Appendix C

Geotechnical Appendix

Princeville, North Carolina
Flood Risk Management Integrated Feasibility Report and Environmental Assessment

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Princeville, North Carolina Flood Risk Management Integrated Feasibility Report and Environmental Assessment

Geotechnical Engineering

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1.0 Purpose

The purpose of the Feasibility Study for the Princeville Flood Risk Management project is to determine the most economical method to provide the Town of Princeville with protection from the 0.333% (300-year) flood event. The present project has gaps (low elevation areas) that permit flood waters at elevations below the 1% (100 year) flood level to inundate portions of Princeville that were intended to be protected by the original project.

The purpose of the Geotechnical Appendix is to present the results of the subsurface investigations and required analyses using current levee criteria (U.S. Army Corps of Engineers Engineering Manual (EM) 1110-2-1913) to determine if any remediation to the existing levee is required to bring it up to the current standards.

2.0 General

The existing levee system is located on the western, southwestern, and northern sides of the Town of Princeville and was constructed in 1964 by the US Army Corps of Engineers (Figure 1). The existing levees are constructed of sandy soils with side slopes at 3H to 1V on the riverside and 2.5 H to 1V on the landside. The levee system's purpose is to provide Princeville with protection from flooding by the Tar River. It was overtopped by flooding associated with Hurricane Floyd in 1999. Water also flowed around the northern and southern ends of the levee causing millions of dollars in damages. Additionally, several locations along the levee were damaged by erosion due to overtopping, as shown in Figure 1. Damaged areas of the levee were repaired to a condition similar to that of the pre-flood condition. This study evaluates the existing levee against current levee criteria, and identifies alternatives that would provide Princeville flood protection with a minimum of a 90% chance of not being exceeded by the 1% annual flood event. The Tentatively Selected Plan (TSP) consists of the existing levee, constructing 2500 feet of new levee to the north of the existing levee, elevating two sections of road in the vicinity of Shiloh Farm Road and NC 111, constructing a new section of levee to the east of US Highway 64, elevating existing roads in the vicinity of US Highway 64 and NC 33, and terminating the levee system where it intersects the CSX/Main Street overpass. Several alternatives for these revisions are identified in this Feasibility Report. The final plan will be evaluated using additional subsurface investigations, slope stability analyses, and the seepage analyses during the Pre-Construction, Engineering, and Design (PED) phase.

Both the existing and proposed project incorporate portions of the US Highway 64 embankment as part of the flood damage reduction system. The highway embankment performed well during the Hurricane Floyd flood event. Although overtopping occurred along a portion of the Highway 64, the embankment was not breached. After Hurricane Floyd, the highway embankment required only minimal repairs to erosion by the North Carolina Department of Transportation (NCDOT). Although the US 64 highway embankment performed well, the Federal Department of Transportation (FDOT) and Federal Highway Administration (FHWA) have determined that any highway or railroad embankment incorporated into a flood reduction levee system must meet the same design requirements as other portions of the earth levee system. This decision is due to the recent poor performance of other highway embankments that serve as levees in the Midwest.

The earthen levee sections (non-highway) of the existing project were constructed in 1964. Currently, no original design calculations have been located. The original foundation and borrow area material information are available for this earth embankment flood reduction levee (CS-1 through CS-40, see Attachment 2, page 36); however, there are no as-built drawings or

reports that indicate where the borrow source was located or what level of compaction was obtained during construction. Historically, the levee has performed well, though during Hurricane Floyd overtopping caused erosion at some locations due to the sandy material from which this levee was constructed.

3.0 Subsurface Investigation Methods

Subsurface investigative methods utilized conventional and widely accepted sampling practices. These methods include Standard Penetration Tests (SPT), Cone Penetration Tests (CPT), Direct Push sampling, and hand auger sampling techniques. Bulk samples were obtained from the borrow area by hand shovel. All samples were visually field classified in accordance with the Unified Soils Classification System (USCS) as required in the US Army Corps of Engineers (USACE) Manual 1110-1-1804.

The SPT is a widely accepted test method of *in situ* testing of foundation soils (ASTM D 1586). A 2-foot long, 2-inch O.D. split-barrel sampler attached to the end of a string of drilling rods is driven 18 inches into the ground by successive blows of a 140-pound hammer freely dropping 30 inches. The number of blows needed for each 6 inches of penetration is recorded. The sum of the blows required for penetration of the second and third 6-inch increments of penetration constitutes the test result or N-value. After the test, the sampler is extracted from the ground and opened to allow visual examination and classification of the retained soil sample. The test holes are advanced to the test depths by rotary drilling with a cutting bit, using circulating fluid to remove the cuttings and hold the fine grains in suspension. The circulating fluid, which is a bentonitic drilling mud, is also used to keep the hole open below the water table by maintaining an excess hydrostatic pressure inside the hole. In some soil deposits, particularly highly pervious ones, NX-size flush-coupled casing must be driven to just above the testing depth to keep the hole open and/or prevent the loss of circulating fluid.

The CPT is also a widely accepted test method of *in situ* testing of foundation soils (ASTM D 3441). An instrumented conical shaped probe (usually 10 to 15 centimeters in diameter) is pushed into a soil deposit at a controlled rate of 1 to 2 cm/sec. Output quantities for both sleeve friction and tip resistance are simultaneously recorded in units of tons per square foot per foot of depth. In addition, dissipation of excess pore water pressure or seismic shear wave velocities can be recorded at discrete depth locations. This testing method is useful in determining the delineation of soil stratigraphy.

Direct Push borings are taken with hydraulically powered equipment, which applies static and dynamic percussion forces to a soil probing hammer. The soil particles are rearranged by the application of weight and percussion to advance the probe further into the ground. Once the probe reaches the desired depth or refusal, the probe is removed and the sample is recovered in a plastic cylinder.

3.1 Previous Subsurface Investigations in 1964, 1965, & 2000

Several previous subsurface investigations were: (1) subsurface investigation performed by the Savannah District / Mobile Drill Crew in 1964; (2) a preliminary geotechnical investigation by Froehling and Robertson, Inc in 1965; and (3) an adjunct draft geotechnical report prepared by Titan Atlantic Group, Inc in 2000. All boring logs and lab data are included in Attachments 2 and 3, respectively. These reports describe subsurface soil conditions encountered during various field and laboratory investigations at locations along the existing levee and borrow areas. Previous field investigations/testing included drilling and SPT (ASTM D 1586), Soils

Classification (ASTM D 2487), Grain Size Distribution (ASTM D 422), Standard Proctor (ASTM D 698), and Atterberg Limits (ASTM D 4318).

Thirty eight SPT borings were taken along the existing levee alignment by the Savannah District in 1964. See Figure 2 for the boring locations. The depth of these borings ranged between 20 and 30 feet below ground surface (BGS). Samples taken from these borings were visually classified in the field and no laboratory soil testing was performed. The types of soils encountered along the existing levee (Dike A, paralleling the Tar River) consisted primarily of clean and silty sands. Several of the borings revealed a layer of fat clay (CH) which was usually encountered between 10 to 20 feet BGS. The presence of CH material beneath a proposed embankment could be problematic for stability and settlement, however; the SPT blow count of nearly all of this clay was exceedingly high, (25 to 60) indicating that this material was very stiff and probably consolidated. No evidence of instability or settlement has been noted along the existing levee during Routine or Periodic Inspections.

