IN-DELTA STORAGE PROGRAM
STATE FEASIBILITY STUDY

RESULTS OF GEOLOGIC EXPLORATION PROGRAM

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Department of Water Resources
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In Delta Storage Program; Results of Geologic Exploration Program

INTRODUCTION

The Project Geology Section in the Division of Engineering has completed geologic exploration for potential borrow sources and integrated facility foundation evaluations on Bacon Island and Webb Tract in the San Joaquin Delta (Plate 1). These islands are being considered for surface water storage under the CALFED Bay Delta Program, In-Delta Storage Program, and the Division of Planning and Local Assistance's Integrated Storage Investigations Program. The geologic exploration work was performed pursuant to our initial meeting with you and the U.S. Bureau of Reclamation (USBR) on July 9, 2002, and modified as a result of subsequent meetings between your staff and my staff in July and August 2002. During these meetings the basic parameters for exploration were established; the foundation investigations would be to a maximum depth of about 100 feet, and the borrow exploration would be between approximately 30 and 50 feet below the surface. The borrow investigation depths were determined based on a mutually agreed upon maximum excavation depth of 25 feet.

The geologic exploration was conducted in two phases. Phase I consisted of Cone Penetrometer Test (CPT) borings ranging from about 30 to 101 feet in depth. Shallow CPT soundings of 28 to 52 feet in depth were used for the characterization of borrow areas and materials on both islands, while deeper, 85 to 101 foot deep, soundings were used in the determination of foundation conditions beneath the two integrated pump facilities proposed for each island. Phase II of the investigation consisted of drilling and sampling one 100 foot drill hole at each of the four integrated facility sites.

This report was prepared by Tim Todd, Associate Engineering Geologist, under the supervision of Brent Lamkin, Senior Engineering Geologist, in the Project Geology Section. Tim Todd also directed the field operations for the Bacon Island portion of Phase I, and all of Phase II, in conjunction with a drilling contractor and U.S. Bureau of Reclamation personnel. Personnel from your office supervised and assisted with the Webb Tract portion of the Phase I CPT work.

Environmental clearance was provided by John Roblus and Leslie Pierce of the Division of Planning and Local Assistance, and Laura Patterson from the Division of Environmental Services.

PREVIOUS INVESTIGATIONS

Several past investigations for geologic and geotechnical characterization have been conducted at both Webb Tract and Bacon Island in the last 50 years. As part of a Sacramento-San Joaquin Delta island levee evaluation, DWR drilled 42 holes on Bacon Island, and 55 holes around the perimeter of Webb Tract in 1957 and 1958 (DWR, 1958). Additional levee stability and subsidence studies were undertaken by DWR in the 1980s that included evaluation of Bacon Island and Webb Tract. In 1987, the Army Corps of Engineers conducted an evaluation of the susceptibility of Sacramento-San Joaquin Delta levees to liquefaction (COE, 1987). Unrelated to the In-Delta (Delta Wetlands) Project, DWR conducted seismic stability studies at Bacon and Webb in 1993. These studies consisted of two borings on Bacon Island and one on Webb; two of the drill holes were advanced to depths of 300 feet and geophyscially logged for shear wave velocities. After logging, the borings were backfilled with bentonite-cement grout. (DWR, 1994).

Harding Lawson Associates conducted a study of the Delta Wetlands Project in 1988 and 1989 that involved a number of CPT and drilled borings on Bacon and Bouldin Islands, and on Webb and Holland Tracts (HLA, 1989). The HLA study included 8 Standard Penetration Test (SPT) and 21 CPT soundings at Bacon, and 7 SPT, 26 CPT borings on Webb Tract. The Bureau of Reclamation and DWR conducted geologic exploration in 2001 for the purpose of determining the feasibility of constructing the In-Delta Storage Program. The USBR drilled eight CPT soundings along the perimeter of each island in May 2001 (USBR, 2001). To supplement the CPT data, DWR drilled four soil borings at Webb Tract, and five at Bacon Island (DWR, 2001).

As part of any additional geologic investigation, we recommend that a map be compiled showing all completed exploration to date for both islands. An updated version of the map the USBR produced for the first In-Delta Consulting Board meeting (USBR, 2001) would be appropriate.

PHASE I EXPLORATION

Phase l of the In-Delta Geologic Exploration Program consisted of advancing CPT soundings between August 26 and September 3, 2002. As shown on Plate 2, 13 CPT holes were advanced on Bacon Island (Sheet 1) and 17 at Webb Tract (Sheet 2). The holes ranged in depth from 28 to 101 feet. The U. S. Bureau of Reclamation, Denver Service Center, provided the CPT rig and Operator and performed the CPT soundings using DWR personnel as CPT rig Helpers. The CPT work performed at the Bacon Island and Webb Tract sites used a 10 ton subtraction piezocone, manufactured by Hogentogler, Inc., to obtain continuous readings. The CPT testing was conducted in accordance with USBR test procedure 7021, and ASTM Standard D 5778. Upon completion of all CPT soundings supervised by Project Geology personnel, the CPT holes were backfilled with bentonite-cement grout using a tremie pipe and pump.

