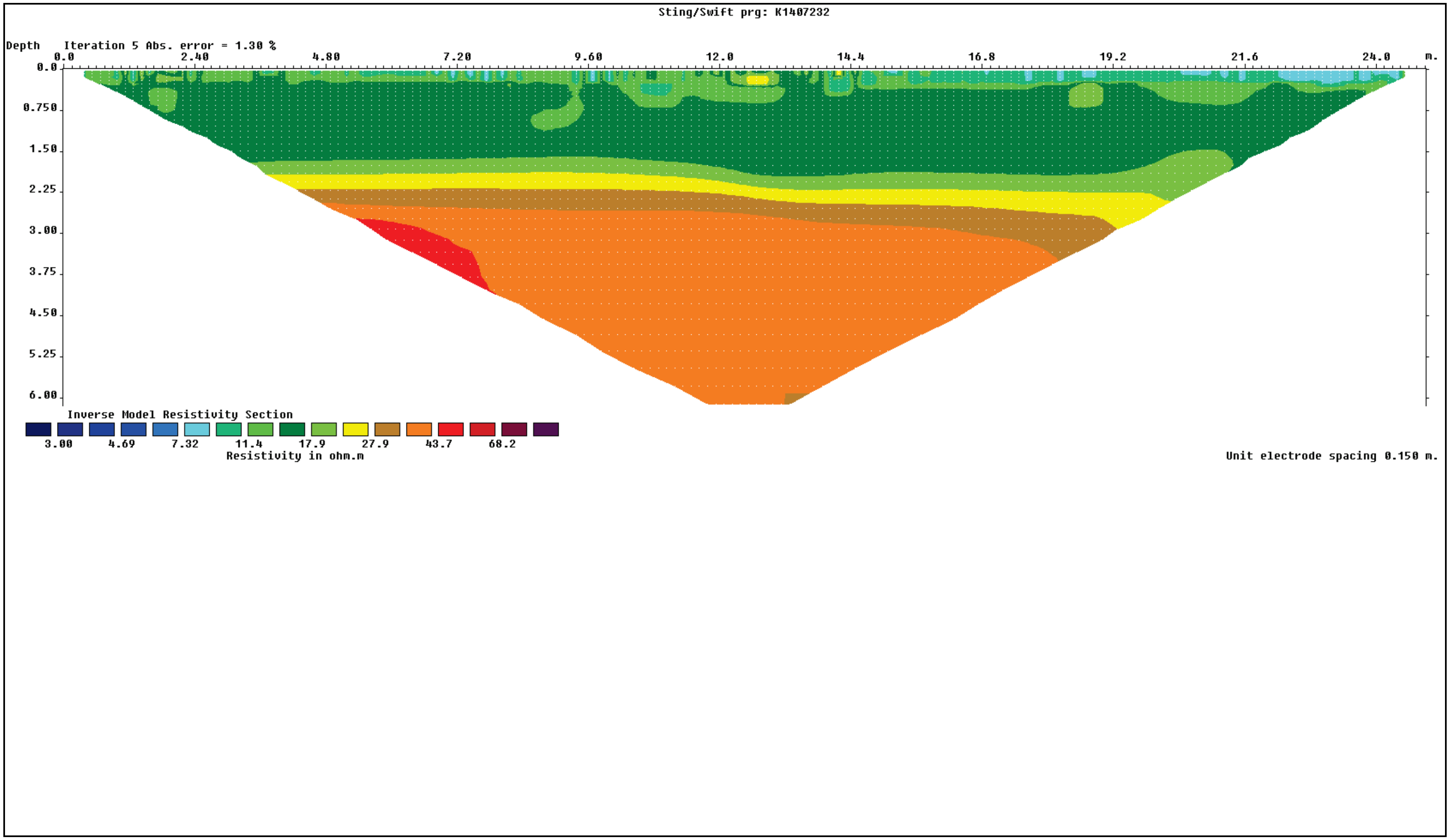


Figure E6. ERT File K1407242.