Repairs were made in 2000 to the eroded areas of the levee by USACE (Figure 1). Four samples from the borrow area were sent to Froehling & Robertson, Inc. for testing. These include Gradation Size Distribution (ASTM D 422), Standard Proctor (ASTM D 698), Atterberg Limits (ASTM D 4318), Moisture Content (ASTM D 2216), and Soils Classification (ASTM D 2487). As part of the repair project, Titan Atlantic Group performed Field Density Tests (ASTM D 1556) as a back check of the repaired structural fill.

3.2 Recent Subsurface Investigations (2006 & 2009)

3.2.1 Levee Investigations

In 2006, the Wilmington District performed a subsurface investigation along the entire existing Princeville levee and the proposed extension of the levee to the northeast (Figure 2). A drill rig and crew from the Savannah District were utilized for this purpose. The drill rig could not access the proposed borrow area and changes were made to the tentatively selected plan after drilling operations were completed. As a result, complete subsurface investigation along the entire levee alignment was not accomplished and the resulting data do not include the entire tentatively selected plan (TSP).

Eleven SPT borings were taken along Section B and the proposed northeast extension. These range in depth from 15 to 31 feet BGS (Table 1). The boring logs show interbedded sand layers, consisting of silty sands, clayey sands and poorly graded sands. Fat clay (CH) was encountered 11 to 15 feet BGS at three locations (PFR-06-SS-13, PFR-06-SS-14, & PFR-06-SS-21). At the boring location PFR-06-SS-19, fat clay (CH) was encountered at 2 feet BGS.

Seven Direct Push borings were taken along Section B and the proposed northeast extension (PFR-06-GP-02, 03, 04, 05, 06, 15, & 16), four of which were taken in roadways, ranging in depth from 15.5 to 30 feet BGS (Table 1). The boring logs indicate a significant presence of poorly-graded sands, clayey sands and silty sands. Fine-grained soils, such as lean silts and sandy lean clays, were also encountered. Fat clay (CH) was encountered at two of these borings.

Four combination core/SPT borings were taken on Highway 258 and Shiloh Farm Road. The depths of these borings were approximately 3 to 4 feet BGS. A few inches of asphalt/concrete were cored and the underlying silty and clayey sands were sampled with a splitspoon.

Seven CPT's were performed to corroborate the SPT and Direct Push borings results. They appear to correlate well to the companion borings.

A field exploration program was conducted by the Wilmington District of USACE on April 14 - 18, 2009. Nineteen SPT holes were advanced to total depths ranging from 15 to 30 feet BGS. Eleven borings were drilled in the existing levee areas, three borings were drilled in the vicinity of Highway 64, and five borings were drilled in the newly proposed borrow area. See Figures 3 through 6 for the locations of the borings. Two hundred fifty samples obtained from the nineteen SPT borings were delivered by USACE to Ardaman & Associates, Inc. in Orlando, Florida for laboratory testing. In addition, three boxes of soil samples obtained from the proposed borrow area were also tested. Table 1 summarizes the field exploration conducted in 2009.

Based on the subsurface information, clean, pervious sands inter-bedded with layers of silty and clayey sands exist in the study area, especially in close proximity to the river. Further from the river, layers containing higher percentages of fine-grained soils may be expected. A moderately stiff layer of fat clay (CH) several feet beneath the surface is revealed in some of the borings and may be present beneath most of the study area. Correlation of subsurface layers from one boring to another is not readily apparent due to the inter-bedded nature of the river sediments. For seepage and stability analyses, assumed subsurface conditions were based on the nearest borings.

3.2.2 Borrow Area Investigation

In 2006, four hand auger borings (A-1 thru A-4) were taken adjacent to the proposed borrow area, a heavily wooded area on the southeastern side of town (Figure 2). These borings were intended to provide an indication of the types of soils that might exist inside the borrow area. The depth of these borings ranged from 5.0 to 7.5 feet BGS. The types of soils (SP/SM, SP, SC, CL, and SP/SC) found at these locations are considered suitable for levee construction. However, due to land ownership and sufficient quantity issues, the borrow area was not investigated further. A new borrow area was proposed and investigated in 2009.

In 2009, five SPT borings (PD-BP-BA-1 through PD-BP-BA-5) were taken in the newly proposed borrow area, located north of the intersection of US Highway 64 and County Road 1524. The proposed borrow area is approximately 5 miles east of Princeville at the Sauerborn Property (Figure 6). In addition to the SPT samples, three boxed samples were obtained from the borrow area and shipped for laboratory testing. The boxed samples were labeled Box 1, Box 2 and Box 3, respectively. Borings taken from the site indicated the water table is approximately eight feet BGS. Quantities of available suitable borrow material may be limited due to the depth of the water table. The available borrow material available for levee construction has not been quantified.

4. Laboratory Testing Results

4.1 Levee Index Testing Results

Visual classification of the 67 soil samples taken in 2009 was performed in accordance with ASTM Standard D 2488 on representative portions of each soil sample. Unified soil classification was performed on selected soil samples in accordance with ASTM D 2847.

Moisture content determinations were performed in accordance with ASTM Standard D 2216 on representative portions of selected soil samples oven dried at 110° C.

The particle size distributions of soils samples were determined using mechanical sieving test methods in general accordance with ASTM Standard D 422.

Liquid and plastic limit measurements were performed on soils samples in general accordance with ASTM Standard D 4318 (Method A).

Based on the results of boreholes PDP-BP-SS-5, PD-BP-SS-8 AND PD-BP-SS-11, the following are the range of soil and parameters for the encountered soils:

Soil Description: Loose sand (SP) to Clayey sand (SC)
Saturated Unit Weight (pcf): 120-125
Φ' (degrees): 28-30

Soil Description: Medium dense to dense silty sand (SM) to clayey sand (SC)
Saturated Unit Weight (pcf): 125-135
Φ' (degrees): 33-36

Soil Description: Stiff Clay
Saturated Unit Weight (pcf): 130-135
Cohesion (psf): 1000-2000

Based on the results of boreholes PD-BP-SS-3, PD-BP-SS-7 AND PD-BP-SS-10, the following are the range of soil and parameters for the encountered soils:

Soil Description: Stiff Clay
Saturated Unit Weight (pcf): 120-125
Cohesion (psf): 1000-2000

Soil Description: Medium dense to dense sand (SP), sand with clay (SP-SC), and clayey sand (SC)
Saturated Unit Weight (pcf): 120-125
Φ' (degrees): 31-35

Soil Description: Very loose to medium dense silty sand (SM) and clayey sand (SC)
Saturated Unit Weight (pcf): 120-135
Φ' (degrees): 29-35

Soil Description: Medium stiff to stiff clay (CL)
Saturated Unit Weight (pcf): 130-135
Cohesion (psf): 1000