Cone penetrometer testing was performed for both borrow area characterization and integrated pump facility foundation studies on both islands. The two integrated pump facility sites on each island were characterized by two 96 to 101 foot CPT soundings at each of the Bacon Island locations, and three 85 to 100 foot soundings each at the Webb Tract sites, for a total of four and six deep CPT holes, respectively. Shallow, 30 to 50 foot deep CPT soundings were using to characterize sources of borrow and excavation characteristics for use in levee construction as part of the proposed reservoir project. The shallow CPT locations were limited to areas outside of environmental and cultural exclusion zones, and by physical access. All of the borrow study CPT holes were located along the edge of farm roads and tracks. Borrow areas were characterized using nine CPT soundings on Bacon Island, and eleven for Webb Tract.

The CPT data was recorded in the field and transmitted to the USBR office in Denver for processing. A field copy of the data was also given to you by the CPT rig Operator on September 3, 2002, at the conclusion of the field work. The USBR's Jeff Farrar (Earth Sciences and Research Laboratory) processed the data using CPTINTR1, V3.0, a computer program developed by the University of British Columbia that interprets CPT data (Grieg, 1986). Processing the CPT tip resistance and sleeve friction data using the CPTINTR1 program, Mr. Farrar determined a geologic log of Robertson's (1990) soil behavior types and basic engineering parameters, including undrained strength, SPT blow count equivalent, friction angle, and relative density, for soils at each sounding location (Appendix A). Additional CPT data processing has been conducted by DOE's Dams and Canals Section, and will be transmitted separately.

PHASE II EXPLORATION

The second phase (Phase ll) of field work consisted of drilling exploration holes to provide data on the foundation conditions for the proposed integrated pump facilities. Drilling operations commenced September 24, 2002, and were completed on October 3, 2002. Originally, shallow soil borings were to be used with the CPT data to further characterize potential borrow sources and delineate their extent. However, budgetary constraints only allowed for one boring at each proposed integrated facility for foundation evaluations, with no borings to confirm the borrow study CPT data.

Four drill holes were drilled to a depth of approximately 85 to 101 feet bgs in the area of the proposed pump facilities at each island (Plate 2). These holes were drilled to define the subsurface conditions beneath the proposed structures, in conjunction with the CPT holes, on the northeast and southeast corners of Bacon Island and Webb Tract. Project Geology's Northern California Drilling Contractor, Layne Christensen of Fontana, California, performed the drilling using a CME 750, all-terrain, drill rig. The four facility borings were drilled using a combination of hollow-stem auger and rotary wash methods. While hole BIS-1 on Bacon Island was initially drilled from 0 to 10 with 8.25-inch O.D. hollow-stem augers, the rest of the hole, and the remaining three foundation investigation borings were drilled using a 4.5- inch, side-discharge, drag bit and Nx drill rod. The drilling fluid used for circulation consisted of high-yield bentonite clay mixed with water. Upon completion of the drill holes, they were backfilled with bentonite-cement grout using a tremie pipe and Moyno pump. Drill cuttings and mud were disposed of on-site at the direction of the geologist, and pursuant to the conditions of the environmental clearance granted by Leslie Pierce, of your staff.

Each boring was geologically logged and sampled by Mr. Todd. Soil types encountered and sampled in each boring were classified pursuant to ASTM Standards D-2487 and D-2488, and recorded on a geologic log. Logs for the four facility bore holes are located in Appendix B. Soil samples were collected from each boring at five-foot intervals below 30 feet in depth, and at 10-foot intervals from 30 to 100 feet. At each sample interval a 3.0-inch I.D. by 30-inch thin-walled Shelby tube sample was pushed, with the downward force recorded for each interval. The Shelby tube samples were then trimmed, capped, and labeled for transport to the DWR Soils Laboratory in West Sacramento. Immediately following the Shelby tube sample collection, a 1.38-inch inside diameter Standard Penetration Test sample barrel was driven 18 inches using a CME automatic hammer (140 lb.) set at 50-55 blows per minute with a 30-inch drop pursuant to ASTM D-1586 and D-6066. Uncorrected SPT

"N" values are reported on the geologic logs for each samples interval. Samples collected from the SPT sample barrel were bagged after field classification and retained for laboratory testing. The soil samples will be tested by the DWR soils lab, with the results reported under separate cover.

Drilling went smoothly at all sites but one. Drill hole BIS-1, at the Bacon Island Pump Station 1 site, was the initial boring and experienced the most difficulty during drilling. Lost circulation and caving/sanding-in problems, along with flowing artesian conditions and generally weak soils were encountered during drilling. Water welled up and flowed out of the drill hole after the boring advanced below 53 feet bgs, and sat overnight. The flowing groundwater conditions encountered were controlled by advancing conductor casing to 35 feet bgs, thickening the drilling mud, and pumping that drill mud into the boring under pressure while drilling. The borehole also exhibited sloughing, sanding in the drill stem, between approximately 30 to 50 feet bgs. Zones of lost fluid circulation were encountered intermittently between 30 and 40 feet, at about 63 feet, and between 75 to 90 feet bgs. Drill fluid circulation was restored by thickening the drilling mud by adding powdered bentonite.

After completion of the Phase I and Phase II field work, the CPT and bore-hole logs were compiled and used to develop geologic cross sections (Plate 3) and isopach maps (Plate 4) showing the thickness of soft and/or organic soils overlying potential borrow materials.

