Geotechnical Engineering Report

Landing Ditch Slope Evaluation

League City, Texas

April 28, 2017

Terracon Project No. 91175006

Prepared for:

ARKK Engineers
Houston, Texas

Prepared by:

Terracon Consultants, Inc.
League City, Texas

Terracon

April 28, 2017

ARKK Engineers
7322 Southwest Freeway, Suite 1040
Houston, Texas 77074

Attn: John Rudloff, P.E.

Re: Geotechnical Engineering Report
Landing Ditch Slope Evaluation
FM 518 and Landing Boulevard
League City, Texas
Terracon Project No. P91175006

Dear Mr. Rudloff:

Terracon Consultants, Inc. (Terracon) is pleased to submit our geotechnical engineering report for the project referenced above in League City, Texas. We trust that this report is responsive to your project needs. Please contact us if you have any questions or if we can be of further assistance.

We appreciate the opportunity to work with you on this project and look forward to providing additional geotechnical engineering and construction materials testing services in the future.

Sincerely,
Terracon Consultants, Inc.
(Texas Firm Registration No.: F-3272)

Rehan Khan

Rehan Khan, E.I.T.
Staff Geotechnical Engineer

Brett Pope

Brett A. Pope, P.E.
Project Manager

for: Patrick M. Beecher, P.E.
Geotechnical Services Manager

STATE OF TEXAS
BRETT POPE
111644
LICENSED
PROFESSIONAL ENGINEER

Copies Submitted: (1) Electronic

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EXECUTIVE SUMMARY

This geotechnical engineering report has been prepared for evaluating the local slope movement leading to tilting of the adjacent storage facility fence along the western bank at the northern end of Landing ditch in League City, Texas. One boring, designated B-1, was drilled on top of the crest of ditch, one boring, designated B-2, was drilled inside the adjacent storage facility, and one boring, designated B-3, was drilled on the slope about 10 feet below the crest. Borings B-1 through B-3 were drilled to a depth of about 40 feet below existing grade in the areas of the observed slope movement.

Based on the information obtained from our subsurface exploration, the following geotechnical considerations were identified:

- Groundwater was not observed at borings B-1 through B-3 during or upon completion of drilling.

- Based on a site visit, tension cracks were observed along the depressed section of the ditch.

- Based on the above observation, the soils observed during our field program, and the results of our laboratory program, the presence of high plasticity clay soils, which are susceptible to desiccation and subsequent cracking during periods of dry weather, has likely contributed to the slope movement.

- To achieve a minimum factor of safety for long term and rapid drawdown global stability, we have presented slope repair options including installation of a sheetpile wall along the slope, removal of in-situ soils and replacement with cement stabilized sand (CSS) soils, backfilling with CSS soils, and their combination. The final sideslope configuration should be 3.5H:1V or flatter and a 15-foot wide shelf should be constructed between the adjacent storage facility fence and crest of the slope. In addition, the adjacent pavement between the edge of the pavement and the nearest expansion joint should be removed in order to access the underlying subgrade. Any existing voids should be backfilled and wet/weak soils should be removed and replaced with CSS or flowable fill.

This executive summary should be used in conjunction with the entire report for design purposes. Details were not included or fully developed in this section, and the report must be read in its entirety for a comprehensive understanding of the items contained herein. The section titled **"5.0 GENERAL COMMENTS"** should be read for an understanding of the report limitations.

GEOTECHNICAL ENGINEERING REPORT
LANDING DITCH SLOPE EVALUATION
LEAGUE CITY, TEXAS
Project No. 91175006
April 28, 2017

1.0 INTRODUCTION

Terracon is pleased to submit our geotechnical engineering report prepared for evaluating the local slope movement along the western bank at the northern end of Landing ditch in League City, Texas. This project was authorized by Mr. John Rudloff, P.E., Senior Project Manager with ARKK Engineers, through signature of the client's 'Agreement for Services' on February 9, 2017. The project scope was performed in general accordance with Terracon Document No. P91175006, dated January 16, 2017.

The purpose of this report is to describe the subsurface conditions observed at the three borings, analyze and evaluate the test data, and provide recommendations with respect to:

- Slope stability analyses at the slope failure cross section with recommended improvements;
- Slope reconstruction methods; and
- Slope protection and erosion control.

2.0 PROJECT INFORMATION

2.1 Project Description

Item	Description
Project location	The project site is the existing Landing ditch located at the northeast quadrant of the intersection of FM 518 and Landing Boulevard in League City, Texas. See Appendix A, Exhibit A-1, Site Location Plan.
Site layout	See Appendix A, Exhibit A-2, Boring Location Plan.
Proposed improvements	Reconstruction of sideslopes that have exhibited movement.

2.2 Site Description

Item	Description
Existing conditions	■ Based on information from the client, Landing ditch drains into Clear Creek, which is tidally influenced. Therefore, the water level within the ditch is influenced by both rainfall and storm surge. ■ Based on a survey report provided by the client, the existing ditch is 18 feet deep. The area of interest is an approximate 100-foot section along the western bank on the northern end of the ditch. Evidence of tension cracks, depression of the sideslopes, and leaning of adjacent fencing were observed along this section. ■ No slope movement was observed or reported at the southern end of the ditch. ■ Based on information obtained from the City of League City, we understand that the sideslopes at the southern end of the ditch was repaired using cement stabilized sand in 2000-2001. No repair was performed at the northern end which has currently undergone movement.
Existing sideslopes	Based on a survey performed on the ditch after our field program, the sideslopes of the ditch vary from about 2.5H:1V to 3H:1V at the southern end where no slope movement was observed and about 4H:1V at the north end where the slopes have undergone movement. Sideslope configurations prior to slope movement were not available.
Current ground cover	Grass and few trees along slopes and at the crest of the slope.

3.0 SUBSURFACE CONDITIONS

3.1 Geology

Based on the geologic maps published by the Bureau of Economic Geology, the site for the proposed construction is located on the Beaumont formation, a deltaic nonmarine Pleistocene deposit. The Beaumont formation is heterogeneous containing thick interbedded layers of clay, fine sand, and silt.

The coastal plain in this region has a complex tectonic geology, several major features of which are: Gulf Coastal geosyncline, salt domes, and major sea level fluctuations during the glacial stages, subsidence and geologic faulting activities. Most of these geologic faulting activities have ceased for millions of years, but some are still active. A detailed geologic fault investigation and study of the site geology are beyond the scope of this report.

3.2 Typical Profile

The particular subsurface stratigraphy, as evaluated from our field and laboratory programs, is shown in detail on the Boring Logs in Appendix A. Stratification boundaries on the Boring Logs represent the approximate location of changes in soil types; in-situ, the transition between materials may be gradual.

Fill soils were observed at boring B-1 at the ground surface and extended to a depth of about 2 feet. The native subsurface soils generally consisted of fat clay and lean clay soils to the termination depth (approximately 40 feet) of the borings.

Based on our field and laboratory programs, the subsurface conditions can be summarized as follows:

Subsurface Soils					
Description	**Plasticity Index**	**Moisture Content (%)**	**Moisture Content vs. Plastic Limit**[1]	**Undrained Shear Strength**[2] **(psf)**	**Percentage of Fines**[3] **(%)**
Fill: Fat Clay	---	---	---	0.75[4]	---
Fat Clay	38 to 61	19 to 36	-2 to +17	700 to 2,700	96 to 99
Lean Clay	---	---	---	0.5 to 4.0[4]	---

1. The difference between a soil sample's moisture content and its corresponding plastic limit.
2. Based on unconfined compression strength tests.
3. Percent passing the No. 200 sieve.
4. Hand penetrometer reading in tons per square feet (tsf).

3.3 Triaxial Compression Test Results

To obtain site specific soil parameters for performing slope stability analysis, triaxial compression tests were performed on selected soil samples. The triaxial compression tests were performed under a Consolidated-Undrained (CU) condition with pore pressure measurements. The test results are summarized below and are also included in Appendix B.

Consolidated-Undrained Triaxial Test Results						
Boring No.	**Depth[1] (feet)**	**Soil Description**	**Total Stress**		**Effective Stress**	
			c (psf)	**ϕ (deg)**	**c' (psf)**	**ϕ' (deg)**
B-1	28 – 30	Fat Clay (CH)	197	7.1	185	14.2
B-2	6 – 8	Fat Clay (CH)	182	10.6	95	22.5
B-3	18 – 20	Fat Clay (CH)	370	8	324	17.2

1. Approximate depth below existing grade at the time of our field activities.

3.4 Dispersion Potential

Three crumb tests and three pinhole tests were performed for evaluation of the dispersive nature of the on-site clay soils. The results are summarized below.

Dispersive Potential Test Results				
Boring No.	**Sample Depth (feet)**	**Soil Description**	**Crumb Test Grade**	**Pinhole Test Results**
B-1	10 – 12	Fat Clay (CH)	2	Non-Dispersive, ND1
B-2	2 – 4	Fat Clay (CH)	1	Non-Dispersive, ND1
B-3	13 – 15	Fat Clay (CH)	2	Non-Dispersive, ND1

The crumb test may be used as an indicator of field performance of dispersive soils using the following evaluation of soil crumb reaction:

- Grade 1: No dispersion potential.
- Grade 2: Possible dispersion potential.
- Grade 3 or 4: Definite dispersion potential.

The classification of the dispersive characteristics of soils using the pinhole test is described below:

- D1, D2: Dispersive clays which erode rapidly.
- ND3, ND4: Slightly to moderately dispersive clays which erode slowly.
- ND1, ND2: Non-dispersive clays with very slight to no erosion potential.

Based on the pinhole test results, the on-site clay soils are non-dispersive in nature.

3.5 Groundwater

The borings were advanced by dry drilling to their termination depth (about 40 feet) in an effort to evaluate groundwater conditions at the time of our field program. Groundwater was not observed at borings B-1 through B-3 during or upon completion of drilling.

These groundwater observations are considered short-term, since the borings were open for a short time period. On a long-term basis, groundwater may be present at the depths explored. Additionally, groundwater will fluctuate seasonally with climatic changes and should be evaluated at the time of construction.

4.0 RECOMMENDATIONS FOR DESIGN AND CONSTRUCTION

The following recommendations are based upon the data obtained in our field and laboratory programs, project information provided to us, and on our experience with similar subsurface and site conditions.