Soil Description: Medium dense silty sand (SM), and clayey sand (SC)
Saturated Unit Weight (pcf): 125-135
Φ' (degrees): 31-34

Based on the results of boreholes PD-BP-SS-4, PD-BP-SS-6 AND PD-BP-SS-9, the following are the range of soil and parameters for the encountered soils:

Soil Description: Loose to medium dense silty sand (SM), and clayey sand (SC)
Saturated Unit Weight (pcf): 120-125
Φ' (degrees): 30-34

Soil Description: Very loose to silty sand (SM), and clayey sand (SC)
Saturated Unit Weight (pcf): 120-125
Φ' (degrees): 29-31

Soil Description: Very stiff clay
Saturated Unit Weight (pcf): 125-135
Cohesion (psf): 1000-2000

Based on the results of boreholes PD-BP-SS-1, PD-BP-SS-2, the following are the range of soil and parameters for the encountered soils:

Soil Description: Loose to medium dense clayey sands (SC)
Saturated Unit Weight (pcf): 115-120
Φ' (degrees): 30-31

Soil Description: Loose to dense sands (SM), and clayey sands (SC)
Saturated Unit Weight (pcf): 120-125
Φ' (degrees): 30-35

Soil Description: Loose to medium dense sands (SP) and sands with clay (SP- SC)
Saturated Unit Weight (pcf): 120-135
Φ' (degrees): 30-32

Based on the results of boreholes PD-BP-64-1 through PD-BP-64-3 in the vicinity of US HIGHWAY 64, the following are the range of soil and parameters for the encountered soils:

Soil Description: Loose to medium dense silty sands (SM) and clayey sands (SC)
Saturated Unit Weight (pcf): 120-125
Φ' (degrees): 30-33

Soil Description: Very loose to loose sands (SP)
Saturated Unit Weight (pcf): 115-120
Φ' (degrees): 29-31

Soil Description: Medium dense to dense clayey sands (SC)
Saturated Unit Weight (pcf): 125-135
Φ' (degrees): 31-35

Soil Description: Hard clay (CL)
Saturated Unit Weight (pcf): 124-135
Cohesion (psf): 4000-6000

Results of the laboratory testing are provided in Table 2 and Attachment 3, B-39.

4.2 Borrow Area Testing Results

Compaction tests were performed on samples from each of the three boxes using the Standard Proctor method in general accordance with ASTM Standard D 698. The results of the compaction tests are presented in Table 3.

Six constant-head permeability tests were performed in the laboratory on borrow area samples, two tests from each box. Prior to testing, the specimens were compacted in rubber molds to a dry density equivalent to or greater than 95 percent of the Standard Proctor dry density value obtained for each box sample during the compaction tests. Table 4 summarizes the results of the laboratory permeability tests.

A total of nine direct shear tests were performed on samples from the three boxes. Three tests were performed on samples from each box with varying normal stress. The direct shear tests

were performed to determine the shear strength parameters, c' and φ', of the samples. The results of the direct shear tests are presented in Table 5.

Based on the results of the borings, the following are the range of soil parameters for the encountered soils:

Soil Description: Very loose to loose sand (SP), sand with clay (SP-SC), silty sand (SM), and clayey sand (SC)

Moist Unit Weight (pcf): 103-107
Saturated Unit Weight (pcf): 115-120
Φ' (degrees): 29-30

Results of the laboratory testing are provided in Attachment 3, page 37.

5. Seepage Analysis

5.1 SEEP/W

Steady-state seepage analysis was performed using GeoStudio's SEEP/W, a two dimensional finite element modeling program. Seepage analyses were performed to verify that the existing levee meets the current levee safety criteria with regard to seepage exit gradients. The phreatic surface and pore-pressure distribution was modeled for 5 year, 50 year, and 100 year flood events within the levee. Levee cross sections were developed using subsurface data and the 2001 breach repair as-builts, then converted to finite element meshes. Hydraulic conductivity functions were defined, boundary conditions were applied, calibration analyses were performed, and seepage conditions were predicted for various riverside and landside water elevations.

SEEP/W provides values for the resultant seepage gradients. However, it only provides gradient information across an individual element. The View Element Information is appropriate for evaluating exit gradients for the case when there is no surface blanket. If the soil profile can be idealized with a top blanket of uniform thickness overlying a foundation layer of uniform thickness and seepage flow is assumed to be horizontal in the foundation and vertical in the blanket, then simple blanket theory equations can be used. The provided design criteria for allowable seepage gradients of 0.3 and 0.8 were developed primarily for blanket materials with a unit weight of approximately 115 pounds per cubic foot (pcf), and that factors of safety for piping and uplift vary significantly depending on the unit weight of soils (Engineering Technical Letter (ETL) 1110-2-569). Determining gradients and factors of safety for piping and uplift are different depending on whether or not there is a surface blanket of less pervious materials (clay, silt or peat) overlying more pervious materials (sand, gravel or pervious rock). EM 1110-2-1913 provides design criteria in terms of allowable seepage gradients.

5.2 Seepage Analysis Assumptions and Input Parameters

For the preliminary designs, the levee profiles were modeled from the 2001 Princeville Levee as-builts. These drawings were from the 2000 Princeville Levee re-build after the Hurricane Floyd event damaged portions of the levee. Topographical surveys were not available at the time of the modeling. Critical and non-critical sections of the levee were based on areas that were overtopped during the Hurricane Floyd flood event. Critical sections are areas where overtopping occurred. Non-critical sections are areas where no overtopping occurred (Figure 1).

The Princeville levee system, constructed with available material (SM or SC) from local borrow areas, is considered to be an urban levee. Foundation assumptions are based on worst case scenarios from the available soil borings and lab testing data. It is assumed that the levee system is non-homogeneous, with a maximum height of approximately 10 ft. The crest of the levee system ranges from 9 to 12 feet wide. The seepage model follows steady-state conditions, with water surface elevations (headwater) at the crest of the levee system.

Four design profiles of the existing levee were created to analyze seepage and stability. The four profiles analyzed are listed below:

Station 32+00: Identified as a critical section, the levee is approximately 9 feet high with a top elevation of 49.0 feet. The levee has a 10-ft crest width. The side slopes for this section is 2.5 H to 1 V for the landside and 3.0 H to 1 V for the riverside. The riverside water elevation used in the analysis is 48 ft. The soil profile characteristics consist of loose clayey sand underlain by medium dense to dense silty sand.

Station 38+00: Identified as a non-critical section, the levee is approximately 9 feet high with a top elevation of 49.0 feet. The levee has a 10-ft crest width. The side slopes for this section is 2.5 H to 1.0 V for the landside and 3.0 H to 1.0 V for the riverside. The soil profile characteristics consist of medium to dense sand to clayey sand underlain by very loose to medium dense silty to clayey sand.

Station 40+00: Identified as a critical section, the levee is approximately 9 feet high with a top elevation of 49.0 feet. The levee has a 9-ft crest width. The side slopes for this section is 2.5 H to 1.0 V for the landside and 3.0 H to 1.0 V for the riverside. The soil profile characteristics consist of loose to medium silty to clayey sand underlain by very loose to loose silty sand.