GEOLOGIC CONDITIONS

The project area lies within the central/south-central portion of the Sacramento-San Joaquin Delta. Surficial geology of Bacon Island was reported by Atwater (1982) and Wagner, et al (1990) as Late Quaternary intertidal deposits of soft mud and peat. Webb Tract was also mapped by Atwater (1982) and Wagner, et al (1981) primarily as peat and soft mud originally deposited in marshes, swamps, and adjacent waterways; extensive eolian deposits of the Upper Modesto Formation have also been mapped by Atwater (1982) on the west side of Webb Tract. The eolian sand deposits of Webb tract look like sand dunes, and have been tentatively identified as "Piper Soils" that have been associated with potential archaeological resources. Surface elevations of both islands are typically 10 to 20 feet below sea level. Groundwater elevations below both islands are artificially maintained at or near the surface by a series of pumps and drainage ditches. Natural groundwater levels would be expected to be near sea level.

Generally, most of the exploration holes indicate a stronger, more cohesive, "surface crust" material typically two to five feet thick overlying soft and/or organic soils. Inorganic clays, silts, and silty sand lie beneath the weaker, soft and/or organic layer. The crust consists of clay or silty sand surface soils that has been compacted by farm equipment and/or consolidated naturally since the island was reclaimed. Typical CPT cone tip resistance readings of about 10 to 50 tons per square foot (tsf) defined the surface crust. This crust is thickest over levees and roadways, and thinnest over the open fields. The organic and/or soft soil layer typically consists of organic clay, peaty organic soils, lean and fat clay, silt, and even some silty sand. Peat was also identified beneath the islands in previous exploration conducted by DWR (2001) and USBR (2001). While the organic and/or soft soils are not always organic, they are typically soft, or loose, saturated, and exhibit low SPT N values or low cone tip resistance and sleeve friction, typically less than 10 tsf and 0.20 tsf, respectively. The lower, inorganic soil unit is comprised of lean and fat clay, silt, and silty sand. Drill hole and CPT exploration conducted by DWR and USBR in 2001 also found poorly graded sand beneath both island levees. The inorganic soil unit is typically fine-grained, moist to saturated, and exhibits cone tip resistance values between about 10 and 400 tsf, or SPT N values of about 15 or greater. The previous DWR and USBR investigations indicated that the top of the inorganic soil layer typically consists of sand or silty sand underlain by lean clay. It should be noted that no soil samples were collected at the CPT sounding locations, and soil types or groupings were determined from indirect methods.

BACON ISLAND

The near-surface geology of Bacon Island consists primarily of soft, moist to wet, organic soils overlying stiff clays, silty sands, and silts comprising the underlying, deeper, inorganic soils. The surface crust and organic and/or soft soils range in thickness from about 0 to 28 feet. The geologic conditions at Bacon Island were characterized primarily using cone penetrometer and borehole data. Cone penetrometer data was used exclusively to determine the excavation depth to potential borrow material, while a combination of CPT and borehole data were used for the foundation investigations at each of the proposed integrated pump facilities.

The CPT data was used to group the near-surface geology of Bacon Island into three units: the surface crust described above, an intermediate layer of soft and/or organic soils, and a deeper inorganic soils unit. Soils identified in the two pumping plant boreholes were grouped as either Organic Soils or Inorganic Soils.

Borrow Study

A preliminary borrow study at Bacon Island was undertaken to determine the depth to the top of inorganic soils that could potentially be used for construction of buttressed levees. Nine CPT soundings were advanced between 31 and 52 feet below ground surface to determine the thickness of overburden soils that would have to be removed to reach granular, borrow soils (Plate 2, Sheet 1). Plate 3, Sheet 1, is a geologic cross section through the island compiled from one borehole and eight CPT logs. The section, A-A, shows the subsurface divided into three units: Surface Crust Soils (Cr), Organic and Soft Soils (Oss), and Inorganic Soils (Ios). Section A-A displays CPT data showing that there is between approximately 9 to 28 feet of surface crust and organic and/or soft soils overlying the inorganic soils that may be used as potential borrow material. However, boring BIS-2, adjacent to CPT sounding BSC-12, encountered no organic soils. The section also shows that the crust and soft soils are thickest along the eastern portion of the island, and shallowest in the north-central area. However, the CPT sounding data has been projected up to 1,500 feet at Cross Section A-A, and may not reflect the actual depths of the individual soil units directly beneath the section.

The data from the most recent CPT soundings was combined with CPT data from the 2001 USBR study, and used to produce a contour map of soft soils overlying the inorganic soils. Plate 4, Sheet 1, is an isopach map of Bacon Island showing the contoured thickness of surface crust soils, peat, organic, and soft clays overlying a laterally extensive bed of silty sand that may be used as borrow. U.S. Bureau of Reclamation CPT data gathered in 2001, and as part of this 2002 study, was used to produce the isopach map that shows the estimated excavation depth to reach potential borrow material. The map on Plate 4 shows that the excavation depth to potential borrow material is shallowest along the north-south axial center of the island, at roughly 10 feet. The thickness of the peat and soft clay overburden increases along the outside edge of the island, to a maximum of about 28 feet at the Pump Station 1 site (Plate 3).