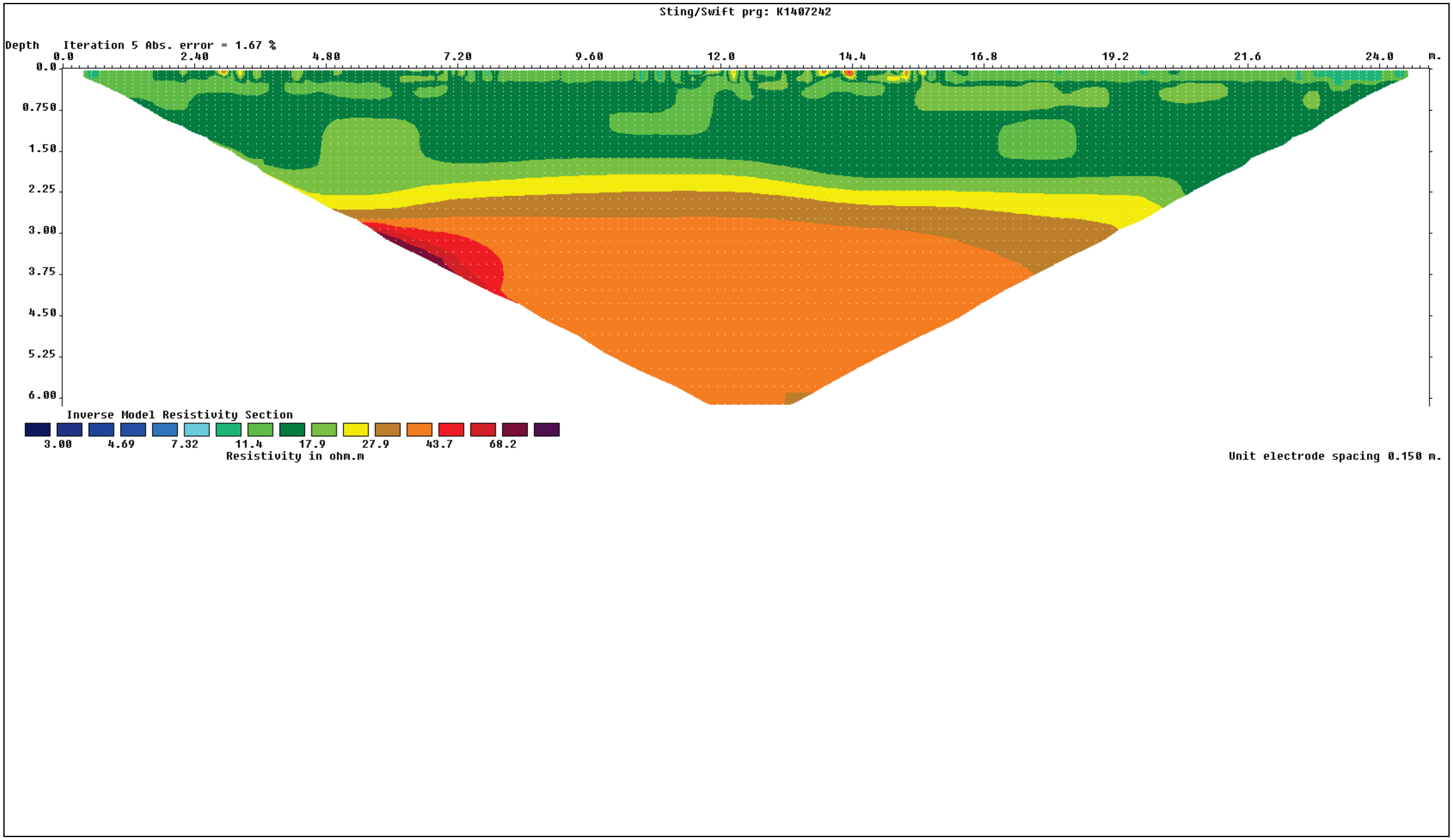


Figure E7. ERT File K1407243.

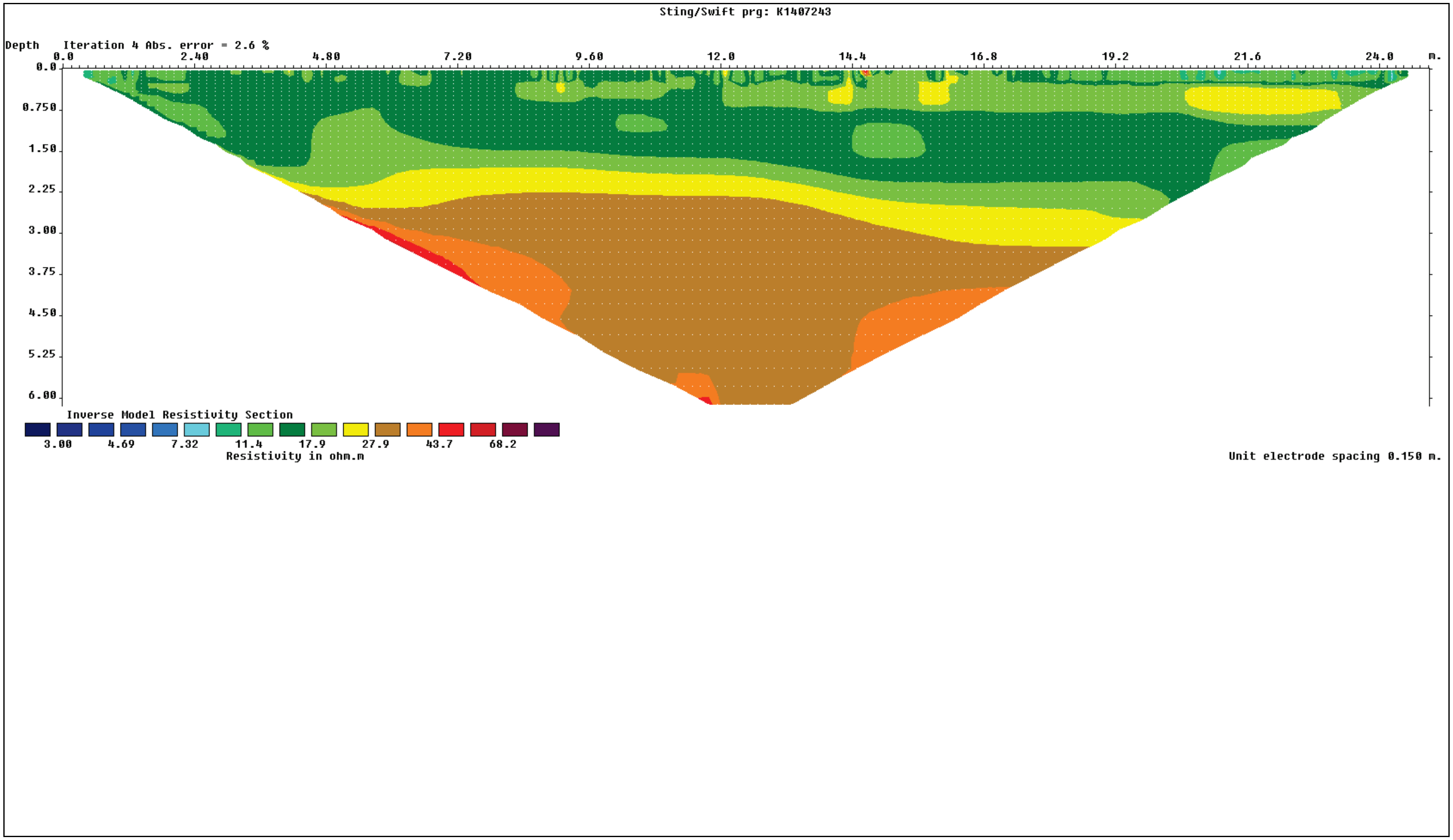


Figure E8. Close-up of the four ERT surveys conducted in the vicinity of boil #3.