Station 74+00: Identified as a critical section, the levee is approximately 15 feet high with a top elevation of 49.0 feet. The levee has a 10-ft crest width. The side slopes for this section is 2.5 H to 1.0 V for the landside and 3.0 H to 1.0 V for the riverside. The soil profile characteristics consist of loose to medium dense clayey sand underlain by loose to dense silty sand.

SEEP/W inputs consist of cross sectional geometry, hydraulic conductivity and boundary conditions for the flow domain. Output results from SEEP/W consist of phreatic surface, head distribution, hydraulic gradient, flow directions and flow quantities within the flow domain.

Each soil layer was assigned a vertical permeability (kv) value based on experience with soil types and laboratory permeability tests. The horizontal coefficient of permeability (kh) of each layer was assumed to be one to two times the vertical permeability.

5.3 Seepage Analysis Results

As determined by Seep/W, the seepage pore water pressure within the levee was minor. The phreatic surface exits near the landside toe of the slope at lower storm events, and farther up the landside slope with higher storm events. Lateral hydrostatic forces and seepage gradients within the levee and underlying foundation indicate the overall stability of the existing levee is acceptable. The results of the seepage analyses for each section are presented in Table 6 and Figures 9 through 20.

Results from SEEP/W were used for development of a levee fragility curve for utilization into Hydraulic Engineering Center's Flood Damage Analysis (HEC-FDA) program. The inputs used

for generating the probability of failure [Pr(f)] at different water elevations were cross sectional geometry, hydraulic conductivity, and boundary conditions. The reliability function is formulated for selected failure mechanisms and the constituting failure modes. Once the probability of failure for different water elevations was calculated, the results were graphically plotted for a resulting fragility curve [Pr(f) -vs- water elevation]. As shown by the fragility curve, the reliability of the levee decreases with increases in water elevation. This function indicates the probability of structure failure conditional upon loading. The probable failure point (PFP) at 85% occurs once the levee is overtopped with a water elevation of 49 feet. The probable non-failure point (PNP) of 15% occurs with a water elevation of 39 feet. The resulting fragility curve is shown in Figure 8.

6.0 Stability Analyses

Undrained slope stability analyses for the existing levees were performed using Spencer's method in the computer program SLOPE/W. SLOPE/W uses an iteration scheme to find the critical slip surface and the corresponding minimum factor of safety. The factors of safety for sliding (block) and circular modes of failure were calculated in the analyses.

Rapid drawdown slope stability analyses were also performed using Spencer's method in the computer program Slope/W. Stability analysis during rapid drawdown is an important consideration in the design of embankment levees. During rapid drawdown, the stabilizing effect of the water on the upstream face is lost, but the pore-water pressures within the embankment may remain high. As a result, the stability of the upstream face of the levee can be much reduced.

The results of the steady seepage, undrained slope stability analyses for the existing levee cross sections are presented in Table 7 and Figures 21 through 23. The minimum factors of safety for the existing levee range from 1.1 to 2.0, the minimum of which does not satisfy the minimum required factor of safety of 1.4 as per EM 1110-2-1913. This indicates that stability control measures are needed. Station 32+00 has a less than minimum factor of safety of 1.4. The factor of safety will rise to 1.407 if a berm is placed at the inside toe of the levee at Station 32+00. The berm should be built on an approximate 1V:8H slope in order to obtain the factor of safety of 1.407 (Figure 29). More analysis is needed to determine the total length of the berm, but it is assumed that the berm will be built from Station 30+00 to Station 34+00.

The results of the rapid drawdown slope stability analyses for the existing levee cross sections are presented in Table 7 and Figures 24 through 27. The minimum factors of safety for the existing levee range from 1.0 to 1.03, satisfying the minimum required safety factor of 1.0 for water levels unlikely to persist for a long period of time, as per EM 1110-2-1913.

7.0 Fragility Curve

It is recommended that the levee fragility curve should be updated prior to completion of the feasibility study, utilizing a representative cross section from the current levee configuration. Economic data output may be impacted by the updated fragility curve results. The levee fragility curve is to be created for incorporation into Hydraulic Engineering Center's Flood Damage Analysis (HEC-FDA) program. ETL 1110-2-556 (Risk Based Analysis in Geotechnical Engineering for Support of Planning Studies) provides guidance on risk informed analysis in geotechnical engineering.

Utilizing previously identified critical sections, seepage and stability analysis were performed at various locations. Critical sections were defined as failure areas resulting from Hurricane Floyd in September 1999. These failures were a result of backward erosion due to the overtopping of the levee. Only one critical section had a factor of safety less than 1.4, which is the minimum factor of safety for long term (steady seepage) stability for existing levees (EM 1110-2-1913, Design and Construction of Levees).

Seepage and stability analysis will again be performed on the critical section using GeoStudio's Seep/W and Slope/W programs. The model will be created using the 2001 Princeville levee as-builts. This as-built data was from the 2000 Princeville levee repair for the damage sustained after Hurricane Floyd. Topographical surveys are currently not available. The Princeville levee system was constructed with available materials from borrow sources, which were predominately silty and clayey sand (SM or SC); soil parameters will be based on laboratory analyses performed on borrow area material. Foundation assumptions are based on assumed worst case scenarios from the available soil borings and lab testing data.
The inputs used for generating the probability of failure [Pr(f)] at different water elevations will be cross sectional geometry, hydraulic conductivity, undrained sheer strengths, and boundary conditions. Undrained slope stability analyses for the cross section of the levee will be performed using Spencer's method in GeoStudio's Slope/W. SLOPE/W uses an iteration scheme to find the critical slip surface and the corresponding minimum factor of safety. The factors of safety for sliding (block) and circular modes of failure will be calculated in the analyses. Steady-state seepage analysis will be performed using GeoStudio's SEEP/W, a two dimensional finite element modeling program. SEEP/W results provide values for the resultant seepage gradients.

The phreatic surface and pore-pressure distribution will be modeled for every foot of head from the toe of the levee to the top of the dike. The approximate height of the levee cross section being modeled is 10 feet from natural ground (elevation 49 feet, NGVD 29t). Variables for stability analysis modeling will include the friction angle (Φ) and cohesion (c) for the embankment and foundation material. Variables for seepage analysis will include vertical hydraulic conductivity (Kx), coefficient of volumetric compressibility (Mv), and the ratio of vertical to horizontal hydraulic conductivity (Ky/Kx). A standard deviation is then assigned to each variable (usually greater deviation for lower valued variables, and lower deviation for higher valued variables). The model is then recalculated changing one variable's input parameter by the standard deviation (higher and lower value). For the stability analysis, the three random variables will yield nine different model runs at each foot of head. This includes the base model, as well as the embankment friction angle, foundation friction angle, embankment cohesion, and foundation cohesion each changed by one standard deviation both higher and lower. For through seepage and underseepage, the two random variables will yield seven different model runs at each foot of head. This includes the base model, as well as embankment hydraulic conductivity, coefficient of volumetric compressibility, and hydraulic conductivity ratio changed by one standard deviation both higher and lower. Each one foot of head will produce twenty-three different model runs utilizing the GeoStudio's program. For the Princeville modeling effort, seven different water surface elevations will be analyzed, with an expected number of model runs utilizing all random variables to be approximately 161.