4.1 Evaluation of Slope Movement and Repair Methods

We have developed the following conclusions and recommendations for the northern end of the ditch that exhibited slope movement.

- Based on a site visit, tension cracks were observed along the depressed section of the ditch.
- Based on our field and laboratory programs, high plasticity clay soils were observed in borings B-1 through B-3. These soils are susceptible to volumetric change with changes in their moisture contents.
- Based on the information presented above, presence of high plasticity clay soils which are susceptible to cracking during periods of dry weather has likely contributed to the observed slope movement. Cracks within the subgrade would get filled with water during a rain event which would exert hydrostatic loading on the slope.
- Based on email correspondence with ARKK Engineers, we understand that the water level within this ditch may fluctuate very quickly due to its influence by both rainfall and storm surge. We analyzed the following two rapid drawdown cases: a) where the water level was assumed to be at the top of the bank outside the ditch and at a depth of 10 feet within the ditch (8 feet of freeboard), and b) where the water level was assumed to be at the top of the bank outside the ditch and at the surface of the sideslopes and at the bottom inside the ditch.

- The various slope repair methods for the two cases are discussed below. The final sideslope configuration should be 3.5H:1V or flatter and a 15-foot wide shelf should be constructed between the adjacent storage facility fence and crest of the slope. In addition, the adjacent pavement between the edge of the pavement and the nearest expansion joint should be removed in order to access the underlying subgrade. Any existing voids should be backfilled and wet/weak soils should be removed and replaced with CSS or flowable fill. The limits of repair, the height of sheetpile wall and the thicknesses of fill required, and the factors of safety obtained are shown on the attached Exhibits C-1 through C-8. We understand that a detailed design of the sheetpile wall for this project is to be performed by others. The fill soils should be properly placed and compacted per recommendations provided in "**4.3 Earthwork"** section of this report.
  - Rapid drawdown with water level inside the ditch assumed at 10 feet below the crest:
    - The existing soils should be replaced with one foot of embankment fill underlain by 5 feet of cement stabilized sand, or
    - A 15-foot deep sheetpile wall should be installed at a location 15 feet upslope from the toe of the ditch; the existing soils downslope of the wall should be replaced with one foot of embankment fill; and the existing soils upslope of the wall should be replaced with one foot of embankment fill underlain by 2 to 3 feet of cement stabilized sand, or
    - A 20-foot deep sheetpile wall should be installed at the middle of the slope; the existing soils downslope of the wall should be replaced with one foot of embankment fill underlain by one foot of cement stabilized sand; and the existing slope upslope of the wall should be backfilled with embankment fill (one foot thick) and cement stabilized sand.
  - Rapid drawdown with water level at the surface of the sideslopes and at the bottom inside the ditch:
    - A 26-foot deep sheetpile wall should be installed at a location 15 feet upslope from the toe of the ditch; the existing soils downslope of the wall should be replaced with one foot of embankment fill; and the existing soils upslope of the wall should be replaced with one foot of embankment fill underlain by 3 feet of cement stabilized sand, or
    - A 30½-foot deep sheetpile wall should be installed at the middle of the slope; the existing soils downslope of the wall should be replaced with one foot of embankment fill; and the existing slope upslope of the wall should be backfilled with embankment fill (one foot thick) and cement stabilized sand.

4.2 Slope Stability Analyses

Global stability analyses were performed for the recommended repair methods as discussed in "**4.1 Evaluation of Slope Movement and Repair Methods"** section utilizing a commercial slope stability software program, SLIDE. This software calculates the factor of safety against slope failure using a two-dimensional limiting equilibrium method. The factors of safety for analyzing slope stability were computed utilizing the Bishop (simplified) method.

Based on the field and laboratory test results and our experience with similar subsurface soil conditions, the strength parameters presented in the following table were used in the slope stability analysis.

Summary of Soil Parameters for Slope Stability Analysis				
Soil Description	**Depth (feet)**	**Total Unit Weight (pcf)**	**Long Term/Rapid Drawdown**	
			c' (psf)	**ϕ' (deg)**
Embankment Fill	-	120	180	19
Cement Stabilized Sand	-	120	1500	0
Fat Clay	0 – 10	125	20	20
Fat Clay	10 – 25	125	20	16
Fat Clay	25 – 40	125	150	15

Where,

c' Consolidated-Drained Cohesion
ϕ' Consolidated-Drained Friction Angle

Utilizing these soil parameters, a 3.5H:1V sideslope configuration, and recommended improvements within the limits described in "**4.1 Evaluation of Slope Movement and Repair Methods"** section, we obtained factors of safety which either exceed or meet the minimum required factor of safety of 1.25 for rapid drawdown conditions and 1.5 for long term conditions. The results of the analyses are presented in Appendix C.

4.3 Earthwork

Construction areas along the slope should be stripped of vegetation, topsoil, concrete pavement, and other debris/unsuitable surface material and properly de-mucked. De-mucking should include the removal of all soft and wet soils in order to expose firm native subgrade or competent material. Proper site drainage should be maintained during construction so that ponding of surface runoff does not occur and cause construction delays and/or inhibit site access.

Once initial site stripping is completed to expose the native subgrade and the required depth of on-site soils have been removed, any loose soil present should be removed prior to fill placement. Embankment fill should be compacted to at least 95 percent of the Standard Effort (ASTM D 698) maximum dry density at a moisture content between optimum and 4 percent wet the optimum moisture content. The use of a sheepsfoot roller is recommended to help knead the clays and break up any secondary structures within the clays. Cement stabilized sand should be compacted and moisture conditioned in accordance with HCFCD Specification 02321. The loose thickness of the lifts for the fill along sideslopes and bottom should be approximately 8 to 9 inches (maximum) with a compacted lift thickness not to exceed 6 inches. Fill should be placed on a flat level surface in horizontal lifts.

The sideslopes of the ditch should be benched as backfilling proceeds. Benching the sideslopes will improve compaction capabilities and reduce the potential for separation between the newly placed fill and existing in-situ soils. The benches should be limited to a maximum height of 18 inches. Care should be taken to provide relatively uniform compaction throughout the entire slope. The placement of the fill material for the replacement of the slope should be continuously observed by an experienced soil technician.

Embankment fill soils should have a Plasticity Index (PI) between 10 and 35 and should classify as a CL or CH soil in accordance with the Unified Soil Classification System (USCS).

If flowable fill is utilized to backfill the voids underneath the pavement within the storage facility, it should meet the applicable requirements stated in Harris County Item 434. The compressive strength of the flowable fill should be maintained between 50 and 100 pounds per square inch (psi).

Prior to any filling operations, samples of the proposed borrow materials should be obtained for laboratory moisture-density testing. The tests will provide a basis for evaluation of fill compaction by in-place density testing. A qualified soil technician should perform sufficient in-place density tests during the filling operations to evaluate that proper levels of compaction, including dry unit weight and moisture content, are being attained.

4.3.1 Wet Weather/Soft Subgrade Considerations

Construction operations may encounter difficulties due to wet or soft surface soils becoming a general hindrance to equipment, especially following periods of wet weather. If the subgrade cannot be adequately compacted to the minimum densities as described previously, one of the following measures will be required: 1) removal and replacement with select fill, 2) chemical treatment of the soil to dry and improve the condition of the subgrade, or 3) drying by natural means if the schedule allows. Based on our experience with similar soils in this area, chemical treatment is an efficient and effective method to improve the condition of wet and weak subgrade. Terracon should be contacted for additional recommendations if chemical treatment is planned due to soft and wet subgrade.

4.4 Slope Protection and Erosion Control

If water flow is permitted along the sideslopes of the ditch, the near-surface soils will likely erode, causing gradual steepening and subsequent sloughing of the sideslopes. Therefore, the sideslopes should be protected against sheet flow down the banks and concentrated high velocity water flow. Measures to protect the sideslopes may include slope paving, rip-rap, geofabrics, or vegetation with an aggressive root system. Preventative maintenance should be planned and provided for the sideslopes at the site. Preventative maintenance activities are intended to slow the rate of erosion, and consist of both localized maintenance (e.g. regrading and/or removal and recompaction of affected areas) and global maintenance (e.g. removal and recompaction of the sideslope surficial soils).

5.0 GENERAL COMMENTS

Terracon should be retained to review the final design plans and specifications so comments can be made regarding interpretation and implementation of our geotechnical engineering report in the design and specifications. Terracon also should be retained to provide observation and testing services during grading and other earth-related construction phases of the project.

The analyses and results presented in this report are based upon the data obtained from the borings performed at the indicated locations and from other information discussed in this report. This report does not reflect variations that may occur in between borings, across the site, or due to the modifying effects of weather. The nature and extent of such variations may not become evident until during or after construction. If variations appear, we should be immediately notified so that further evaluation can be provided.

The scope of services for this project does not include either specifically or by implication any environmental or biological (e.g., mold, fungi, and bacteria) assessment of the site or identification or prevention of pollutants, hazardous materials or conditions. If the owner is concerned about the potential for such contamination or pollution, other services should be undertaken.

This report has been prepared for the exclusive use of our client for specific application to the project discussed and has been prepared in accordance with generally accepted geotechnical engineering practices. No warranties, either express or implied, are intended or made. Site safety, excavation support, and dewatering requirements are the responsibility of others. In the event that changes in the nature, design, or location of the project as outlined in this report are planned, the conclusions contained in this report shall not be considered valid unless Terracon reviews the changes and either verifies or modifies the conclusions of this report in writing.