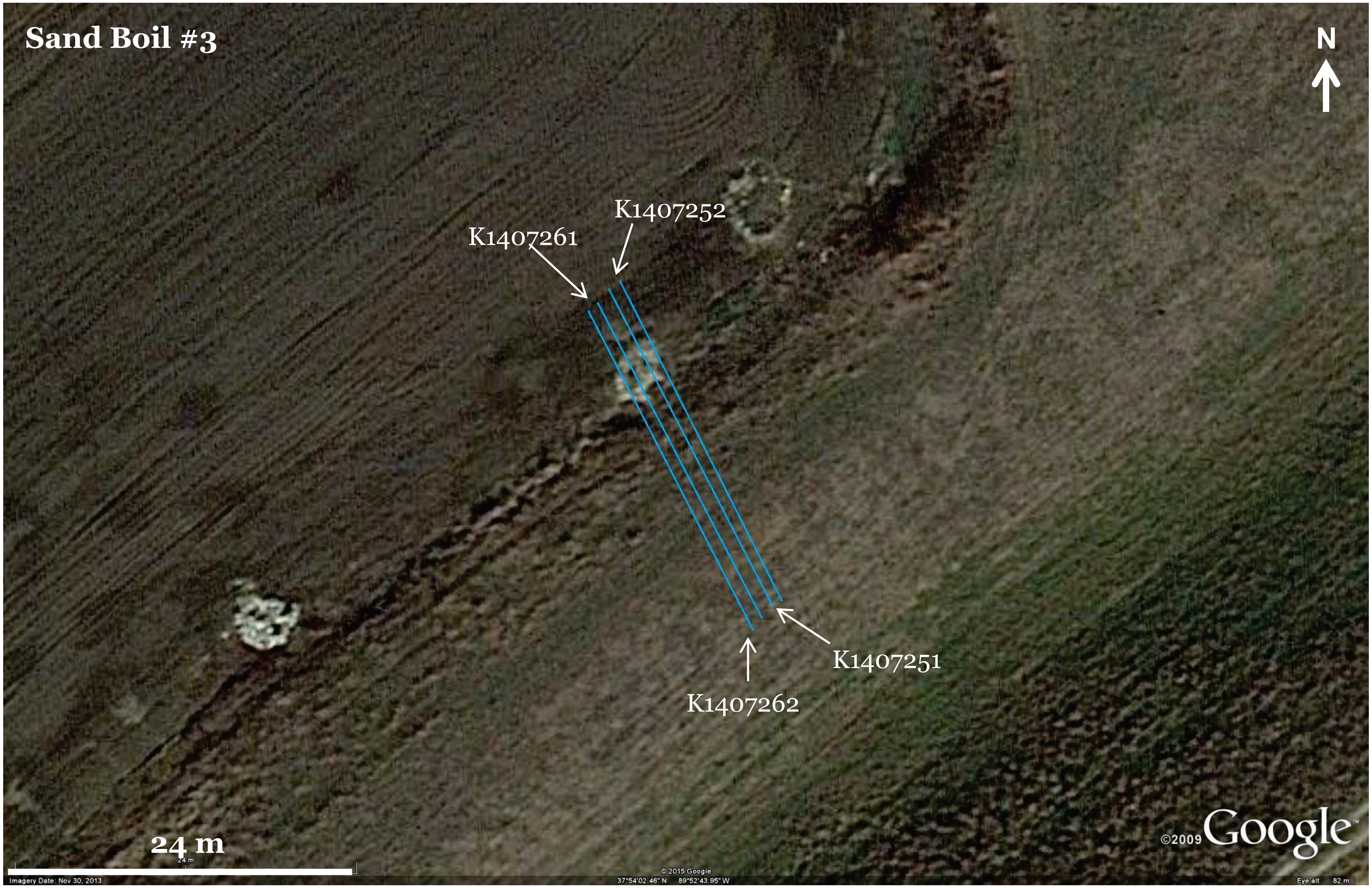


Figure E9. ERT File K1407262.

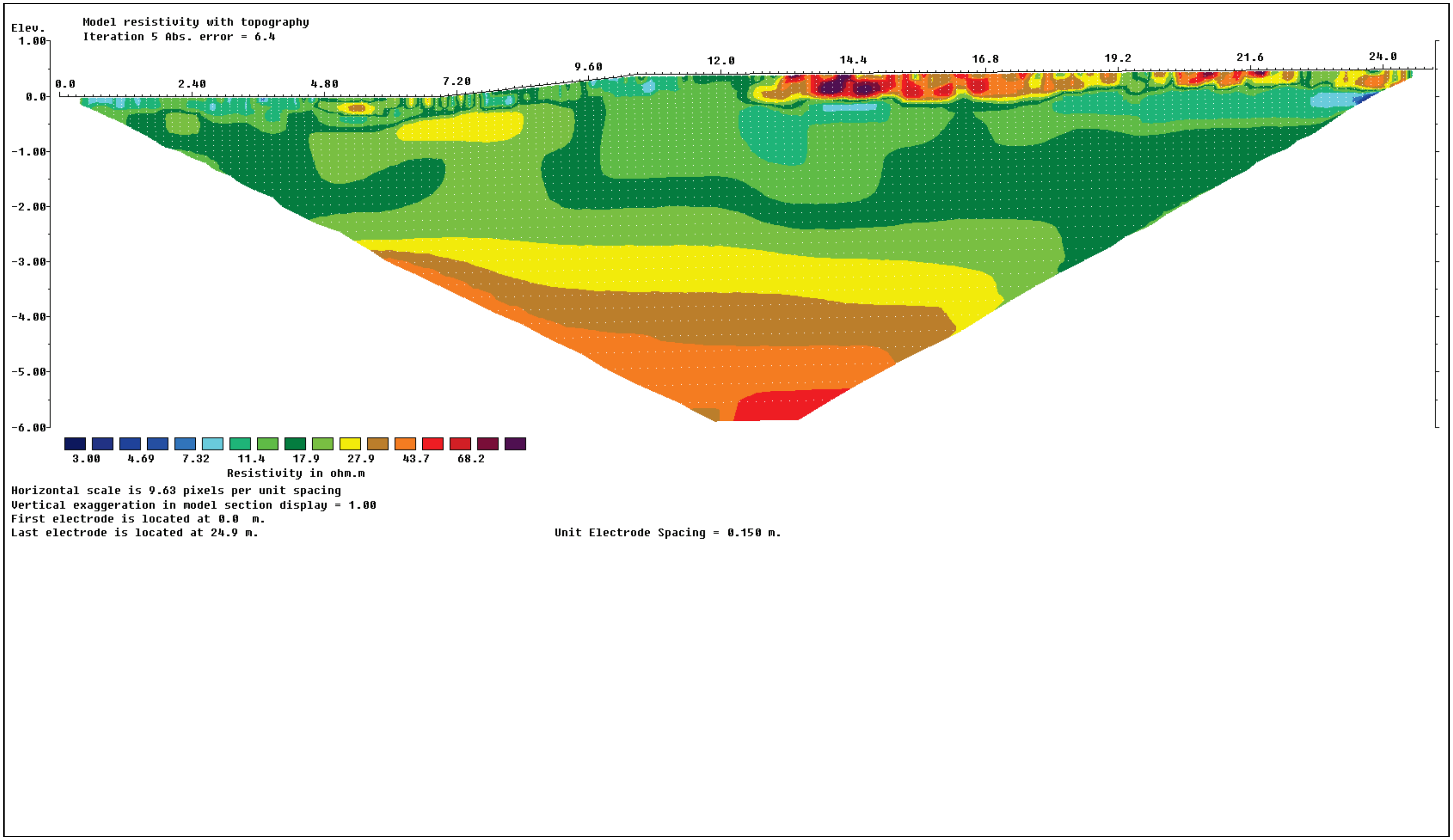


Figure E10. ERT File K1407261.