The reliability function is then formulated for selected failure mechanisms and the constituting failure modes. Once the output from Slope/W and Seep/W is calculated (F.S., hydraulic gradient), it is entered into a excel spreadsheet, which has pre-determined formulas those inputs. The spreadsheet then generates the probability of failure points (PFP) for different water elevations. Levee reliability utilizing the probable failure point (PFP) at 85% and probable non-

failure point (PNP) of 15% is then determined. Once the results are calculated, they are graphically plotted for a resulting fragility curve [Pr(f) -vs- water elevation] (Figure 7). These data are entered into the HEC-FDA program with economic analyses following.

8.0 Settlement

Historical inspection data and boring logs do not indicate any significant settlement of the existing levee. Additional borings along the selected alignment are needed for settlement analysis. If the analysis indicates any settlement in the embankment or the foundation, the final design will accommodate for this.

9.0 Earthquakes and Potential for Liquefaction

The Princeville levee project is in a seismic Zone 1 (least susceptible to earthquakes), therefore; earthquake loadings were not considered in analyzing the stability of the levee. Also, the probability of an earthquake coinciding with periods of high water conditions is low. Earthquake impacts on the levee and the potential for liquefaction are not evaluated in this study and will not be required for the final design.

10.0 Geotechnical Investigations Deferred to PED Phase

A geotechnical investigation is to be deferred to PED phase for Alignment I of the Princeville Flood Risk Management project. Current boring data in Alignment I consists of two subsurface Standard Penetration Tests (SPT) borings and one core sample taken in 2006. Drilling, laboratory testing, seepage and stability analysis, and development of a fragility curve for Alignment I is recommended prior to construction. This investigation should include SPT borings along the actual alignment and undisturbed sampling of any shallow fat clay (CH) or soft soil layers that may be present. If it is determined that more borrow is necessary, other areas should also be investigated. Additional subsurface information needed for the selected alternative includes Standard Penetration Test (ASTM D 1586) and Thin-Walled Tube Sampling (ASTM D 1587). Recommended laboratory tests include Particle Size Analysis (ASTM D 422), Moisture Content Determination (ASTM D 2216), Visual Classification (ASTM D 2487), Standard Proctor (ASTM D 698), and Atterberg Limits (ASTM D 4318). After further investigations and testing, all analyses should be reviewed and recalculated, if necessary, utilizing GeoStudio's SEEP/W© and SLOPE/W© programs.

11.0 Foundation Preparation during Construction

As is common in levee construction, the foundation should be properly prepared prior to placement of the embankment to minimize potential problems with stability, settlement, and seepage. This involves clearing and grubbing all woody vegetation, as well as the removal of any debris that may be present. An exploration trench (inspection trench) should be excavated under the levee to intercept any undesirable underground features. These can include water or sewer lines, buried logs, or other debris. Unsuitable materials in the subgrade should be removed and the foundation disked and compacted to bond with the embankment.

12.0 Embankment Placement/Compaction

Much of the existing levee embankment was constructed with clayey sand and lean clay, and has performed well under flooding conditions. For the new embankment levee, similar

performance should be expected with similar soil types. However, it is recommended that for the final design, a minimum percentage of fines be specified for embankment construction to reduce seepage problems developing during a flood event. Underseepage of the new embankment should not be a concern unless the surficial soils encountered are clean sands or gravels. If these materials are encountered, they should be removed to a depth determined in the final design and replaced with soils containing fine-grained material. This will be evaluated prior to construction.

Standard placement procedures to be used during construction of the levee include the repetitive process of disking, placement in lifts, and compaction of the soil to a specified density. Moisture-density control will be required and frequent field density tests performed to assure quality control. Compaction requirements are based on the properties of the borrow material. Compaction, hydraulic conductivity, and direct shear tests were performed on the borrow area samples in the laboratory to determine soil parameters.

13.0 Summary of Results

The following is a summary of geotechnical study results:

a) The stability of Levee A of the existing levee meets the required minimum factor of safety at stations 34+00, 40+00, and 70+00 (calculated factors of safety range from 1.4 to 2.0) based on the assumptions and geotechnical information available. The safety factor of these existing cross sections satisfies the minimum required safety factor of 1.4, as per EM 1110-2-1913. The factor of safety at station 32+00 on the protected side is 1.1, indicating that stability control measures are needed at this location.

b) The rapid drawdown stability analysis of the existing levee meets the minimum factor of safety at stations 32+00, 34+00, 40+00, and 74+00 (minimum factors of safety from 1.0 to 1.03). This satisfies the minimum safety factor of 1.0 as per EM 1110-2-1913.

c) Results of the seepage analysis show through- and under-seepage of the existing levee are minor under short term high water conditions. This appears consistent with the function of the existing levee during flood events. The hydraulic gradients range from -0.326 to 0.265 for the 100 year flood events at all stations. This satisfies the maximum hydraulic gradient of 0.5 as per EM 1110-2-1913.

d) Seepage pore water pressure within the existing levee is minor and the phreatic surface was near the landside toe of the slope. Lateral hydrostatic forces and seepage gradients within the levee and underlying foundation indicate the overall stability of the existing levee is acceptable.

14.0 Recommendations

a) Further analyze proposed berm at Station 32+00 to determine total length of placement.

b) Perform additional subsurface investigation for the alignments of the selected plan. This investigation should be focused along the alignments to define the subsurface conditions and strength parameters of the foundations. The borings should extend deep enough for analysis where sheet piling or wall foundations are proposed.

c) Determine required and available quantities of suitable borrow material and investigate new or expanded borrow areas.

d) Establish recommended placement and compaction requirements for design based on analysis and laboratory data.

e) Perform laboratory testing on representative samples from the selected levee alignments to determine strength parameters and permeability of shallow sandy soils. Perform consolidation tests on any fine-grained soils considered problematic. Perform laboratory compaction tests of expanded borrow area samples as needed for the final design.

f) For the selected plan, perform slope stability analysis and seepage analysis of the levee using SLOPE/W stability software and SEEP/W seepage software and additional subsurface information.

g) Perform final design analysis for any levee walls of the selected plan using additional subsurface information.

h) Perform settlement calculations for the design of the new levee.

i) Review historical aerial photography and topographic information to determine the locations old channels and other drainage features. These historical features may present design challenges.

j) During construction of the selected plan, clear and grub all woody vegetation, as well as the remove any debris that may be present. Unsuitable materials in the subgrade, such as clays and silts, should be removed and the foundation disked and compacted to bond with the embankment.

k) A minimum percentage of fines should be specified for embankment construction to reduce seepage problems developed during a flood event.

l) The stability of the embankment for the final selected plan should be evaluated for the final design using additional subsurface information.

m) The US Highway 64 road fill will be investigated and analyzed to determine if it meets the Corps design standards required for levees.