Foundation Studies, Integrated Pump Facilities

Two integrated pump facility locations on Bacon Island were investigated as part of this study, Pump Station 1, located at northeast corner of the island, and Pump Station 2, at the southeast corner. Two CPT holes and one drilled boring were advanced and sampled to characterize the foundation conditions at each pump facility site; the borings and CPT soundings were advanced to a depth of 99 to 101 feet bgs at each site. Soil samples were collected from the drilled borings for

laboratory testing. The soil sample test results will be reported separately by DOE Dams and Canals Section personnel.

The geologic conditions at the Bacon Island Pump Station 1 site consist of very soft organic silt, peaty organic, and fat and lean clay surficial soils to a depth of about 15 to 22 feet below ground surface (bgs). Firmer layers of inorganic silty sand, silt, and clay are found below the soft and/or organic surface soils to a depth of at least 100 feet bgs. A thin surface crust was detected overlying the soft and/or organic soils. Groundwater was measured at 0.4 feet bgs, while seeps and moist soil were observed at the ground surface.

Data from CPT holes BSC-1 and BSC-2 show a surface crust 1 to 2 feet thick overlying very weak, soft and/or organic soils extending from 1 to 1 feet bgs to approximately 15 to 22 feet bgs at the Pump Station 1 site. These soils have been labeled as sensitive fine-grained, clay, silty clay, and organic materials using Robertson's (1990) soil behavior classification. Underlying the weak soils are cohesive, inorganic, fine-grained clay and silt, and granular silty sand and sand soil behavior types. Surface crust soils displayed cone tip resistance values from 3.01 to 14.09 tons per square foot (tsf); cone sleeve friction for the surface crust soils ranged between 0.02 and 0.44 tsf. The shallow, soft and/or organic soils exhibited cone tip resistance readings from 0.24 tsf (12', BIS-1) to 9.21tsf (21', BSC-1), and sleeve friction values between -0.01 tsf (9 TO 14', BSC-2) and 0.28 tsf (3', BSC-1). The deeper, inorganic soils indicated peak tip resistance values ranging between 12.53 tsf (40', BSC-1) to 243.03 tsf (31', BSC-2), and sleeve friction readings of 0.03 tsf (16', BSC-2) to 4.75 tsf (25', BSC-2). Appendix A contains the CPT soil behavior type logs and supporting data for each penetrometer sounding.

Boring BIS-1 was paired with CPT sounding BSC-1 for comparison and calibration. The boring shows that the soils at the Bacon Island Pump Station 1 site consist of 16 feet of organic soils ranging from fat, organic clay to peaty organic soil. Uncorrected Standard Penetration Test blow counts for the organic soils ranged from N=0 to N=3. Inorganic soils beneath the surficial organic soils consist of lean and fat clays, silty sands, and silt. Uncorrected SPT blow counts for the inorganic soils ranged from N=5 (lean clay at 92-93.5') to N=31 (silty sand at 73-74.5'). Particularly "soft" zones were observed from 0 to 22, 40 to 43.5, 52 to 62, and 80 to 100 feet bgs, as noted from the single digit SPT "N" values and lack of hydraulic pressure needed for advancing Shelby tubes. The geologic drill logs, with lithologic and uncorrected SPT data are contained in Appendix B. It should be noted that tip resistance data from the adjacent CPT sounding showed the base of the soft and organic soil at about 22 feet bgs, corresponding to the top of a silty sand encountered in BIS-1.

The proposed site of Bacon Island Pump Station 2, located at the southeast corner of Bacon Island, contains surficial soils of about four feet of very soft clay and 15 feet of a loose to slightly compact silty sand. Firmer layers of inorganic clay and silty sand are found below the softer surface soils. Groundwater was measured at about 0.1' below the surface in drill hole BIS-2. Two CPT soundings, and one rotary drill hole were advanced and sampled at the site to a depths between 96 and 101 feet bgs.

The cone penetrometer data for Pump Station 2, as depicted in the logs for BSC-12 and BSC-13, show that a crust of stronger clayey silt or silty clay extends from the surface to about five to six feet bgs. Beneath that crust are weaker, soft soils that were classified by USBR as silty clay, clay, sensitive fine grained soil, silt, and silty sand soil behavior types between approximately 5 to 6 and 22 to 28 feet bgs. CPT data for the surface crust soils indicated tip resistance readings between 6.96 tsf (2', BSC-12) and 51.90 tsf (2', BSC-13), while sleeve friction values ranged from 0.14 tsf (5', BSC-13) to 1.73 tsf (2', BSC-13). Within the low strength, soft and/or organic, near surface soils, cone tip resistance was measured as low as 1.45 tsf (10', BSC-13), and as high as 56.47 tsf (13', BSC-12); the organic and/or soft soils exhibited sleeve friction values ranging from -0.03 tsf (12-13', BSC-13) to 0.53 tsf (23', BSC-12). The deeper, inorganic soils, beneath about 21 to 28 feet bgs showed tip resistance values ranging from 11.94 tsf (48', BSC-12) to 391.88 tsf (61', BSC-12), while sleeve friction values varied from 0.12 tsf (24', BSC-13) to 6.34 tsf (61', BSC-12). With the exception of a few thin clay layers, these soils were generally characterized as silt, silty sand, sand, and gravelly sand soil behavior types when the data was processed by the USBR.