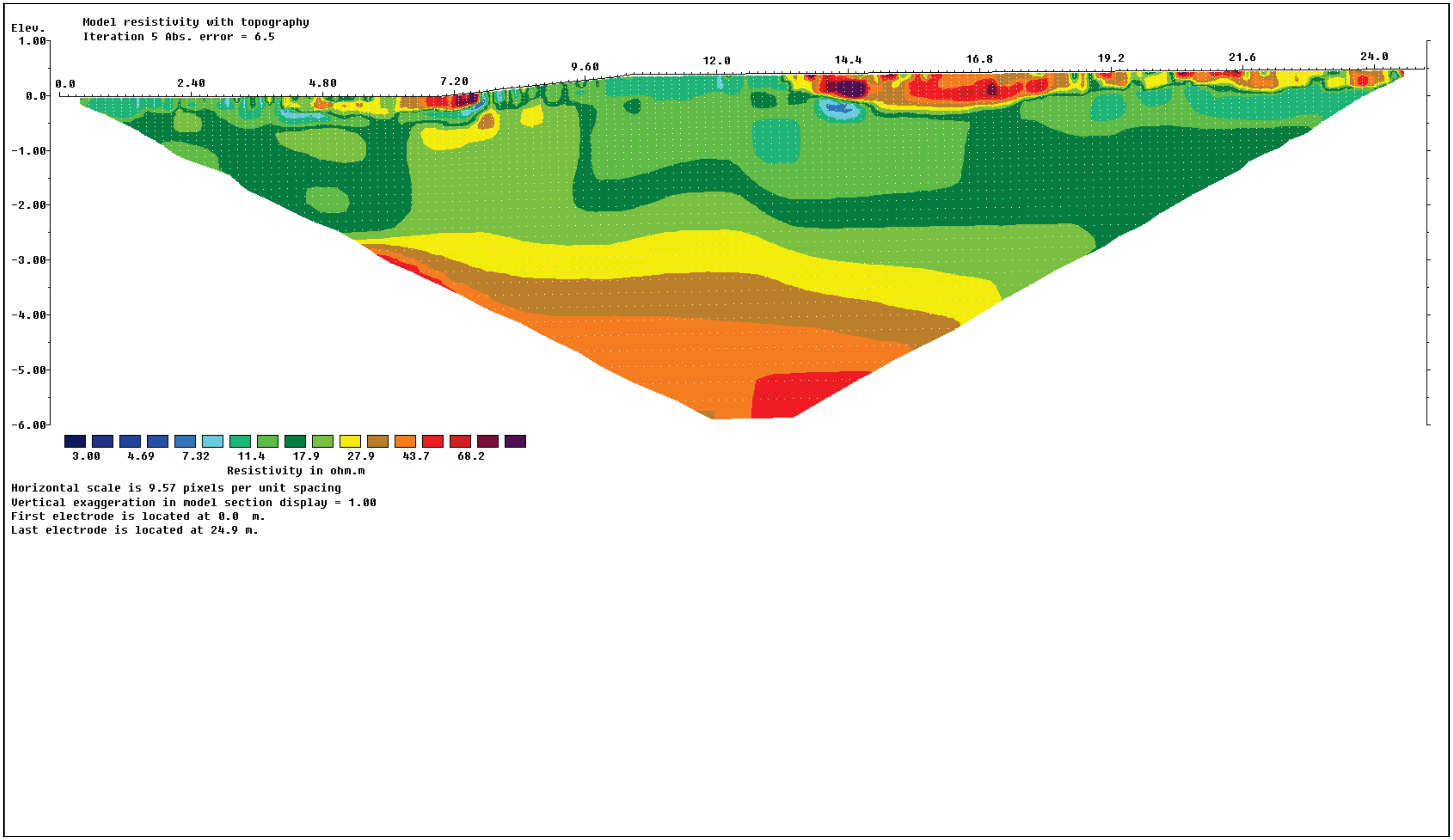


Figure E11. ERT File K1407251.

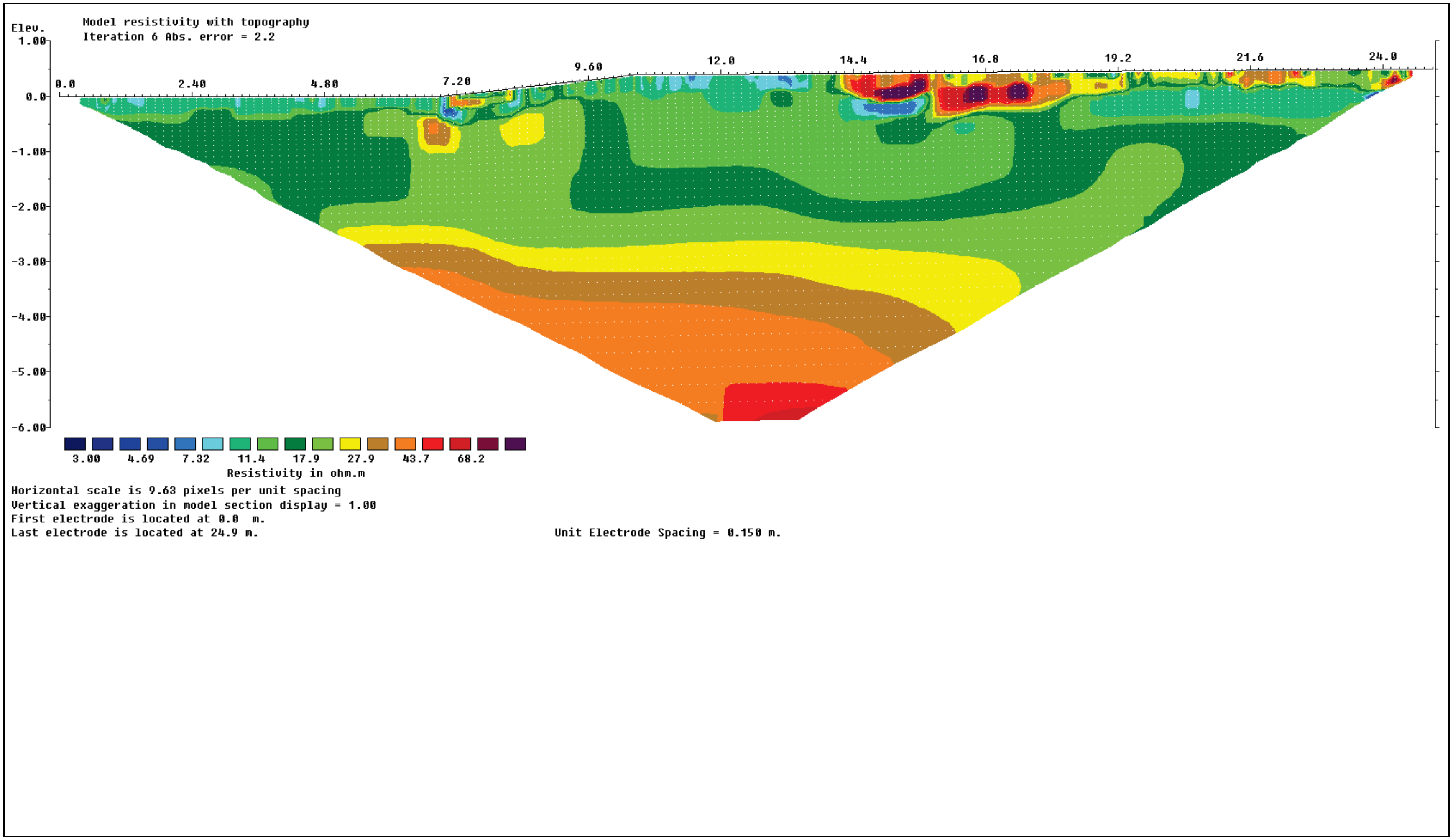


Figure E12. ERT File K1407252.