15.0 Sources Cited

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Table 1. Summary of 2006 and 2009 Boring Data

Boring Name	Easting	Northing	Ground Surface Elevation (ft) MSL	Total Depth (ft)	Date Completed
PD-B-64-1	776319	2435980	50.0	30.0	4/18/2009
PD-B-64-2	776649	2435921	45.0	30.0	4/18/2009
PD-B-64-3	776731	2436009	48.0	15.0	4/18/2009
PD-BP-BA-1	770503	2455035	35.0	15.0	4/14/2009
PD-BP-BA-2	770144	2455406	35.0	15.0	4/14/2009
PD-BP-BA-3	770316	2455889	35.0	15.0	4/14/2009
PD-BP-BA-4	770720	2456152	35.0	15.0	4/15/2009
PD-BP-BA-5	770788	2455600	35.0	15.0	4/15/2009
PD-BP-SS-1	782491	2434632	34.0	15.0	4/15/2009
PD-BP-SS-2	782502	2434579	49.0	30.0	4/15/2009
PD-BP-SS-3	783714	2437544	49.0	30.0	4/15/2009
PD-BP-SS-4	783708	2437393	49.0	30.0	4/16/2009
PD-BP-SS-5	783726	2438337	49.0	30.0	4/16/2009
PD-BP-SS-6	783672	2437420	38.0	15.0	4/17/2009
PD-BP-SS-7	783685	2437520	45.0	15.0	4/17/2009
PD-BP-SS-8	783817	2438339	36.0	15.0	4/17/2009
PD-BP-SS-9	783734	2437425	38.0	15.0	4/17/2009
PD-BP-SS-10	783765	2437525	40.0	15.0	4/17/2009
PD-BP-SS-11	783861	2438341	34.0	15.0	4/17/2009
PFR-06-SS-1	776368	2435605	43.4	25.5	7/19/2006
PFR-06-SS-5	779031	2435326	44.7	30.0	7/20/2006
PFR-06-SS-6	779896	2434686	47.5	31.0	7/20/2006
PFR-06-SS-11	784838	2442112	46.4	15.5	7/18/2006
PFR-06-SS-12	785318	2443114	46.5	15.6	7/18/2006
PFR-06-SS-13	786338	2444685	47.4	15.5	7/18/2006
PFR-06-SS-14	787418	2445659	45.5	15.6	7/18/2006
PFR-06-SS-17	781264	2443542	48.9	15.5	7/19/2006
PFR-06-SS-18	780515	2445158	48.4	15.5	7/19/2006
PFR-06-SS-19	779979	2447467	49.1	15.6	7/19/2006
PFR-06-SS-20	780139	2449866	48.1	15.5	7/18/2006
PFR-06-GP-02	776969	2435606	42.8	30.0	6/29/2006
PFR-06-GP-03	777626	2435580	43.9	30.0	6/29/2006
PFR-06-GP-04	778302	2435487	43.6	30.0	6/29/2006
PFR-06-GP-05	779031	2435326	44.7	30.8	6/28/2006
PFR-06-GP-06	779896	2434686	47.5	30.6	6/28/2006
PFR-06-GP-15	787154	2446244	44.6	15.5	6/29/2006
PFR-06-GP-16	785737	2447024	47.8	15.5	6/29/2006
PFR-06-CS-07	784438	2441259	46.9	4.1	6/22/2006
PFR-06-CS-08	785725	2443958	45.9	4.4	6/22/2006
PFR-06-CS-09	787652	2445863	46.4	4.1	6/22/2006
PFR-06-CS-10	786342	2446693	46.6	3.3	6/22/2006
PFR-06-A-1	776249	2443464		5.0	7/21/2006
PFR-06-A-2	776428	2443654		7.5	7/21/2006
PFR-06-A-3	777217	2444081		5.0	7/21/2006
PFR-06-A-4	778158	2444561		6.5	7/21/2006

Table 2. Summary of Index Testing Results

Boring Name	Stratum Upper Depth (ft)	Stratum Lower Depth (ft)	Sample Number	Soil Description	SPT N-value (blows/ft)	Moisture Content (%)	Percent Passing U.S. Std. No. 200 Sieve (%)	Plasticity Index
PD-BP-64-1	1.5	3.0	2	SILTY SAND, fine-grained, trace of clay, brown (SM)	4	12	23	-
	12.0	13.5	9	SILTY SAND, poorly sorted, fine-grained, little clay, dry, light brown (SM)	18	9	21	-
	27.0	28.5	19	SAND, poorly sorted, fine to coarse-grained, trace of clay, light brown (SP)	30	14	5	-
PD-BP-64-2	1.5	3.0	2	CLAYEY SAND, medium-grained, trace of silt, light brown (SC)	12	10	28	-
	4.5	6.0	4	SILTY SAND, poorly sorted, fine-grained, dark brown (SM)	7	10	39	-
	6.0	7.5	5	CLAYEY SAND, poorly sorted, fine-grained, little silt, reddish brown (SC)	7	15	42	-
	15.0	16.5	11	SAND, poorly sorted, fine to coarse-grained, trace of silt, light brown (SP)	8	16	3	-
	19.5	21.0	14	CLAYEY SAND, fine-grained, trace of silt, dry, greenish gray (SC)	41	18	19	-
	22.5	24.0	16	CLAY, stiff, medium plasticity, little fine-grained sand, trace of silt, greenish gray (CL)	30	19	88	-

Table 2. Summary of Index Testing Results (cont.)

Boring Name	Stratum Upper Depth (ft)	Stratum Lower Depth (ft)	Sample Number	Soil Description	SPT N-value (blows/ft)	Moisture Content (%)	Percent Passing U.S. Std. No. 200 Sieve (%)	Plasticity Index
PD-BP-64-3	3.0	4.5	3	CLAYEY SAND, fine-grained, trace of silt, light brown (SC)	5	15	44	-
	6.0	7.5	5	SAND, poorly sorted, medium-grained, little clay, wet, light gray (SP)	4	21	4	-
	9.0	10.5	7	CLAY, stiff, medium plasticity, little fine-grained sand, trace of silt, woody fragments, green (CL)	8	25	-	25
	12.0	13.5	9	SILTY SAND, poorly sorted, little clay, light gray (SM)	20	22	19	-
	13.5	15.0	10	CLAY, stiff, medium plasticity, some fine-grained sand (CL)	18	21	-	15
PD-BP-BA-1	9.0	10.5	7	SAND with CLAY, poorly sorted, fine and medium-grained, light reddish brown (SP-SC)	5	24	9	-
PD-BP-BA-2	3.0	4.5	3	CLAYEY SAND, poorly sorted, fine-grained, moist, light reddish brown (SC)	3	14	32	-
	12.0	13.5	9	SAND, poorly sorted, fine to medium-grained, light brown (SP)	8	21	2	-
PD-BP-BA-3	0.0	1.5	1	SILTY SAND, fine-grained, trace of clay, trace of organics, brown (SM)	7	2	19	-
	3.0	4.5	3	SAND with CLAY, fine-grained, poorly sorted, light reddish brown (SP-SC)	4	6	8	-
	12.0	13.5	9	SAND with CLAY, poorly sorted, fine and medium-grained, light gray/light brown (SP-SC)	5	20	11	-

Table 2. Summary of Index Testing Results (cont.)