The borehole log for BIS-2, at the Bacon Island Pump Station 2 site, was paired with CPT sounding BSC-12. The soil boring encountered no organic soils at the site, even though the adjacent CPT sounding (BSC-12) recorded data indicating soft and/or organic soils between about 1 and 28 feet bgs. A four-foot thick surface "crust" of lean clay was logged overlying saturated, loose to slightly compact silty sand to a depth of 19 feet bgs, and fat clay from 19 to 26 feet bgs. Below 26 feet bgs, the primary soils encountered consisted of lean clays, fat clays, and silty sands. Uncorrected SPT blow count values for the low strength surficial soils (0 –26' bgs) ranged from N=2 (2.0-3.5') to N=12 (7.0-8.5'), with an average of N=6.6. Between 26 and 100 feet bgs SPT blow counts ranged between N=9 (27.0-28.5') and N=53 (98.5-100.0'). It should be noted that SPT blow count and Shelby tube push pressure increased markedly in a silty sand from 48 to 75 feet bgs, then dropped somewhat in the fat clays and silty sand from 75 to 92 feet bgs. Shelby push

pressure and blow count values increased again in a lean to fat clay and silty sand units between 92 and 100 feet bgs (Appendix B).

WEBB TRACT

The geologic conditions at Webb Tract were characterized using CPT and borehole data. Cone penetrometer data was used exclusively to determine the excavation depth to potential borrow material, while a combination of CPT and borehole data were used for the foundation investigations at each of the two proposed integrated pump facilities.

The near-surface geology of Webb Tract consists primarily of silty sands and silt with clay interbeds overlain by soft, dry to wet, fat clay and organic clays. The CPT data was used to group the near-surface geology of Webb Tract into three units: a surface crust, an intermediate layer of soft and/or organic soils, and a deeper inorganic soils unit. Soils identified in the two Webb Tract pumping plant boreholes were grouped as Recent Alluvium, Organic Soils, or Inorganic Soils. The Recent Alluvium consists of a “hard crust” of fat clay encountered from zero to three feet bgs in boring WTS-2; the Recent Alluvium is represented on Cross Section B-B (Plate 3, Sheet 2) as Surface Crust Soils. CPT data identified organic and/or soft soils beneath Webb Tract ranging in thickness from 2 (WSC-5) to about 42 feet (WSC-11); no organic soils were encountered in drill hole WTS-1. The top of the inorganic soils unit, underlying the organic soils, ranges from ground surface (WTS-1) to about 42 feet bgs (WSC-11).

Borrow Study

A preliminary borrow study of Webb Tract was undertaken to determine the depth to the top of inorganic soils that could potentially be used for construction of buttressed levees. Eleven CPT holes were advanced between 28 and 32 feet below ground surface to determine the thickness of overburden soils that would have to be removed to reach inorganic soils. The deeper foundation study CPT and drill hole data were also used in the borrow study. Plate 3, Sheet 2, is a geologic cross section through the island compiled from one borehole and eight CPT logs. The geology depicted in the section, B-B, is divided into three units: Surface Crust Soils (Cr), Organic and Soft Soils (Oss), and Inorganic Soils (Ios). Section B-B shows that there is between approximately 2 (WSC-5) and at least 36 (WSC-13) feet of surface crust and organic and/or soft soils overlying inorganic soils that may be used as potential borrow material. The section also shows that the crust and soft soils are thickest at the northeast corner of the island, and shallowest at the western and west-

central portions of the island. The top of the inorganic soils unit was found deeper, at 42 feet bgs, in CPT sounding WSC-11, but it was not included in Section B-B. It should be noted that CPT sounding data has been projected up to 3,350 feet along Cross Section B-B, and may not reflect the actual depths of the individual soil units directly beneath the section.

The data from this investigation was combined with CPT data from the 2001 USBR study was used to produce a geologic contour map of soft and organic soils overlying inorganic soils on Webb Tract. Plate 4, Sheet 2, is an isopach map showing the contoured thickness of organic and soft soils overlying a laterally extensive bed of silty sand that may be used as borrow. The Webb Tract isopach map shows that the excavation depth to potential borrow material is shallowest in the west-central portion of the island, with sandy dune deposits exposed at the surface. The thickness of the peat and soft soil overburden increases to a maximum of over 40 feet along the northeastern edge of Webb Tract.

Foundation Studies, Integrated Pump Facilities

Two integrated pump facility locations on Webb Tract were investigated as part of this study. Pump Station 1 is located at northeast corner of the island, while the Webb Tract Pump Station 2 site is located at the southeast corner of the island. Three CPT soundings between 85 and 101 feet bgs, and one drilled boring of 100 feet bgs, were advanced and sampled to characterize the foundation conditions at each pump facility site. Soil samples were collected from the drilled borings for laboratory testing. The soil sample test results will be reported separately by DOE Dams and Canals Section personnel.

The geologic units at the Webb Tract Pump Station 1 site consist of a surface crust, organic and/or soft soils, and inorganic soils. The silty sand surface crust ranges in thickness from 0 (WTS-1) to about 6 feet (WSC-11, 13, and 15). Soft and/or organic soils underlying the surface crust range from 6 to, as deep as, 42 feet bgs. The top of the inorganic soils ranges from 35 to 41 feet beneath the Pump Station 1 site. From drill hole WTS-1, soils encountered consist of 11 feet of silty sand, underlain by 20 feet of fat clay, and 6 feet of silt to a depth of 37 feet bgs. Silty sand, sandy silt, and silt, with some lean clay interbeds, extend beneath the site from 37 to 100 feet bgs. Groundwater was measured at 5.0 feet bgs, in drill hole WTS-1.