APPENDIX A

FIELD EXPLORATION

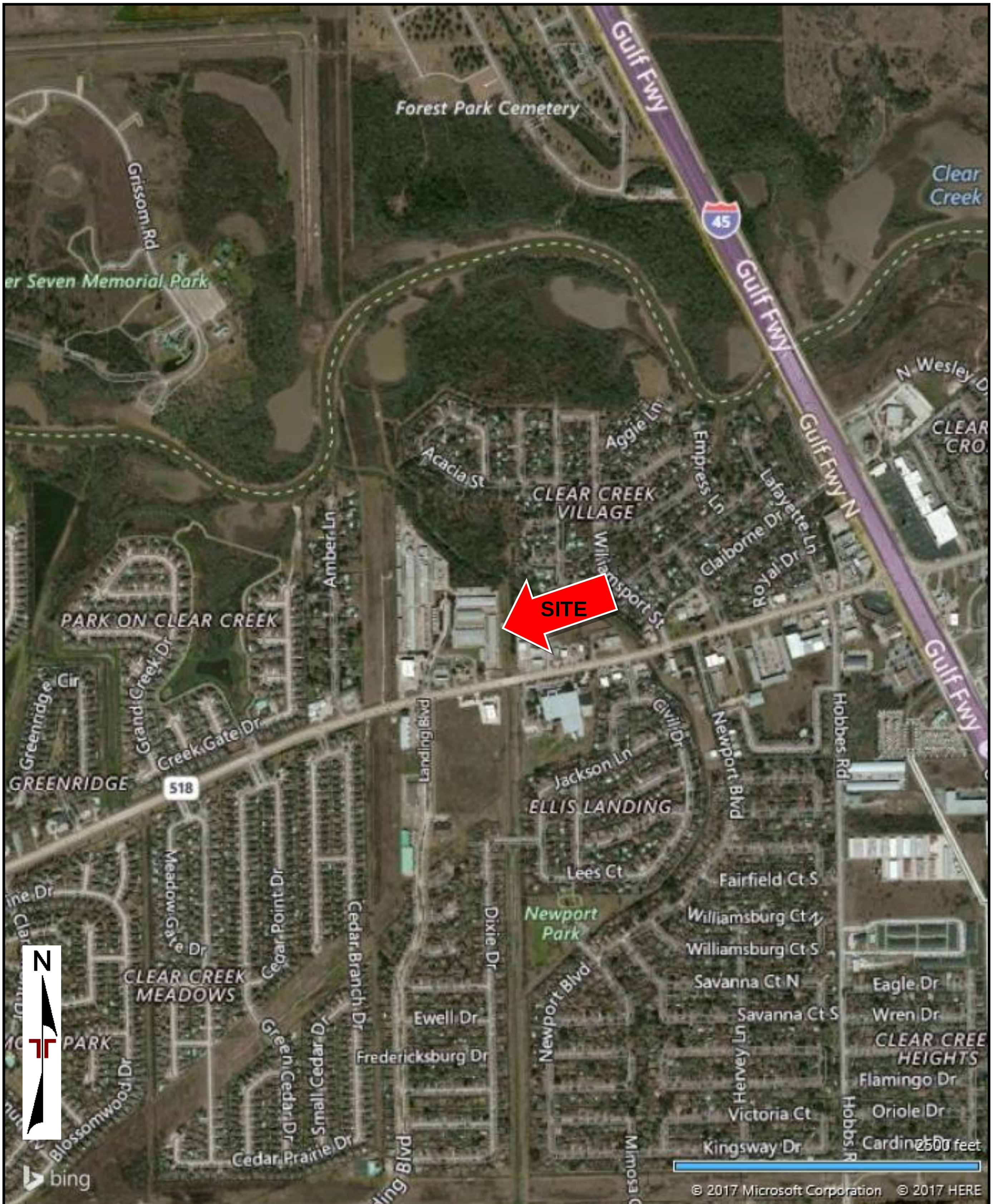


DIAGRAM IS FOR GENERAL LOCATION ONLY, AND IS NOT INTENDED FOR CONSTRUCTION PURPOSES

AERIAL PHOTOGRAPHY PROVIDED BY MICROSOFT BING MAPS

Project Manager: RK	Project No. 91175006	Terracon	SITE LOCATION PLAN	Exhibit
Drawn by: RK	Scale: AS SHOWN	551 League City Pkwy Ste F	Landing Ditch Slope Evaluation	A-1
Checked by: BP	File Name: CAD	League City, TX 77573-5463	FM 518 and Landing Boulevard	
Approved by: PB	Date: 3/9/2017		League City, Texas	

DIAGRAM IS FOR GENERAL LOCATION ONLY, AND IS NOT INTENDED FOR CONSTRUCTION PURPOSES

AERIAL PHOTOGRAPHY PROVIDED BY MICROSOFT BING MAPS

Project Manager: RK	Project No. 91175006	Terracon	BORING LOCATION PLAN	Exhibit
Drawn by: RK	Scale: AS SHOWN	551 League City Pkwy Ste F	Landing Ditch Slope Evaluation	A-2
Checked by: BP	File Name: CAD	League City, TX 77573-5463	FM 518 and Landing Boulevard	
Approved by: PB	Date: 3/9/2017		League City, Texas	

Field Exploration Description

Subsurface conditions were evaluated by drilling one boring, designated B-1, on top of the crest of ditch, one boring, designated B-2, inside the adjacent storage facility, and one boring, designated B-3, on the slope about 10 feet below the crest. Borings B-1 through B-3 were drilled to a depth of about 40 feet below existing grade in the areas of the observed slope movement.

The borings were drilled using all-terrain vehicle (ATV) mounted drilling equipment at the approximate locations shown on the Boring Location Plan, Exhibit A-2 of Appendix A. The borings were located by measuring from a hand-held Global Positioning System (GPS) unit with an accuracy of approximately ± 25 feet. Boring depths were measured from the existing grade at the time of our field activities. Upon completion of our field program, the borings were backfilled using soil cuttings.

The Boring Logs presenting the subsurface soil descriptions, type of sampling used, and additional field data, are presented on Exhibits A-4 through Exhibit A-6 of Appendix A. The General Notes, which define the terms used on the Boring Log, are presented on Exhibit D-1. The Unified Soil Classification System is presented on Exhibit D-2 of Appendix D.

Soil samples obtained from the boring were generally recovered using open-tube samplers. Hand penetrometer tests were performed on samples of cohesive soils to serve as a general measure of consistency.

Samples obtained from the boring were removed from samplers in the field, visually classified, and appropriately sealed in sample containers to preserve their in-situ moisture contents. Samples were returned to our laboratory in Houston, Texas.

BORING LOG NO. B-1

PROJECT: Landing Ditch Slope Evaluation

CLIENT: ARKK Engineers
Houston, Texas

SITE: FM 518 and Landing Boulevard
League City, Texas

LOCATION See Exhibit A-2

Latitude: 29.50222° Longitude: -95.12446°

GRAPHIC LOG DEPTH	DESCRIPTION	DEPTH (Ft.)	WATER LEVEL OBSERVATIONS	SAMPLE TYPE	FIELD TEST RESULTS	STRENGTH TEST: TEST TYPE	STRENGTH TEST: COMPRESSIVE STRENGTH (tsf)	STRENGTH TEST: STRAIN (%)	WATER CONTENT (%)	DRY UNIT WEIGHT (pcf)	ATTERBERG LIMITS LL-PL-PI
2.0	**FILL - FAT CLAY (CH)**, gray and tan, with ferrous nodules and crushed stones				0.75 (HP)						
	FAT CLAY (CH), gray, medium stiff to very stiff, with ferrous nodules				1.5 (HP)	UC	1.13	6.4	27	93	
		5			1.5 (HP)				26		68-20-48
					2.25 (HP)						
	- light gray and tan, with slickensides 8 to 10 feet				2.0 (HP)	UC	0.88	4.8	19	106	63-21-42
	- tan and light gray 10 to 36 feet	10			2.0 (HP)						
		15			3.5 (HP)						
		20			3.0 (HP)				27		73-21-52
		25			3.5 (HP)						
		30			4.0 (HP)						
		35			3.5 (HP)						
	- reddish brown and tan below 36 feet										
40.0		40			4.5 (HP)	UC	2.70	8.3	26	98	72-22-50
	Boring Terminated at 40 Feet										

Stratification lines are approximate. In-situ, the transition may be gradual.

Advancement Method:
Dry augered to 40 feet.

Abandonment Method:
Backfilled with auger cuttings.

See Exhibit A-3 for description of field procedures.

See Appendix B for description of laboratory procedures and additional data (if any).

See Appendix C for explanation of symbols and abbreviations.

Notes:

WATER LEVEL OBSERVATIONS

No free water observed during augering.

551 League City Pkwy Ste F
League City, TX

Boring Started: 1/26/2017	Boring Completed: 1/26/2017
Drill Rig: All-Terrain Vehicle	Driller: Diamond Geo
Project No.: 91175006	Exhibit: A-4

BORING LOG NO. B-2

PROJECT: Landing Ditch Slope Evaluation

CLIENT: ARKK Engineers Houston, Texas

SITE: FM 518 and Landing Boulevard League City, Texas

LOCATION See Exhibit A-2

Latitude: 29.50247° Longitude: -95.1245°

DEPTH	Description	Depth (Ft.)	Water Level Observations	Field Test Results	Test Type	Compressive Strength (tsf)	Strain (%)	Water Content (%)	Dry Unit Weight (pcf)	Atterberg Limits LL-PL-PI
0.3	**PAVEMENT**, Approximately 4 inches of concrete									
	FAT CLAY (CH), gray, stiff to very stiff, with ferrous nodules			2.5 (HP)				26		59-20-39
				3.0 (HP)						
	- light gray, 4 to 8 feet	5		2.0 (HP)	UC	1.00	9.9	33	94	64-26-38
				1.75 (HP)						
	- tan and light gray 8 to 32 feet			2.75 (HP)						
		10		3.5 (HP)						
				4.0 (HP)	UC	1.76	9.8	26	100	
		15								
				4.0 (HP)						
		20								
	- with slickensides 23 to 25 feet			4.5 (HP)	UC	1.82	3.2	28	96	
		25								
				4.5 (HP)						
		30								
	- reddish brown and light gray below 32 feet			4.5 (HP)	UC	2.67	8.9	29	96	76-22-54
		35								
40.0		40		4.5 (HP)						
	Boring Terminated at 40 Feet									

Stratification lines are approximate. In-situ, the transition may be gradual.

Advancement Method:
Dry augered to 40 feet.

Abandonment Method:
Backfilled with auger cuttings.

See Exhibit A-3 for description of field procedures.

See Appendix B for description of laboratory procedures and additional data (if any).

See Appendix C for explanation of symbols and abbreviations.

Notes:

WATER LEVEL OBSERVATIONS

No free water observed during augering.