Boring Name	Stratum Upper Depth (ft)	Stratum Lower Depth (ft)	Sample Number	Soil Description	SPT N-value (blows/ft)	Moisture Content (%)	Percent Passing U.S. Std. No. 200 Sieve (%)	Plasticity Index
PD-BP-BA-4	0.0	1.5	1	SILTY SAND, fine-grained, trace of clay, trace of organics, roots, brown (SM)	2	7	15	-
	3.0	4.5	3	SILTY SAND, fine-grained, poorly sorted, trace of silt, light brown (SM)	3	10	16	-
	10.5	12.0	8	CLAYEY SAND, poorly sorted, fine to coarse-grained, little clay, light brown (SC)	7	22	17	-
PD-BP-BA-5	0.0	1.5	1	SILTY SAND, fine-grained, trace of clay, trace of organics, brown (SM)	8	5	22	-
	3.0	4.5	3	CLAYEY SAND, poorly sorted, fine-grained, light brown (SC)	6	8	16	-
	10.5	12.0	8	SAND, poorly sorted, fine and medium-grained, trace of clay, light brown (SP)	2	26	3	-
PD-BP-SS-1	0.0	1.5	1	SILTY SAND, medium-grained, little clay, trace of organics, roots, reddish brown (SM)	4	5	13	-
	3.0	4.5	3	CLAYEY SAND, poorly sorted, medium-grained, trace of silt, light brown (SC)	15	9	14	-
	6.0	7.5	5	CLAY, stiff, low plasticity, little silt, little fine-grained sand, light gray (CL)	9	18	-	15
	10.5	12.0	8	SAND with CLAY, poorly sorted, medium-grained (SP-SC)	7	15	9	-

Table 2. Summary of Index Testing Results (cont.)

Boring Name	Stratum Upper Depth (ft)	Stratum Lower Depth (ft)	Sample Number	Soil Description	SPT N-value (blows/ft)	Moisture Content (%)	Percent Passing U.S. Std. No. 200 Sieve (%)	Plasticity Index
PD-BP-SS-2	1.5	3.0	2	CLAYEY SAND, fine-grained, trace of silt, reddish brown (SC)	10	11	41	-
	6.0	7.5	5	CLAY, soft, low plasticity, some fine-grained sand, trace of silt, reddish brown (CL)	9	13	-	12
	10.5	12	8	CLAYEY SAND, fine-grained, trace of silt, brown (SC)	6	13	39	-
	13.5	15.0	10	CLAY, stiff, medium plasticity, little fine-grained sand, trace of silt, reddish brown (CL)	4	16	-	21
	22.5	24.0	16	SAND, poorly sorted, medium and coarse-grained, light brown (SP)	16	15	2	-
PD-BP-SS-3	0.0	1.5	1	CLAY, stiff, low plasticity, some fine-grained sand, trace of silt, trace of gravel ¾" diameter, reddish brown (CL)	10	10	-	19
	9.0	10.5	7	SAND with CLAY, poorly sorted, fine and medium-grained, trace of silt, reddish brown (SP-SC)	25	5	8	-
	22.5	24.0	16	CLAY, stiff, medium plasticity, some coarse-grained sand, trace of silt, light gray (CL)	10	22	-	22
	27.0	28.5	19	CLAYEY SAND, fine-grained, gray (SC)	28	13	25	-

Table 2. Summary of Index Testing Results (cont.)

Boring Name	Stratum Upper Depth (ft)	Stratum Lower Depth (ft)	Sample Number	Soil Description	SPT N-value (blows/ft)	Moisture Content (%)	Percent Passing U.S. Std. No. 200 Sieve (%)	Plasticity Index
PD-BP-SS-4	4.5	6.0	4	CLAYEY SAND, fine-grained, little silt, brown (SC)	12	10	41	-
	12.0	13.5	9	CLAYEY SAND, poorly sorted, fine-grained, trace of silt, light brown (SC)	14	8	18	-
	25.5	27.0	19	CLAY, stiff, low plasticity, little fine-grained sand, roots, dry, gray (CL)	14	25	-	35
PD-BP-SS-5	4.5	6.0	4	CLAYEY SAND, fine-grained, trace of silt, reddish brown (SC)	8	15	43	-
	13.5	15.0	10	SAND with SILT, poorly sorted, fine-grained, light brown (SP-SM)	34	11	11	-
	18.0	19.5	13	CLAYEY SAND, fine-grained, gray (SC)	6	16	42	-
	24.0	25.5	17	SAND, poorly sorted, medium and fine-grained, trace of clay, white/gray (SP)	5	21	4	-
	28.5	30.0	20	CLAY, stiff, medium plasticity, little fine-grained sand, trace of silt, gray (CL)	35	21	-	27

Table 2. Summary of Index Testing Results (cont.)

Boring Name	Stratum Upper Depth (ft)	Stratum Lower Depth (ft)	Sample Number	Soil Description	SPT N-value (blows/ft)	Moisture Content (%)	Percent Passing U.S. Std. No. 200 Sieve (%)	Plasticity Index
PD-BP-SS-6	0.0	1.5	1	CLAY, sandy, trace of silt, roots, reddish brown (CL)	5	15	52	-
	4.5	6.0	4	SAND with CLAY, poorly sorted, fine-grained, light brown (SP-SC)	28	6	10	-
	9.0	10.5	7	CLAY, soft, low plasticity, some fine-grained sand, trace of silt, gray (CL)	4	18	-	11
	12.0	13.5	9	CLAYEY SAND, coarse and fine-grained, trace of silt, gray (SC)	10	15	40	-
PD-BP-SS-7	0.0	1.5	1	CLAYEY SAND, fine-grained, trace of silt, roots, reddish brown (SC)	5	8	20	-
	4.5	6.0	4	SAND with CLAY, poorly sorted, fine and medium-grained, light brown (SP-SC)	30	7	8	-
	9.0	10.5	7	CLAY, stiff, medium plasticity, trace of silt, roots, gray (CL)	3	17	-	13
	12.0	13.5	9	CLAYEY SAND, coarse-grained, trace of silt, light gray (SC)	9	12	39	-

Table 2. Summary of Index Testing Results (cont.)