Data from CPT holes WSC-11, WSC-13, and WSC-15 show weak, soft and/or organic soils starting between about 6 to 7 feet bgs and extending to approximately 35 to 42 feet bgs at the Webb Tract Pump Station 1 site. These soils have been

labeled as sensitive fine-grained and organic soils, clay, sandy silt, and silty sand, using Robertson's (1990) soil behavior classification; some intervals could not be classified as one of Robertson's 12 soil behavior types, and are listed in the CPT data as "undefined". Underlying the soft and/or organic soils are cohesive, inorganic, fine-grained clay and silt, and granular silty sand and sand soil behavior types.

A review of the cone penetrometer data shows three zones based primarily on tip resistance readings. The soil zones are, in decending order, surface crust, shallow low strength, soft and/or organic soils, and deeper, inorganic soils of higher relative strength. The surface crust soils at the site exhibited tip resistance values ranging from 10.37 tsf (6', WSC-15) to 157.19 tsf (2', WSC-15). Cone sleeve friction measurements within the surface crust soils varied from 0.16 tsf (6', WSC-13) to 1.77 tsf (2', WSC-15). The low strength soft and/or organic, shallow soils exhibited cone tip resistance values ranging from 0.21tsf (17', WSC-13) to 16.18 tsf (13', WSC-15), and sleeve friction values from as low as 0.02 tsf (14', WSC-11) up to 0.32 tsf (33', WSC-15). Cone penetrometer data for the deeper soils, beneath 34 to 42 feet, indicated tip resistance values between 16.93 tsf (46', WSC-11) and 257.93 tsf (90', WSC-11). Sleeve friction values for the deeper, inorganic soils ranged from 0.30 tsf (36-37', WSC-13) to 11.79 tsf (90', WSC-11). Appendix A contains the CPT soil behavior type logs and supporting data for each CPT hole.

The drill hole log for boring WTS-1 shows that soils at the Webb Tract Pump Station 1 site consist of 11 feet of silty sand overlying fat clay from 11 to 31 feet bgs. Between 31 and 100 feet bgs, soils beneath the site are primarily silty sands and silts, with five-feet of lean clay. No organic soils were observed in the boring. However, tip resistance data from the adjacent CPT sounding (WSC-13) showed the base of the soft and organic soil at about 36 feet bgs, corresponding closely to the top of a silty sand unit encountered at 37 feet bgs in WTS-1. Uncorrected, SPT blow counts for the silty sands in the borehole ranged from N=10 (42.0-43.5') to N=59 (98.5-100.0'). SPT blow count values for the fine-grained clays and silts varied from N=0 (12.0-28.5') to N=33 (92.0-93.5'). Particularly "soft" zones were observed between about 10 feet and 41 feet bgs. This soft interval encompasses the base of the silty sand exposed at the surface, the underlying fat clay and silt, and extending into the top of a silty sand starting at 37 feet bgs. The fat clay between 11 and 31 feet is particularly noteworthy as the Shelby tube and SPT samplers were advanced from the weight of the sample rods alone, showing aggregate values of N=0 and 0 psi. The geologic drill log for WTS-1, with lithologic descriptions and uncorrected SPT data, is contained in Appendix B.

Soils beneath the proposed site of Pump Station 2, located at the southeast corner of Webb Tract, consist of three to five feet of fat clay surface crust overlying soft and/or organic clays extending to 15 to 23 feet bgs, with inorganic soils from 23 to 101 feet bgs. The inorganic soils consist primarily of silty sand with clay and silt interbeds 1.5 to 8.0 feet thick. Groundwater was measured at about 3.5 feet below the surface in drill hole WTS-2. Three CPT soundings and one rotary drill hole were advanced and sampled at the site to depths between 85 and 101 feet bgs.

The cone penetrometer data for Webb Tract Pump Station 2, as depicted in the logs for WSC-16, WSC-17, and WSC-18 (Appendix A), show three general soil strength layers. They consist of a thin surface crust, a very weak, soft or organic soil middle layer, and a lower layer of higher relative strength inorganic soil extending to the maximum depth of the CPT soundings. The surface crust is about 3 to 6 feet thick, while the soft and/or organic soil middle layer extends from 3-6 to 16-23 feet bgs, and the inorganic soil zone extends from about 16-23 feet to the bottom of the deepest CPT hole at 101 feet bgs.

A review of the cone penetrometer data shows three zones based primarily on tip resistance readings. The soil zones are, in decending order, surface crust, shallow, organic and low strength soils, and deeper, inorganic soils of higher relative strength. The surface crust soils, classified by the USBR as silty clay and clay soil behavior types, exhibited cone tip resistance values ranging from 10.07 tsf (5', WSC-16) to 28.35 tsf (2', WSC-18). Cone sleeve friction measurements within the surface crust soils varied from 0.49 tsf (4', WSC-16) to 1.18 tsf (1', WSC-17). The low strength, middle layer, organic and/or soft soils exhibited cone tip resistance values ranging from 0.21tsf (9', WSC-18) to 8.84 tsf (3', WSC-17), and sleeve friction values from as low as 0.04 tsf (8-10', WSC-18) up to 0.46 tsf (5', WSC-18). Cone penetrometer data for the lower, inorganic soils, indicated tip resistance values between 12.15 tsf (22', WSC-17) and 428.55 tsf (36', WSC-17). Sleeve friction values for the deeper soils ranged from 0.04 tsf (20', WSC-16) to 10.81 tsf (94', WSC-17). Appendix A contains the CPT soil behavior type logs and supporting data for each CPT sounding.