551 League City Pkwy Ste F
League City, TX

Boring Started: 1/26/2017 | Boring Completed: 1/26/2017

Drill Rig: All-Terrain Vehicle | Driller: Diamond Geo

Project No.: 91175006 | Exhibit: A-5

BORING LOG NO. B-3

PROJECT: Landing Ditch Slope Evaluation

CLIENT: ARKK Engineers Houston, Texas

SITE: FM 518 and Landing Boulevard League City, Texas

LOCATION See Exhibit A-2

Latitude: 29.50266° Longitude: -95.1244°

DEPTH	Description	Depth (Ft.)	Water Level Observations	Sample Type	Field Test Results	Strength Test: Test Type	Strength Test: Compressive Strength (tsf)	Strength Test: Strain (%)	Water Content (%)	Dry Unit Weight (pcf)	Atterberg Limits LL-PL-PI
	FAT CLAY (CH), gray, medium stiff to very stiff, with ferrous nodues				1.0 (HP)						
					1.25 (HP)				36		85-24-61
		5			0.75 (HP)						
	- tan and light gray 6 to 32 feet				2.0 (HP)						
					3.5 (HP)						
	- with slickensides 10 to 12 feet	10			2.0 (HP)	UC	0.71	2	32	90	
					1.5 (HP)						
		15									
		20			3.0 (HP)						
	- with calcareous nodules 23 to 32 feet				4.5 (HP)						
		25									
		30			3.5 (HP)	UC	2.54	5.8	25	104	69-22-47
32.0	**LEAN CLAY (CL)**, tan and light gray, soft to very stiff, with calcareous nodules				4.0 (HP)						
		35									
	- with silt seams 38 to 40 feet				0.5 (HP)						
40.0	***Boring Terminated at 40 Feet***	40									

Stratification lines are approximate. In-situ, the transition may be gradual.

Advancement Method:
Dry augered to 40 feet.

Abandonment Method:
Backfilled with auger cuttings.

See Exhibit A-3 for description of field procedures.

See Appendix B for description of laboratory procedures and additional data (if any).

See Appendix C for explanation of symbols and abbreviations.

Notes:

WATER LEVEL OBSERVATIONS

No free water observed during augering.

551 League City Pkwy Ste F
League City, TX

Boring Started: 1/26/2017	Boring Completed: 1/26/2017
Drill Rig: All-Terrain Vehicle	Driller: Diamond Geo
Project No.: 91175006	Exhibit: A-6

APPENDIX B

LABORATORY TESTING

Laboratory Testing

Soil samples were tested in the laboratory to measure their dry unit weight (ASTM D7263) and natural water content (ASTM D2216). Unconfined compression tests (ASTM D2166) were performed on selected samples and a calibrated hand penetrometer was used to estimate the approximate unconfined compressive strength of some cohesive samples. The calibrated hand penetrometer values have been correlated with unconfined compression tests and provide a better estimate of soil consistency than visual examination alone. Selected samples were also classified using the results of Atterberg Limits tests (ASTM D4318) and grain size analysis testing (ASTM D422 and D1140).

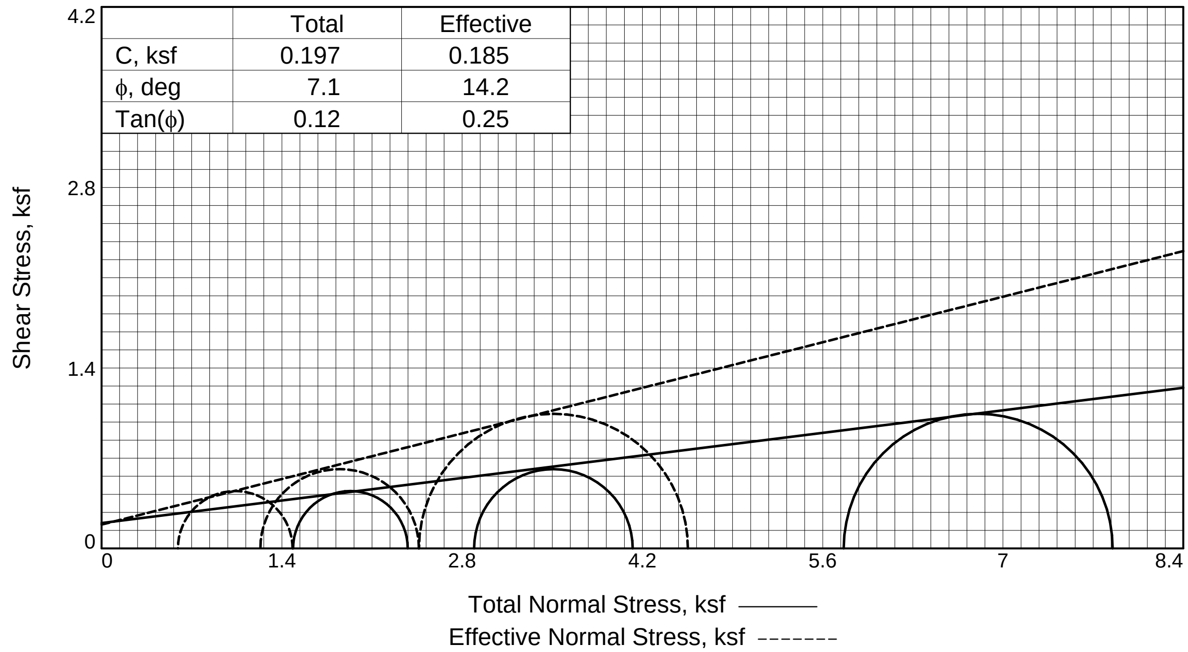
Consolidated Undrained Triaxial tests with pore pressure measurements (ASTM D4767), crumb (ASTM D6572), and pinhole (ASTM D4647) tests were performed on selected samples. The test results are provided on the boring logs included in Appendix A and in the "**3.2 Typical Profile**" section of this report.

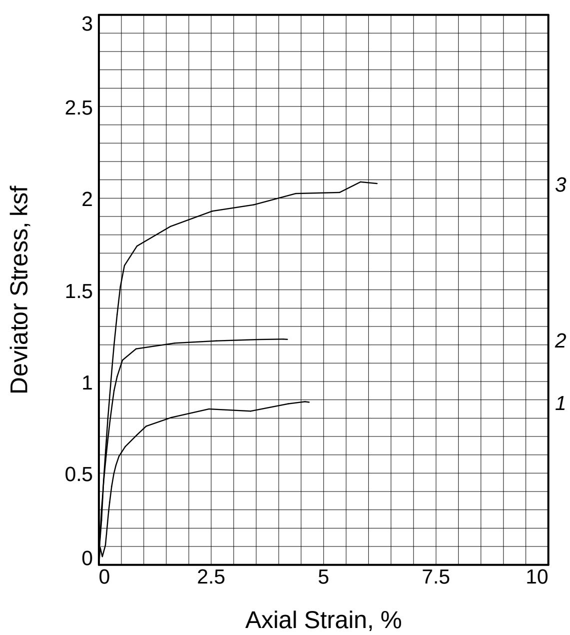
ASTM procedural standards noted above are for reference methodology in general. In some cases, variations to methods are applied as a result of local practice or professional judgment.

Descriptive classifications of the soils indicated on the boring logs are in general accordance with the enclosed General Notes and the Unified Soil Classification System. Also shown are estimated Unified Soil Classification Symbols. A brief description of this classification system is attached to this report. Classification of the soil samples was generally determined by visual manual procedures.

Samples not tested in the laboratory will be stored for a period of 30 days subsequent to submittal of this report and will be discarded after this period, unless we are notified otherwise.

	Total	Effective
C, ksf	0.197	0.185
ϕ, deg	7.1	14.2
Tan(ϕ)	0.12	0.25





Sample No.		1	2	3
Initial	Water Content, %	30.0	30.0	30.0
	Dry Density, pcf	92.6	92.6	92.6
	Saturation, %	96.7	96.7	96.7
	Void Ratio	0.8538	0.8538	0.8539
	Diameter, in.	2.766	2.766	2.766
	Height, in.	5.920	5.920	5.920
At Test	Water Content, %	31.0	31.0	31.1
	Dry Density, pcf	92.6	92.6	92.6
	Saturation, %	100.0	100.0	100.0
	Void Ratio	0.8538	0.8538	0.8539
	Diameter, in.	2.766	2.766	2.766
	Height, in.	5.920	5.920	5.920
Strain rate, in./min.		0.000	0.000	0.000
Back Pressure, psi		60.000	60.000	60.000
Cell Pressure, psi		70.330	80.090	100.020
Fail. Stress, ksf		0.890	1.231	2.088
Excess Pore Pr., ksf		0.894	1.660	3.298
Ult. Stress, ksf				
Excess Pore Pr., ksf				
$\bar{\sigma}_1$ Failure, ksf		1.483	2.464	4.553
$\bar{\sigma}_3$ Failure, ksf		0.593	1.233	2.465

Type of Test:
CU with Pore Pressures

Sample Type: Undisturbed

Description: Tan & light gray Fat Clay

Assumed Specific Gravity= 2.75

Remarks: ASTM D4767

Client:

Project: Landing Ditch Slope Evaluation

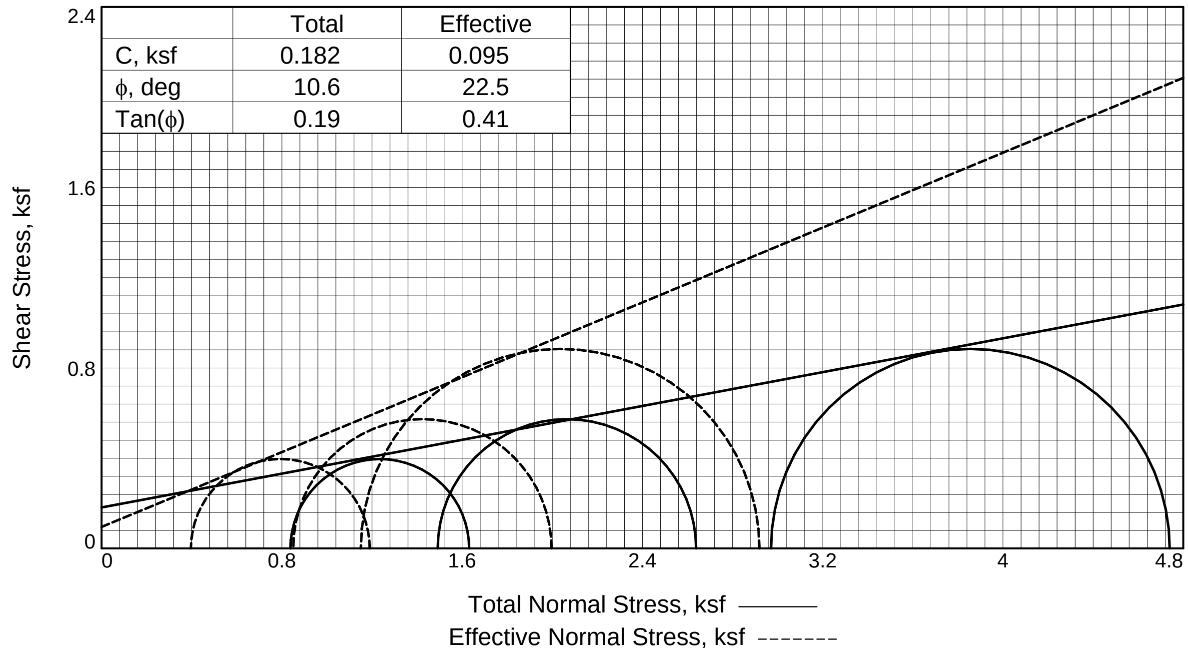
Location: B-1

Depth: 28-30 ft.

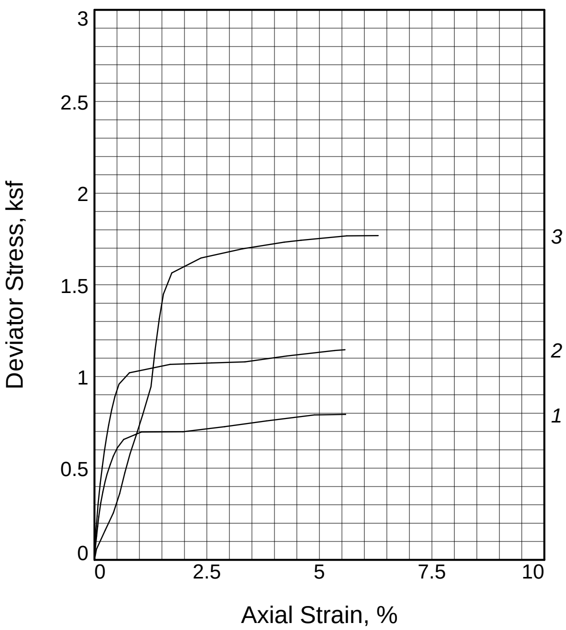
Proj. No.: 91175006 **Date Sampled:**

TRIAXIAL SHEAR TEST REPORT
Terracon Consultants, Inc.
Houston, TX

Exhibit B-2



	Total	Effective
C, ksf	0.182	0.095
φ, deg	10.6	22.5
Tan(φ)	0.19	0.41



Sample No.		1	2	3
Initial	Water Content, %	28.4	28.4	28.4
	Dry Density, pcf	95.5	95.5	95.5
	Saturation, %	97.9	97.9	97.9
	Void Ratio	0.7978	0.7978	0.7978
	Diameter, in.	2.750	2.750	2.750
	Height, in.	5.940	5.940	5.940
At Test	Water Content, %	29.0	29.0	29.0
	Dry Density, pcf	95.5	95.5	95.5
	Saturation, %	100.0	100.0	100.0
	Void Ratio	0.7978	0.7978	0.7978
	Diameter, in.	2.750	2.750	2.750
	Height, in.	5.940	5.940	5.940
Strain rate, in./min.		0.000	0.000	0.000
Back Pressure, psi		60.000	60.000	60.000
Cell Pressure, psi		65.820	70.360	80.630
Fail. Stress, ksf		0.793	1.146	1.769
Excess Pore Pr., ksf		0.442	0.642	1.820
Ult. Stress, ksf				
Excess Pore Pr., ksf				
$\bar{\sigma}_1$ Failure, ksf		1.190	1.997	2.919
$\bar{\sigma}_3$ Failure, ksf		0.397	0.850	1.150

Type of Test:
CU with Pore Pressures

Sample Type: Undisturbed

Description: Tan and light gray Fat Clay

Assumed Specific Gravity= 2.75

Remarks: ASTM D4767

Client:

Project: Landing Ditch Slope Evaluation

Location: B-2

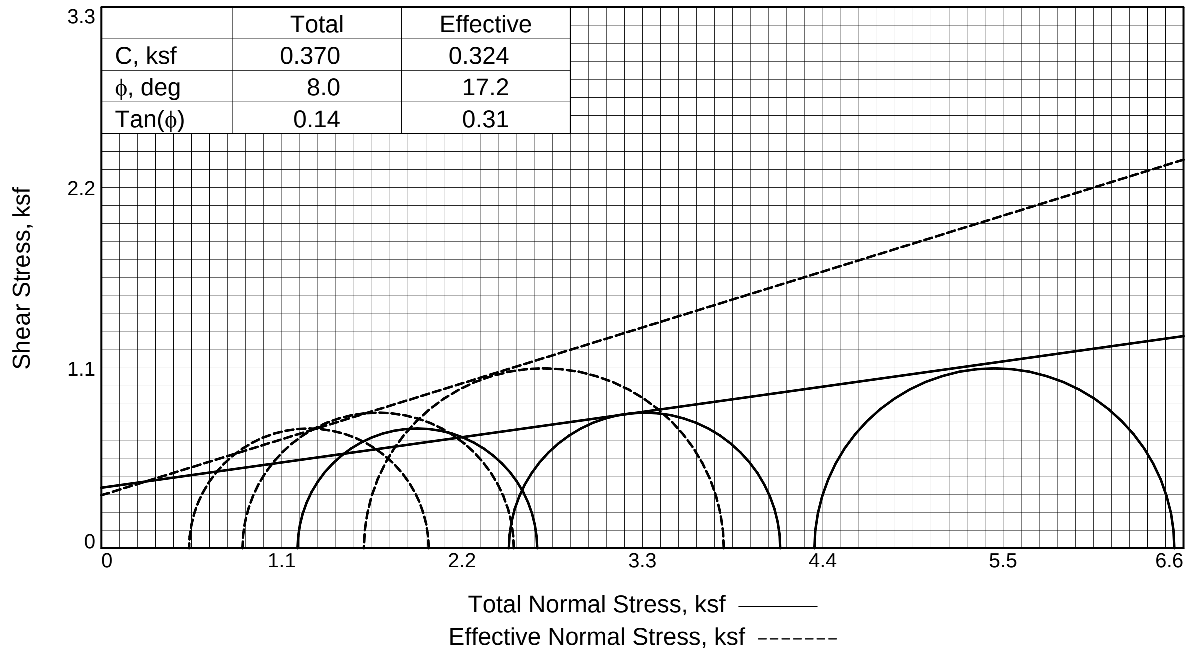
Depth: 6-8 ft.

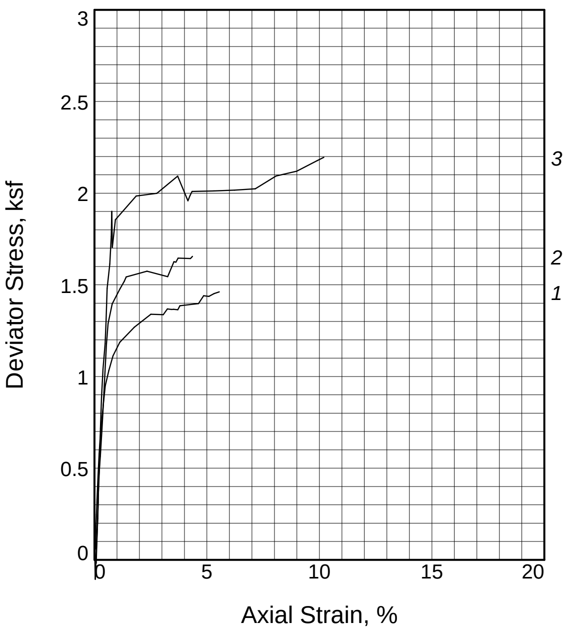
Proj. No.: 91175006 **Date Sampled:**

TRIAXIAL SHEAR TEST REPORT

Terracon Consultants, Inc.
Houston, TX

Exhibit B-3





Sample No.		1	2	3
Initial	Water Content, %	28.8	28.8	28.8
	Dry Density, pcf	96.5	96.5	96.5
	Saturation, %	99.9	99.9	99.9
	Void Ratio	0.8051	0.8051	0.8051
	Diameter, in.	2.740	2.740	2.740
	Height, in.	5.970	5.970	5.970
At Test	Water Content, %	28.9	28.9	28.9
	Dry Density, pcf	96.5	96.5	96.5
	Saturation, %	100.0	100.0	100.0
	Void Ratio	0.8051	0.8051	0.8051
	Diameter, in.	2.740	2.740	2.740
	Height, in.	5.970	5.970	5.970
Strain rate, in./min.		0.000	0.000	0.000
Back Pressure, psi		60.000	60.000	60.000
Cell Pressure, psi		68.310	77.260	90.200
Fail. Stress, ksf		1.461	1.655	2.195
Excess Pore Pr., ksf		0.662	1.625	2.748
Ult. Stress, ksf				
Excess Pore Pr., ksf				
$\bar{\sigma}_1$ Failure, ksf		1.996	2.516	3.796
$\bar{\sigma}_3$ Failure, ksf		0.535	0.861	1.601

Type of Test:
CU with Pore Pressures

Sample Type:

Description: Light gray and reddish brown Fat Clay

Assumed Specific Gravity= 2.79

Remarks: ASTM D4767

Client:

Project: Landing Ditch Slope Evaluation

Location: B-3

Depth: 18-20 ft.