Boring Name	Stratum Upper Depth (ft)	Stratum Lower Depth (ft)	Sample Number	Soil Description	SPT N-value (blows/ft)	Moisture Content (%)	Percent Passing U.S. Std. No. 200 Sieve (%)	Plasticity Index
PD-BP-SS-8	0.0	1.5	1	CLAY, stiff, low plasticity, some fine-grained sand, trace of silt, roots, reddish brown (CL)	8	13	-	18
	4.5	6.0	4	CLAYEY SAND, poorly sorted, medium and fine-grained, little organics, light gray (SC)	20	8	21	-
	7.5	9.0	6	SILTY SAND, fine-grained, trace of clay, moist, dark gray (SM)	29	16	27	-
	9.0	10.5	7	SILTY SAND, fine grained, some clay, reddish brown (SM)	5	22	19	-
	12.0	13.5	9	CLAYEY SAND, fine-grained, poorly sorted, trace of silt, gray (SC)	2	25	13	-
PD-BP-SS-9	0.0	1.5	1	CLAYEY SAND, fine-grained, trace of silt, roots, reddish brown (SC)	12	7	19	-
	4.5	6.0	4	CLAYEY SAND, fine-grained, poorly sorted, trace of silt, light brown (SC)	10	11	27	-
	11.0	12.0	8	CLAYEY SAND, trace of silt, moist, gray (SC)	6	15	39	-

Table 2. Summary of Index Testing Results (cont.)

Boring Name	Stratum Upper Depth (ft)	Stratum Lower Depth (ft)	Sample Number	Soil Description	SPT N-value (blows/ft)	Moisture Content (%)	Percent Passing U.S. Std. No. 200 Sieve (%)	Plasticity Index
PD-BP-SS-10	0.0	1.5	1	CLAYEY SAND, fine-grained, trace of silt, roots, reddish brown (SC)	12	6	24	-
	3.5	4.5	3	CLAYEY SAND, poorly sorted, fine-grained, trace of silt, reddish brown (SC)	12	11	30	-
PD-BP-SS-11	3.0	4.5	3	SAND with CLAY, poorly sorted, fine-grained, trace of silt, reddish brown (SP-SC)	17	10	12	-
	10.5	12.0	8	CLAYEY SAND, poorly sorted, medium-grained, moist, light brown (SC)	10	12	16	-

Table 3. Summary of Compaction Test Results

Sample ID	Sample Description	Optimum Moisture Content (%)	Maximum Dry Density (lb/ft3)
Box 1	Light brown sand with clay, trace roots	12.8	112.4
Box 2	Light brown sand with silt, trace roots	11.0	115.4
Box 3	Light brown sand with trace roots	16.0	108.7

Table 4. Summary of Hydraulic Conductivity Test Results

Sample ID	Initial Dry Density (pcf)	Final Moisture Content (%)	Initial Void Ratio	Vertical Hydraulic Conductivity (cm/sec)
Box 1	107.42	20.22	0.569	4.2 x 10-4
Box 1	107.1	20.27	0.544	9.4 x 10-4
Box 2	109.32	20.15	0.542	1.6 x 10-3
Box 2	110.53	19.56	0.525	4.4 x 10-3
Box 3	101.71	21.05	0.627	2.1 x 10-2
Box 3	101.56	21.82	0.629	2.4 x 10-2

Table 5 Summary of Direct Shear Test Results

Sample ID	Sample Description	Percent By Weight Passing the No. 200 sieve (%)	Cohesion, C (psf)	Effective friction angle (degrees)
Box 1	Brown clayey sand	14.6	144	34.8
Box 1	Brown clayey sand	13.8		
Box 1	Brown clayey sand	15.9		
Box 2	Brown medium to fine sand with silt	11.7	0	41.3
Box 2	Brown medium to fine sand with silt	12		
Box 2	Brown medium to fine sand with silt	11.9		
Box 3	Yellowish-brown medium to fine sand	2	0	40.3
Box 3	Yellowish-brown medium to fine sand	2.4		
Box 3	Yellowish-brown medium to fine sand	3.1		

Table 6 Seepage Results

Station 32+00					
Flood Event	**Riverside Elevation**	**Landside Toe Elevation**	**X-Gradient**	**Y-Gradient**	**XY-Gradient**
5 Year	42 ft	40 ft	0.192	0.100	0.217
50 Year	45 ft	40 ft	0.212	0.187	0.283
100 Year	48 ft	40 ft	0.224	0.245	0.331

Station 38+00					
Flood Event	**Riverside Elevation**	**Landside Toe Elevation**	**X-Gradient**	**Y-Gradient**	**XY-Gradient**
5 Year	42 ft	39 ft	-0.044	-0.345	0.347
50 Year	45 ft	39 ft	-0.040	-0.335	0.337
100 Year	48 ft	39 ft	-0.036	-0.326	0.328

Station 40+00					
Flood Event	**Riverside Elevation**	**Landside Toe Elevation**	**X-Gradient**	**Y-Gradient**	**XY-Gradient**
5 Year	42 ft	39 ft	0.089	-0.195	0.214
50 Year	45 ft	39 ft	0.077	-0.088	0.117
100 Year	48 ft	39 ft	0.064	0.042	0.076

Station 74+00					
Flood Event	**Riverside Elevation**	**Landside Toe Elevation**	**X-Gradient**	**Y-Gradient**	**XY-Gradient**
5 Year	38 ft	34 ft	0.166	0.110	0.199
50 Year	42 ft	34 ft	0.198	0.204	0.284
100 Year	48 ft	34 ft	0.208	0.265	0.337

Table 7 Stability Results

Station 32+00	
Slope Stability Factor of Safety	1.069
Rapid Drawdown Stability Factor of Safety	1.027

Station 38+00	
Slope Stability Factor of Safety	1.879
Rapid Drawdown Stability Factor of Safety	1.011

Station 40+00	
Slope Stability Factor of Safety	2.003
Rapid Drawdown Stability Factor of Safety	0.996

Station 74+00	
Slope Stability Factor of Safety	1.413
Rapid Drawdown Stability Factor of Safety	0.999

Table 8 Soil Characteristics

Station	Boring Name	Soil Description	Saturated Unit Weight (pcf)	Φ' (Degrees)	Cohesion (psf)
32+00	**PD-BP-SS-5, PD BP-SS-8, PD-BP-SS-11**	Loose Sands (SP) to Clayey Sands (SC)	120-125	28-30	-
		Medium dense to dense silty sands (SM) to clayey sands (SC)	125-135	33-36	-
		Stiff Clay (CL)	130-135	-	1000-2000
34+00	**PD-BP-SS-3, PD-BP-SS-7, PD-BP-SS-10**	Medium dense to dense sands (SP), sands with clay (SP-SC), and clayey sands (SC)	120-125	31-35	-
		Very loose to medium dense silty sands (SM) and clayey sands (SC)	120-135	29-35	-
		Medium stiff to stiff clay (CL)	130-135	-	1000
		Medium dense silty sands (SM), and clayey sands (SC)	125-135	31-34	-
		Stiff Clay (CL)	120-125	-	1000-1200
40+00	**PD-BP-SS-4, PD-BP-SS-6, PD-BP-SS-9**	Loose to medium dense silty sand (SM) and clayey sand (SC)	120-125	30-34	-
		Very loose to loose silty sands (SM) and clayey sands (SC)	120-125	29-31	
		Very stiff clay (CL)	125-135	-	1000-2000
74+00	**PD-BP-SS-1, PD-BP-SS-2**	Loose to medium dense clayey sands (SC)	115-120	30-31	-
		Loose to dense silty sands (SM), and clayey sands (SC)	120-125	30-35	-
		Loose to medium dense sands (SP) and sands with clay (SP-SC)	120-125	30-32	-