The borehole WTS-2, located at the Webb Tract Pump Station 2 site, was paired with CPT sounding WSC-17 for data comparison. A three-foot thick surface "crust" of fat clay, logged as Recent Alluvium, was encountered overlying moist to wet, organic fat clay to a depth of 23 feet bgs. Below 23 feet bgs, the primary soils encountered consisted of silty sands. Uncorrected SPT blow count values for the low strength organic fat clay (3 –23' bgs) ranged from N=0 (12.0-18.5') to N=14 (7.0-8.5'). Between 23 and 100 feet bgs, SPT blow counts for the inorganic soils ranged

between N=11 (27.0-28.5') and N=62 (92.0-93.5'). The drill hole log for WTS-2, contained in Appendix B, shows the SPT blow count values for each interval tested and sampled.

SEISMICITY

Generally, a geologic investigation for a project such as the proposed In-Delta Project would include a seismic hazard analysis. However, as this was a preliminary investigation for foundation conditions and borrow resources, a seismic hazard analysis was not included in the scope of the work.

Future geologic investigations for the In-Delta Project should evaluate seismic hazards that may impact both the island levees and any structures built as part of the project, if such a study has not already been conducted.

CONCLUSIONS

Geologic exploration at both Bacon Island and Webb Tract has shown that the near-surface geology consists of a surface crust overlying organic and/or soft soils underlain by inorganic clays, silts, and silty sands to depths of at least 100 feet bgs. Localized foundation conditions may be problematic for two of the proposed integrated pumping plant sites. It does not appear that there are any geologic conditions that would preclude construction at any of the sites, as long as adequate foundation preparation and support (such as piles) are achieved. The depth to the top of inorganic, potential borrow material was identified as occurring between 0 to 28 feet bgs at Bacon Island, and 0 to 41 bgs at Webb Tract, depending on specific locations on the islands. Both islands have inorganic soils above the maximum feasible excavation depth of 25 feet bgs, that potentially could be used for borrow materials.

Pump Station Foundations

- Bacon Island Pump Station 1 - Foundation conditions at the Bacon Island Pump Station 1 site were probably the worst encountered out of the four sites. Borehole data showed organic, soft soils were encountered from the surface to 16 feet bgs, and SPT values ranged between N=0 and N=3. CPT data indicated that surface crust and soft and/or organic soils extended to a depth of 15 to 22 feet bgs, which roughly correlates with the boring data. The inorganic soils beneath 16 feet exhibited higher, but less consistent, SPT values ranging from N=3 to N=31; the

majority of the “N” values were single digit, including the last three intervals sampled from 82 to 100 feet bgs.

- Bacon Island Pump Station 2 - In contrast to the first Bacon Island site, the drill hole at the Bacon Island Pump Station 2 site (BIS-2) did not encounter any organic soils. However, the two CPT soundings at the site indicated that surface crust and soft and/or organic soils extended to a depth of 22 to 28 feet bgs. BIS-2 SPT values were recorded ranging from N=2 to N=53. Significantly stronger soils were encountered in the drill hole starting at 48 feet bgs, in a dense silty sand, and extending to the bottom of the boring at 100 feet. Blow count values for this deeper interval ranged from N=27 to N=53.

- Webb Tract Pump Station 1 - The Webb Tract Pump Station 1 site, like the second Bacon Island site, encountered no organic soils in the single drill hole, WTS-1. However, once again the CPT data shows that soft and/or organic soils extend to about 35 to 42 feet bgs. Weak fat clay and silt were encountered beneath the surficial silty sand from 11 to 31 feet bgs in WTS-1, accounting for most of the CPT derived thickness of the soft and/or organic soils at the site. The SPT blow count values for the fat clay and silt units in the upper 42 feet ranged from N=0 to N=2; in the CPT data these soils would appear as soft and/or organic soils, as depicted on Cross Section B-B. Significantly stronger soils were not reached until 72 to feet bgs, where a silty sand was encountered; SPT blow count values from 72 to 100 feet bgs range from N=32 to N=59.

- Webb Tract Pump Station 2 - Organic soils were encountered in drill hole WTS-2, at the Webb Tract Pump Station 2 site, from 3 to 23 feet bgs. These soils are soft and weak, and exhibited SPT values between N=0 and N=8. While the soil blow count values improved slowly with depth, a marked difference was not observed until the silty sand at 55 feet bgs was encountered. Starting at that depth, and extending to the bottom of the boring, higher “N” values of 26 or more were consistently attained; one exception to the higher blow count at depth values was found at 71 to 79, in a fat clay. The base of the organic soils encountered in drill hole WTS-2 corresponds to the CPT data from the site showing the bottom of the soft and/or organic soils from about 16 to 23 feet bgs.