Proj. No.: 91175006 **Date Sampled:**

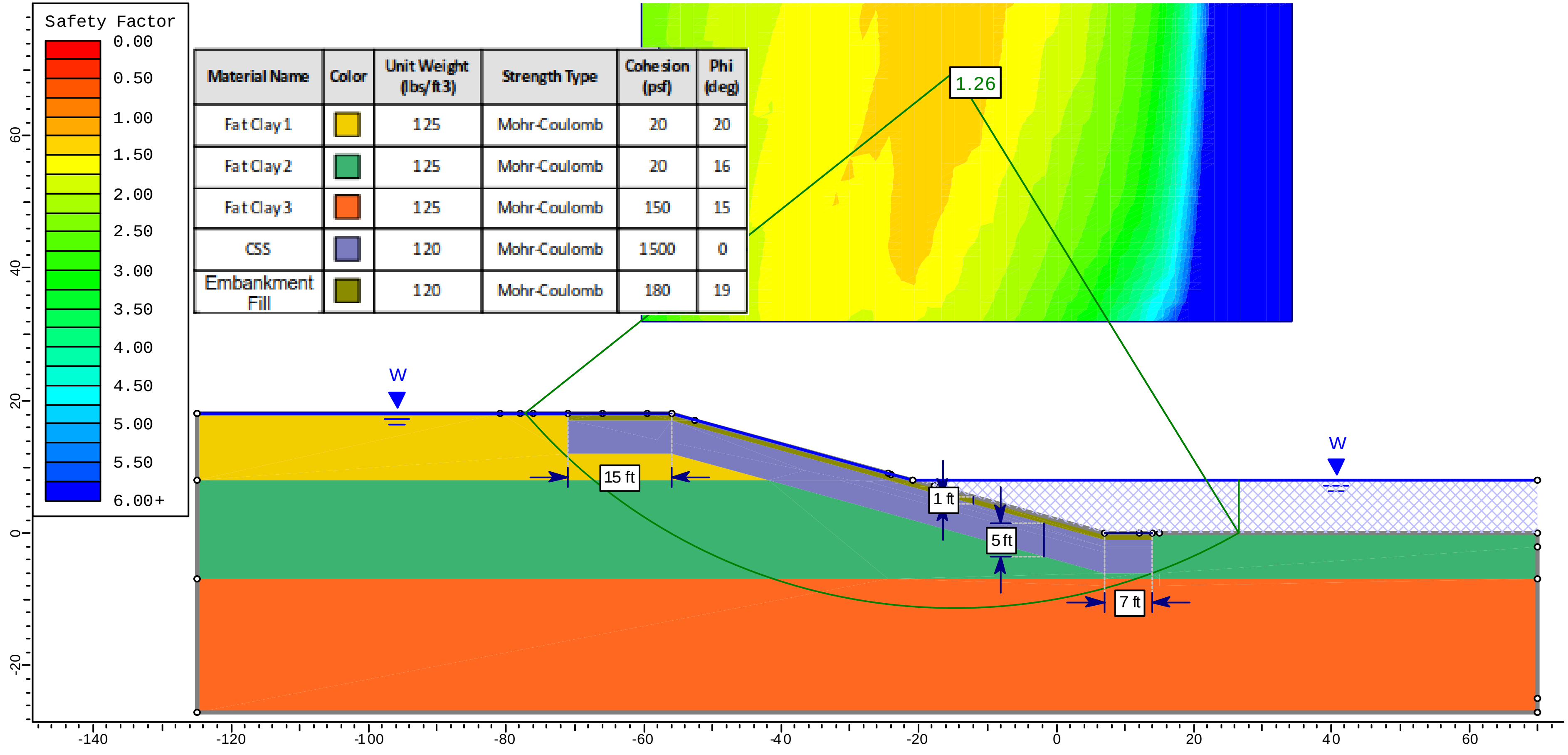
TRIAXIAL SHEAR TEST REPORT

Terracon Consultants, Inc.
Houston, TX

Exhibit B-4

APPENDIX C

ENGINEERING ANALYSIS



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Fat Clay 1		125	Mohr-Coulomb	20	20
Fat Clay 2		125	Mohr-Coulomb	20	16
Fat Clay 3		125	Mohr-Coulomb	150	15
CSS		120	Mohr-Coulomb	1500	0
Embankment Fill		120	Mohr-Coulomb	180	19

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Texas Registration 3272
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Houston, Texas 77043

Rapid Drawdown Slope Stability Analysis using Cement Stabilized Sand

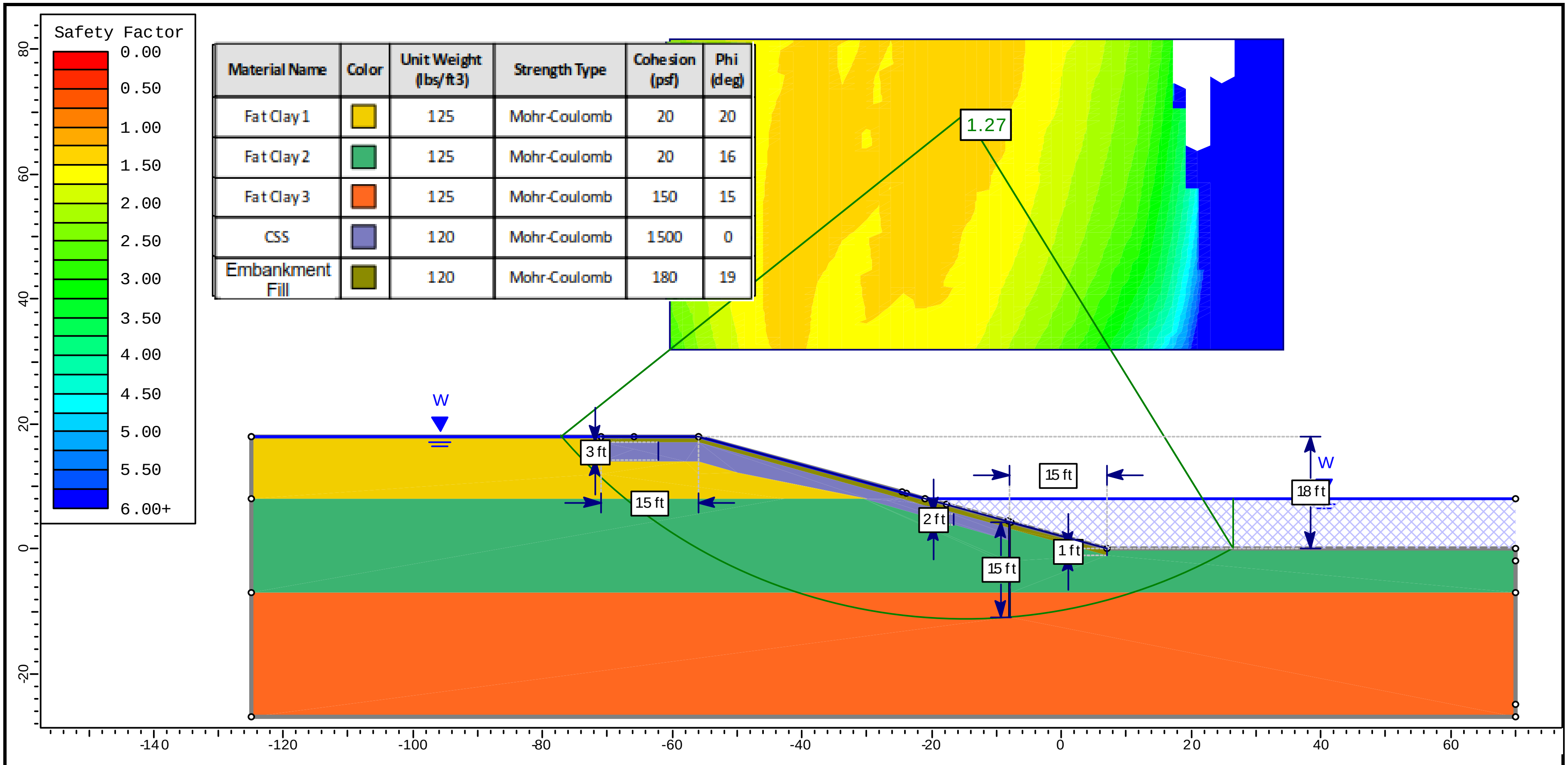
Simplified Bishop's Method

Drawn by: AW
Reviewed by: BP
Approved by: PB

Landing Ditch Slope Evaluation

Terracon Project Number 91175006

Exhibit C-1



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Fat Clay 1		125	Mohr-Coulomb	20	20
Fat Clay 2		125	Mohr-Coulomb	20	16
Fat Clay 3		125	Mohr-Coulomb	150	15
CSS		120	Mohr-Coulomb	1500	0
Embankment Fill		120	Mohr-Coulomb	180	19