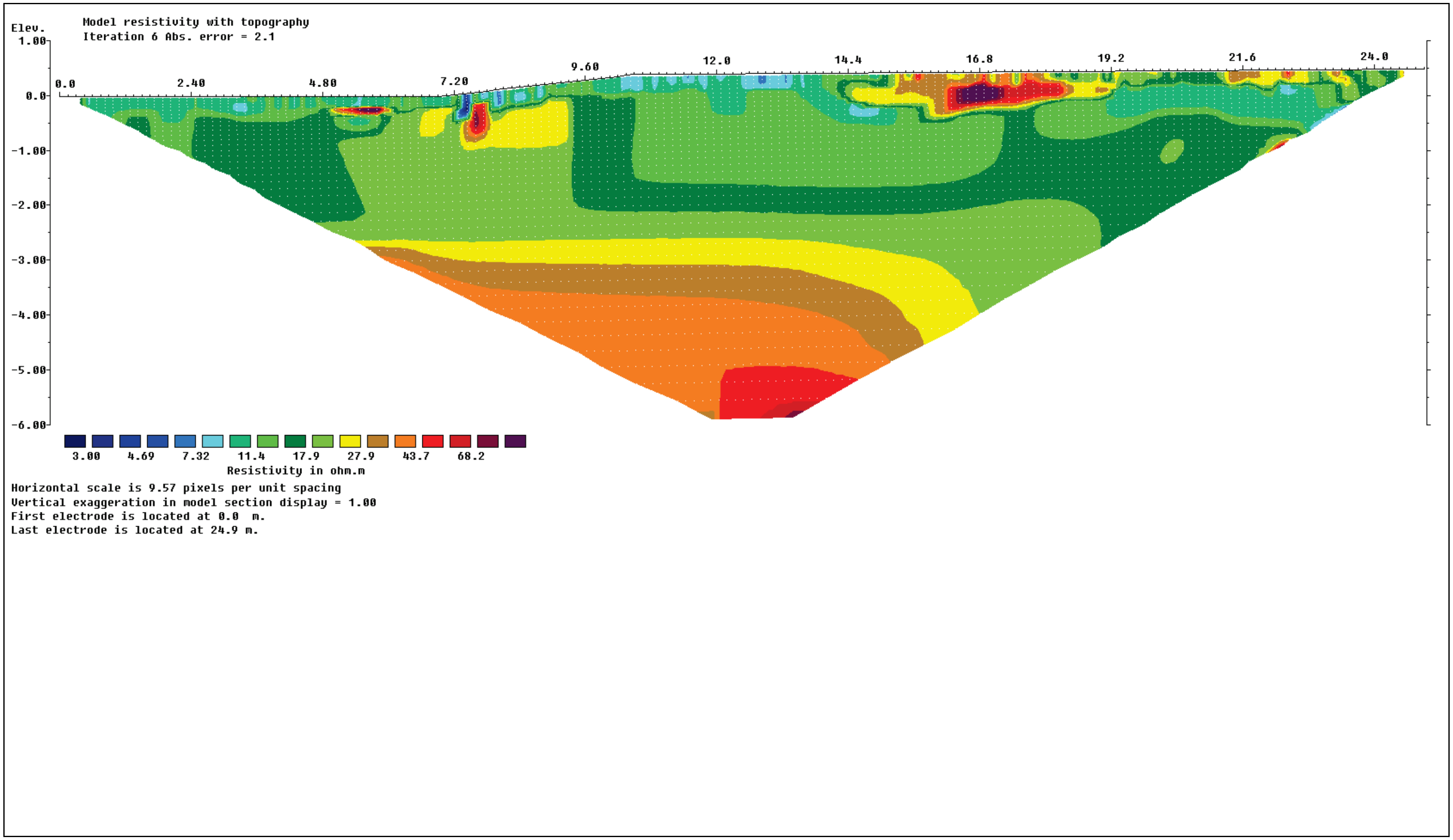


Figure E13. Close-up of the four ERT surveys conducted in the vicinity of slumping.