Borrow Studies

The depth of the silty sand underlying surficial organic and soft sediments at both islands was identified for use as a possible borrow source for levee construction. However, it was agreed among the participating parties that the maximum effective

depth of excavation for borrow sources would be 25 feet bgs. Therefore, any conclusions or recommendations concerning the depth of borrow is related to that maximum effective excavation depth.

Only a limited number of CPT holes were used to determine the depths to potential borrow material, and no soil samples were collected for laboratory analyses. Therefore, the top of the inorganic soils unit, presumed from previous studies to be a silty sand, have not been confirmed with laboratory analyses. It should be noted that the sandy eolian deposits exposed at the surface within the western half of Webb Tract have been tentatively classified as possible culturally significant "Piper Sands", and were excluded from exploration.

- Bacon Island - Cone penetrometer data from nine shallow and four deeper soundings indicated that the top of the inorganic soils varied from about 8 to 28 feet bgs at Bacon Island. The two foundation drill holes, BIS-1 and BIS-2, indicated that organic and soft soils extended from the surface to 21 feet bgs at Pump Station 1, while silty sand was encountered from the 4 to 19 feet bgs at Pump Station 2.

  Section A-A (Plate 3, Sheet 1) shows the approximate thickness of the surface crust and soft and/or organic soils overlying the silty sand unit presumed to be the top of the inorganic soils unit. A contour map showing the depth to inorganic soil, and potential borrow is contained on Plate 4 (Sheet 1); that map shows the surface crust and organic and/or soft soils are thinnest near the center of the island, along a north-south axis. Generally, the central portion of the island contains inorganic soils shallow enough to allow excavation of potential borrow materials. The top of the inorganic soils unit along outside portion of the island is generally greater than 20 feet bgs, and would not be feasible for borrow excavation.

- Webb Tract – CPT soundings and the foundation study drill holes at Webb Tract showed that inorganic soils were encountered from the surface, to as deep as 42 feet bgs. Cross Section B-B (Plate 3, Sheet 2) and the Webb Tract isopach map (Plate 4, Sheet 2), generally shows that the depth to top of the inorganic, potential borrow materials is relatively shallow on the western half of the island, and deeper to the east. The greatest thickness of surface crust and soft and/or organic soils were found at the northeast corner of the island, at the Pump Station 1 site. Sandy soils were exposed within the west-central part of the island, but were excluded from exploration. This area may be the most economical source of borrow material. Other than the surface deposits described above, CPT data

indicates that inorganic soils are shallow enough for feasible borrow excavation within an area encompassing the western two-thirds of the island. The perimeter of the island, and the eastern third contain surface crust and soft and/or organic soils at thicknesses near or beyond the predetermined maximum feasible excavation depth of 25 feet bgs.

Groundwater

Groundwater levels were measured in the foundation drill holes from 0.1 to 0.4 feet bgs at Bacon Island, and from 3.5 to 5.0 feet bgs at Webb Tract. However, the groundwater elevations are artificially maintained with pumps and drainage ditches for the purpose of agricultural cultivation. If the dewatering activities on both islands were discontinued, groundwater elevations would be expected to rise to approximately sea level. This would inundate a majority of the surface of both islands. Assuming current groundwater conditions, extensive dewatering will most likely be required for all borrow and pumping plant foundation excavations. The saturated nature of the soils, along with the soft and weak properties, will also make excavation slope stability a likely problem; it may prove difficult to maintain excavations without shoring in groundwater saturated soils.

RECOMMENDATIONS

Given the limited scope of this foundation and borrow study, we recommend that all previous geologic data be combined. Then it can be determined if additional exploration needs to be conducted prior to design and construction. Each integrated pumping facility should be further investigated with additional borings and soil sample analyses. The borings should target specific features of each facility. Due to the weak soils at depth, additional borings at the Bacon Island Pumping Plant 1 site should be advanced below 100 feet bgs.

The borrow study for both islands was sparse because of budgetary reasons. A second study should be conducted using a combination of CPT soundings and borings to further define the depth of the potential borrow material. Soil samples should be collected for laboratory analyses from each boring advanced as part of any additional borrow investigation. Laboratory testing of soil samples should include analysis for Atterberg limits, gradation, compaction, and, organic content.

If this project goes to design, a seismic hazard analysis should be undertaken for the perimeter levees on each island, and also for the specific structures to be

built. The seismic hazard analyses should also be used to update the liquefaction study that the Army Corps of Engineers conducted in the 1980s.

If this project advances to design and construction, slope stability and aquifer testing should be conducted. Test pits and trenches should be excavated to determine if shoring will be needed, or how shallow excavation slopes should be laid back. Aquifer testing should be conducted to determine construction dewatering measures and pumping rates that will be required for any excavation.

Finally, before any additional exploration is planned for the project, all exploration locations, and the results thereof, should be plotted on a single map. This map will then be used to determine additional exploration needs. A current map of drill hole and CPT locations may have been compiled by the USBR.

Thank you for the opportunity to assist you with this project. If you have any questions or need additional information, please call me at (916) 323-8928, or Brent Lamkin at (916) 323-8925.

Attachments

cc: Mike Driller
Ron Lee

BLamkin:Shelly Asbury/June Pascual
A;\In-Delta Geology Report
Spell Check: 01/08/03

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