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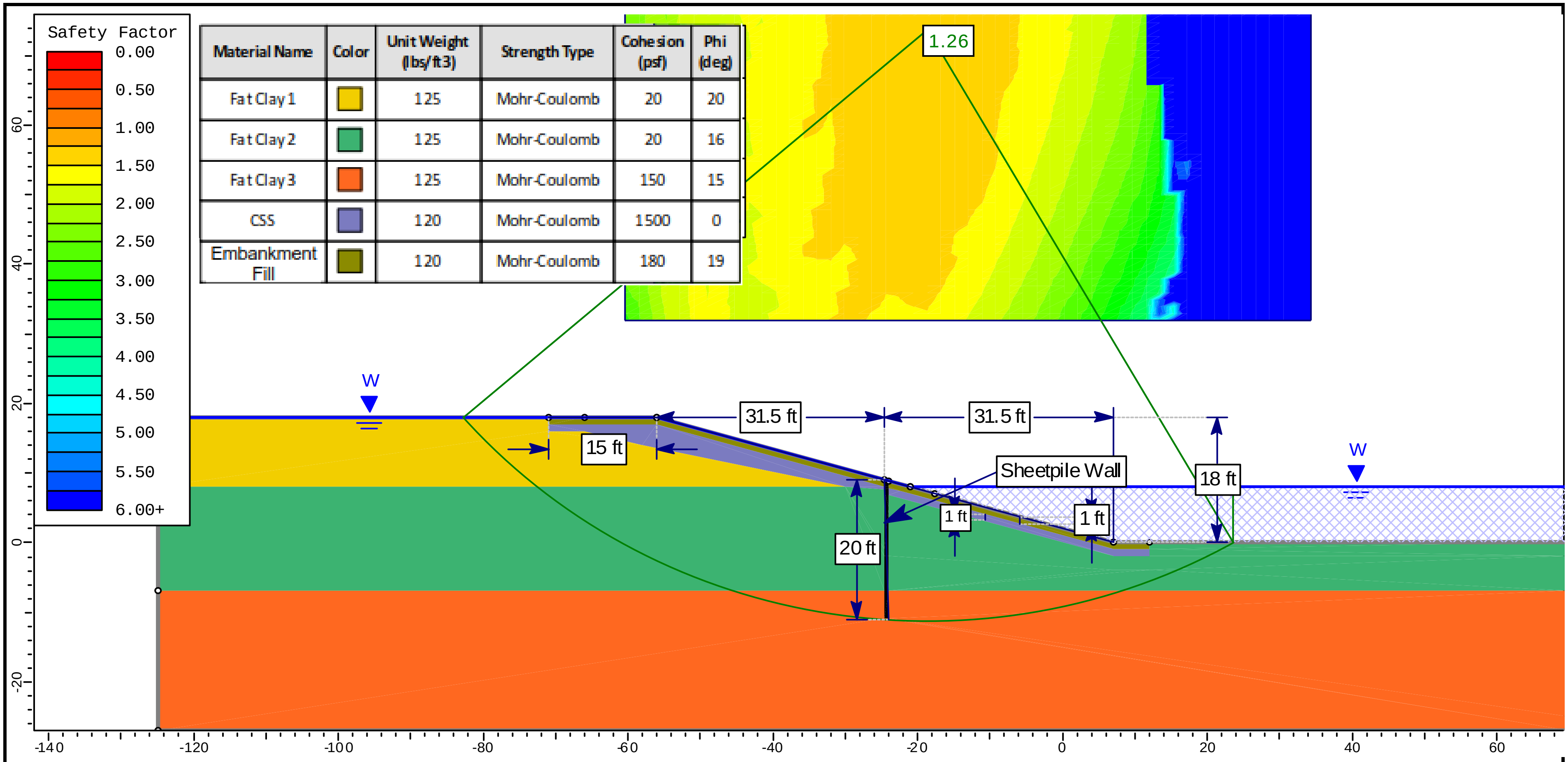
RDD Slope Stability using CSS/Embankment Fill and a Sheetpile Wall at 15 feet Upslope

Simplified Bishop's Method

Drawn by: AW	Landing Ditch Slope Evaluation	Exhibit C-2
Reviewed by: BP		
Approved by: PB	Terracon Project Number 91175006	



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Fat Clay 1		125	Mohr-Coulomb	20	20
Fat Clay 2		125	Mohr-Coulomb	20	16
Fat Clay 3		125	Mohr-Coulomb	150	15
CSS		120	Mohr-Coulomb	1500	0
Embankment Fill		120	Mohr-Coulomb	180	19

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RDD Slope Stability Analysis using CSS/Embankment Fill and a Sheetpile Wall at Mid-Slope

Simplified Bishop's Method

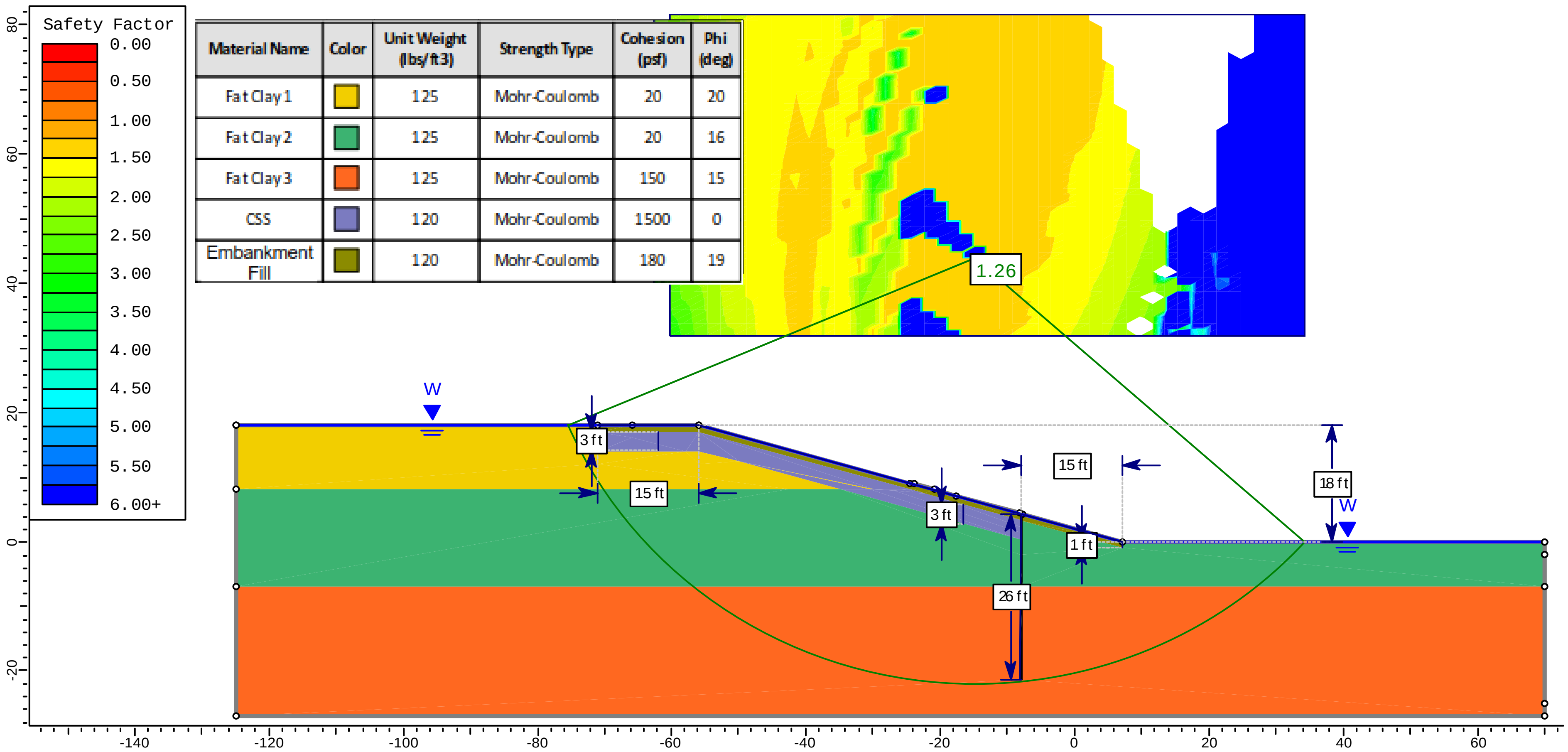
Drawn by: AW
Reviewed by: BP
Approved by: PB

Landing Ditch Slope Evaluation

Terracon Project Number 91175006

Exhibit C-3

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Fat Clay 1		125	Mohr-Coulomb	20	20
Fat Clay 2		125	Mohr-Coulomb	20	16
Fat Clay 3		125	Mohr-Coulomb	150	15
CSS		120	Mohr-Coulomb	1500	0
Embankment Fill		120	Mohr-Coulomb	180	19



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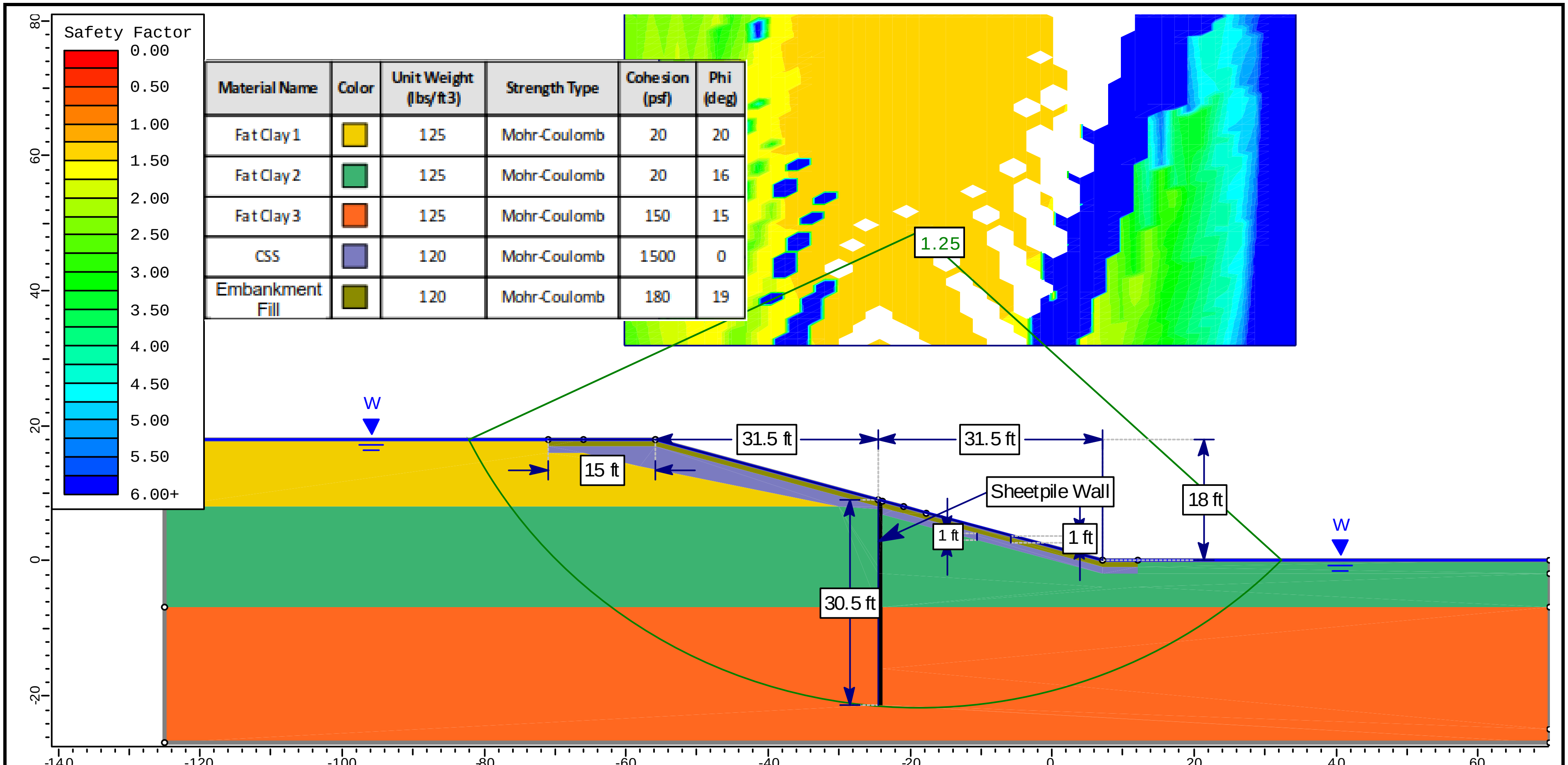
Houston, Texas 77043