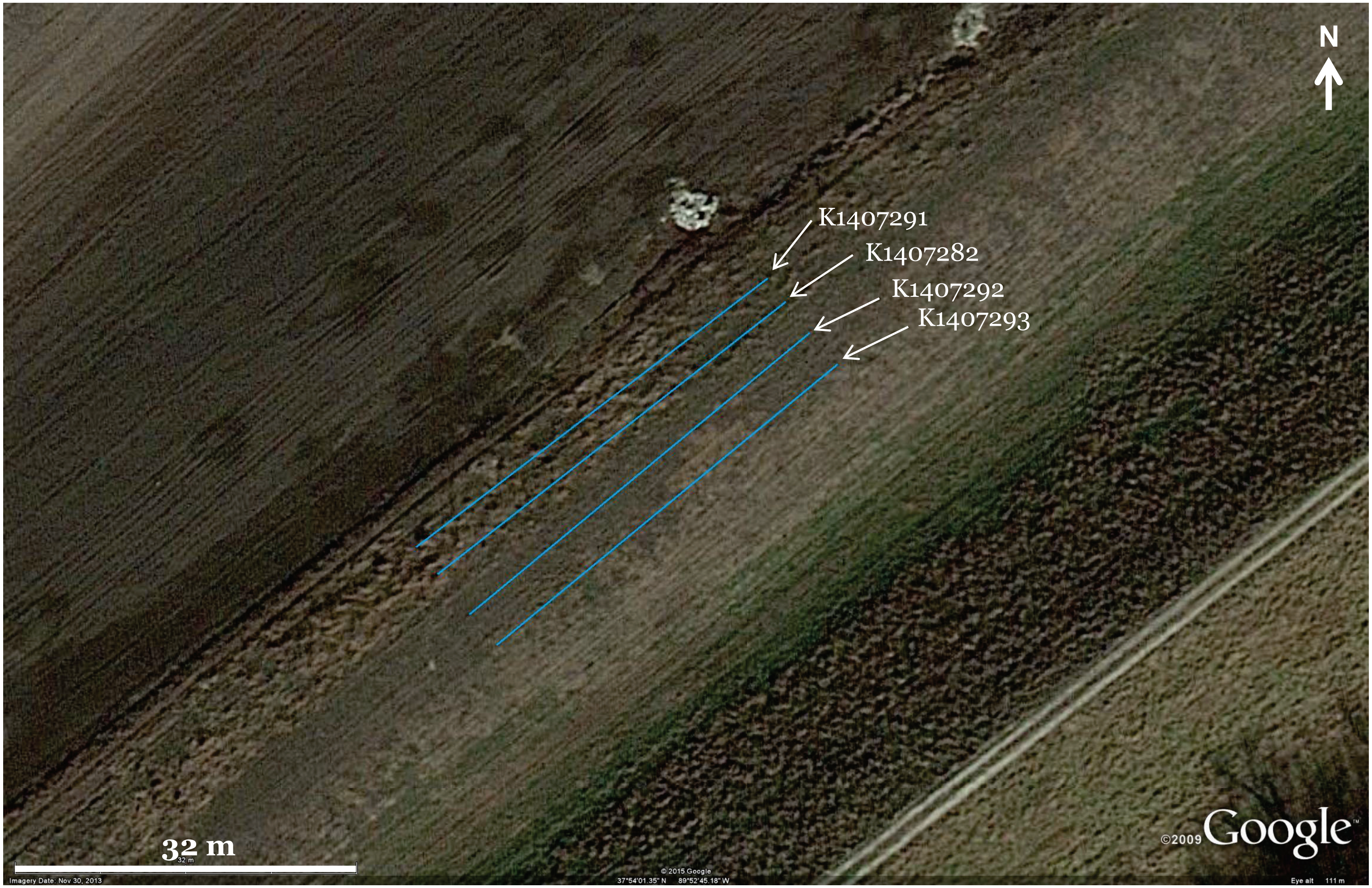


Figure E14. ERT File K1407291.

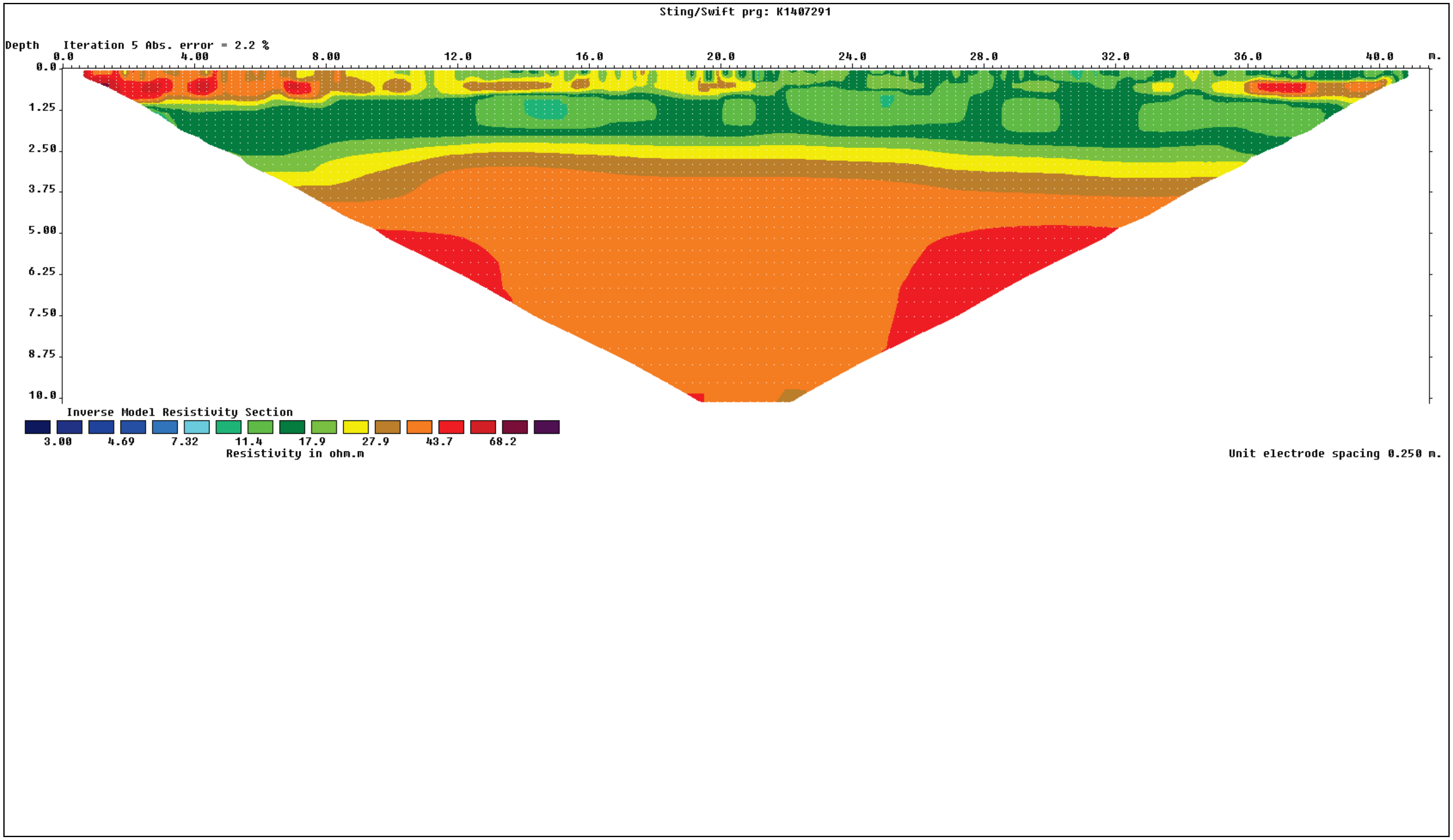


Figure E15. ERT File K1407282.

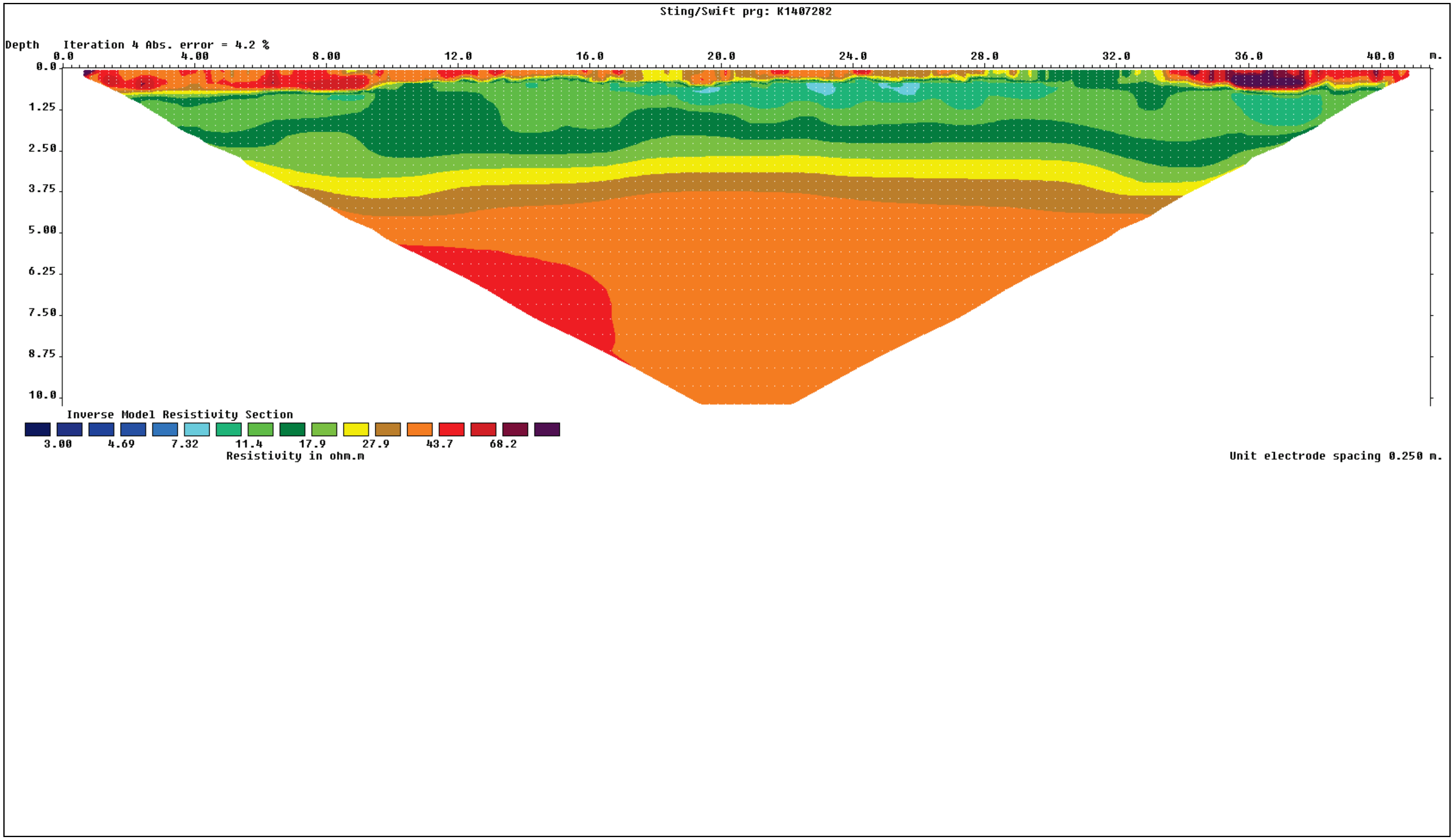


Figure E16. ERT File K1407292.

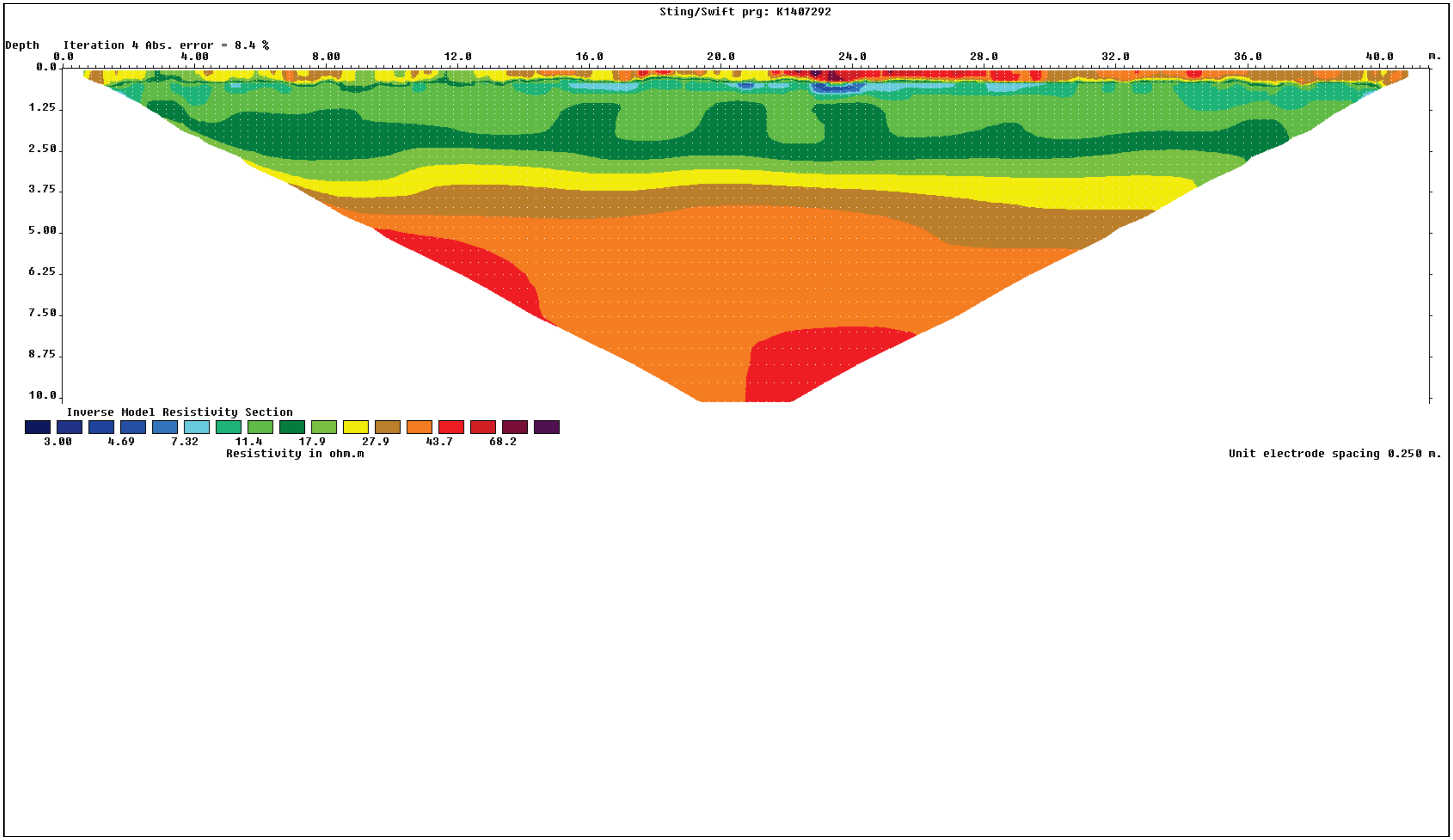
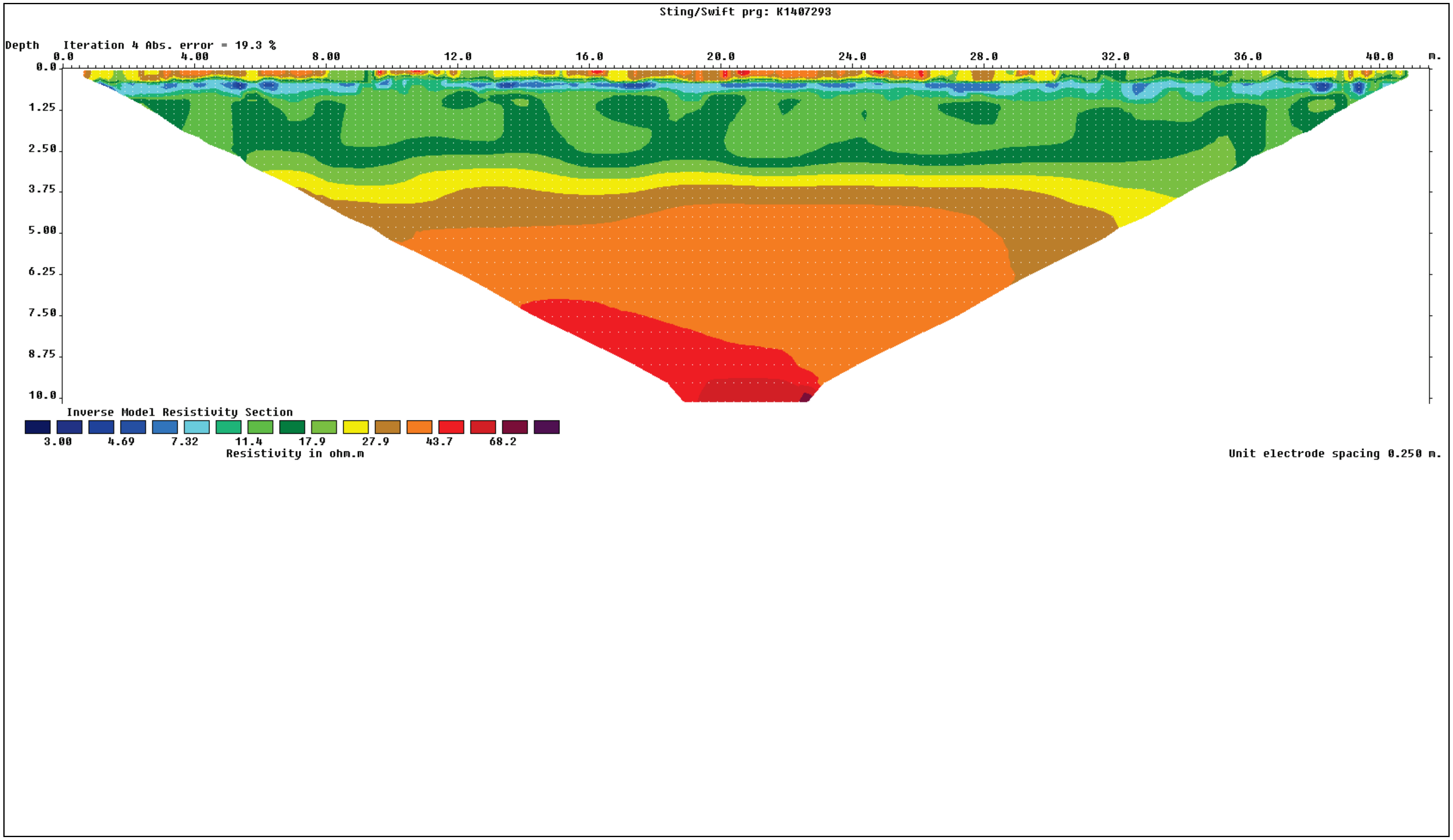


Figure E17. ERT File K1407293.



Unit Conversion Factors

Multiply	By	To Obtain
feet	0.3048	meters
inches	0.0254	meters
miles (US statute)	1,609.347	meters
miles per hour	0.44704	meters per second
mils	0.0254	millimeters
ounces (mass)	0.02834952	kilograms
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per cubic inch	2.757990 E+04	kilograms per cubic meter
pounds (mass) per square foot	4.882428	kilograms per square meter
square feet	0.09290304	square meters
square inches	6.4516 E-04	square meters
square miles	2.589998 E+06	square meters
square yards	0.8361274	square meters
yards	0.9144	meters

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)* September 2020	**2. REPORT TYPE** Final	**3. DATES COVERED *(From - To)***
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		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Julie R. Kelley, Joseph B. Dunbar, Kevin B. Parkman, Ryan C. Strange, Benjamin R. Breland, Maureen K. Corcoran, Thomas E. Berry, M. Elizabeth Lord, Erin R. Gore, and Isaac Stephens		**5d. PROJECT NUMBER** 405372
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Geotechnical and Structures Laboratory, U.S. Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199; Environmental Laboratory, U.S. Army Engineer Research and Development Center, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199		**8. PERFORMING ORGANIZATION REPORT NUMBER** ERDC TR-20-19
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Corps of Engineers, Washington, DC 20314-1000		**10. SPONSOR/MONITOR'S ACRONYM(S)** USACE
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES
Flood and Coastal Storm Damage Reduction Program (FCSDRP)

14. ABSTRACT

Mississippi River flooding in 2013 and 2016 caused severe underseepage and development of several medium to large high-energy sand boils behind the landside levee toe at Kaskaskia Island, IL. This levee system is located between St. Louis and Cape Girardeau, MO, and is part of the Kaskaskia Island Drainage and Levee District on the Middle Mississippi River. Flooding on the Mississippi River in 2013 and 2016 was below the design flowline for this levee. This report documents a case history study into the causes of seepage, piping, and sand boil development at a levee reach at Kaskaskia. Site-specific geotechnical data were collected and evaluated to determine the causes for poor performance at the studied levee reach locations. Data collected involved design documents, geologic and geotechnical borings, closely spaced cone-penetrometer tests (CPTs), electrical resistivity surveys, laboratory soil testing of sand boil ejecta, CPT samples from targeted stratigraphic horizons in the subsurface, and both piezometer and river-stage data. These data indicate sand boils present within this levee reach involved a chronic seepage condition that became progressively worse through time. This condition was directly related to the underlying site geology, namely the top stratum thickness and the depositional environment in this levee reach.

15. SUBJECT TERMS

Sand Boil	Levee	Flooding—Mississippi River
Internal Erosion	Cone Penetrometer (CPT)	Levees—Mississippi River Valley
Seepage	Electrical Resistivity Tomography (ERT)	Islands—Mississippi River
	Piping	Kaskaskia River (Ill.)
	Borings	Soils--Testing

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			**19b. TELEPHONE NUMBER *(include area code)***
Unclassified	Unclassified	Unclassified	SAR	335	