RDD Slope Stability Analysis using CSS/Embankment Fill and a Sheetpile Wall at 15 feet Upslope

Simplified Bishop's Method

Drawn by: AW	Landing Ditch Slope Evaluation	Exhibit C-4
Reviewed by: BP		
Approved by: PB	Terracon Project Number 91175006	



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Fat Clay 1		125	Mohr-Coulomb	20	20
Fat Clay 2		125	Mohr-Coulomb	20	16
Fat Clay 3		125	Mohr-Coulomb	150	15
CSS		120	Mohr-Coulomb	1500	0
Embankment Fill		120	Mohr-Coulomb	180	19

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RDD Slope Stability Analysis using CSS/Embankment Fill and a Sheetpile Wall at Mid-Slope

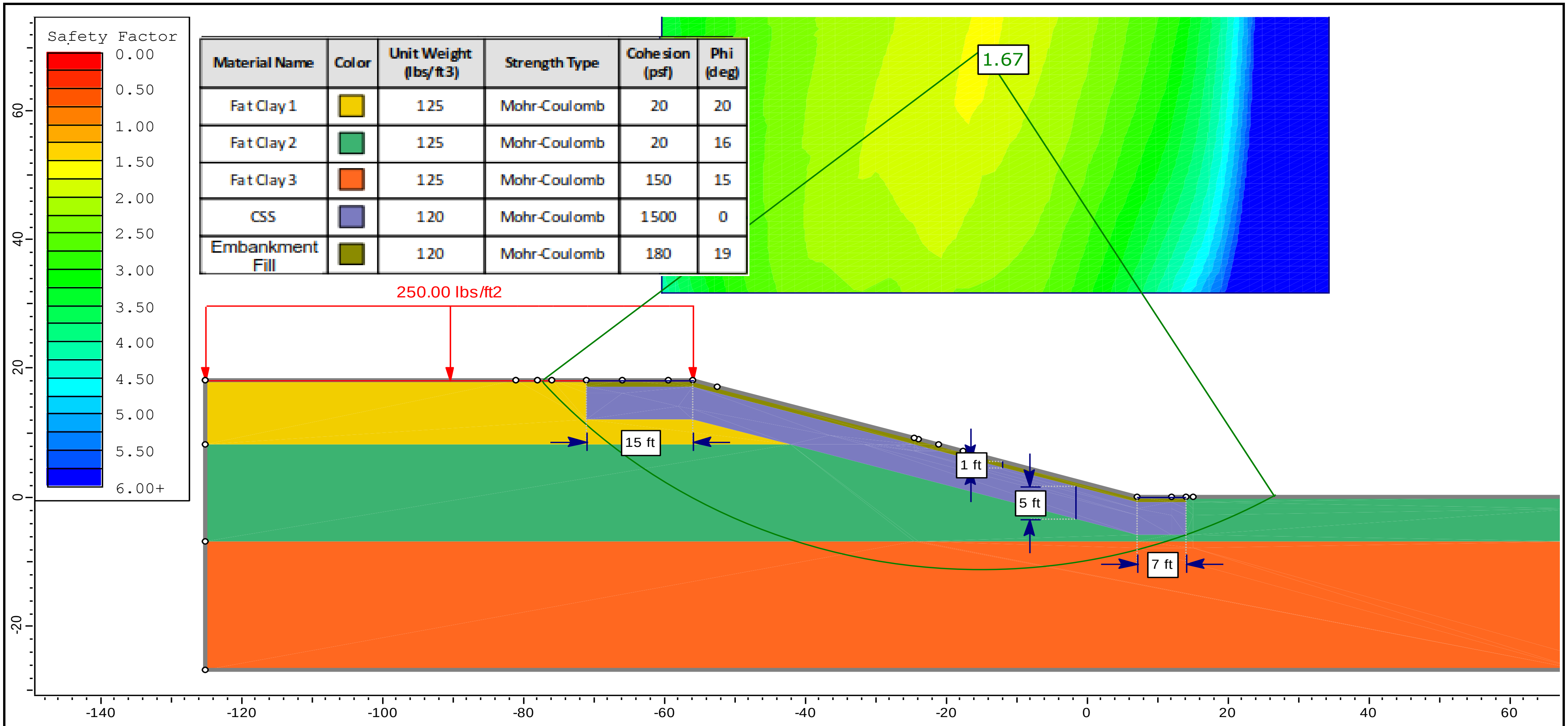
Simplified Bishop's Method

Drawn by: AW
Reviewed by: BP
Approved by: PB

Landing Ditch Slope Evaluation

Terracon Project Number 91175006

Exhibit
C-5



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Fat Clay 1		125	Mohr-Coulomb	20	20
Fat Clay 2		125	Mohr-Coulomb	20	16
Fat Clay 3		125	Mohr-Coulomb	150	15
CSS		120	Mohr-Coulomb	1500	0
Embankment Fill		120	Mohr-Coulomb	180	19

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Houston, Texas 77043

Long Term Slope Stability Analysis using Cement Stabilized Sand

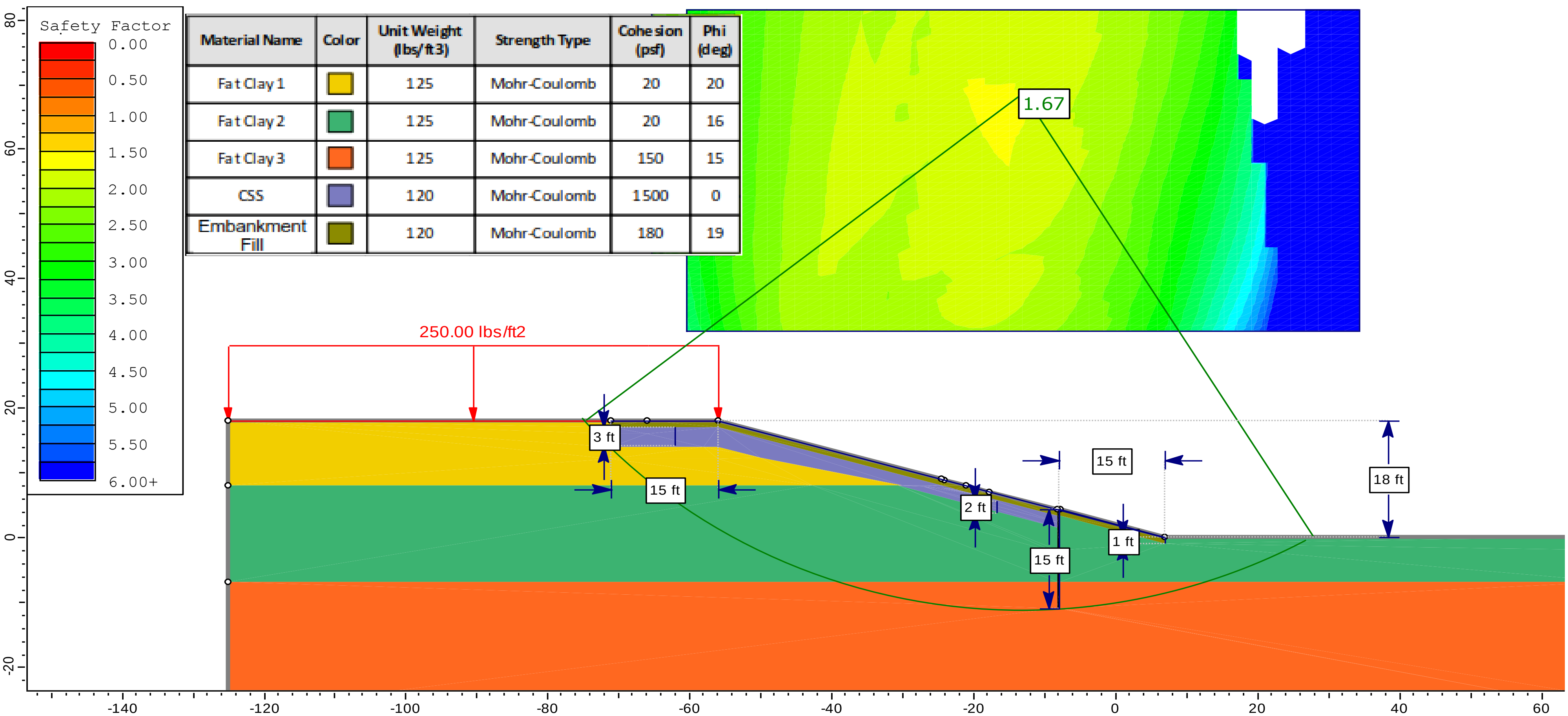
Simplified Bishop's Method

Drawn by: AW
Reviewed by: BP
Approved by: PB

Landing Ditch Slope Evaluation

Terracon Project Number 91175006

Exhibit
C-6



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Fat Clay 1		125	Mohr-Coulomb	20	20
Fat Clay 2		125	Mohr-Coulomb	20	16
Fat Clay 3		125	Mohr-Coulomb	150	15
CSS		120	Mohr-Coulomb	1500	0
Embankment Fill		120	Mohr-Coulomb	180	19

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Houston, Texas 77043

Long Term Slope Stability Analysis using CSS/Embankment Fill and a Sheetpile Wall at 15 feet Upslope

Simplified Bishop's Method

Drawn by: AW

Reviewed by: BP

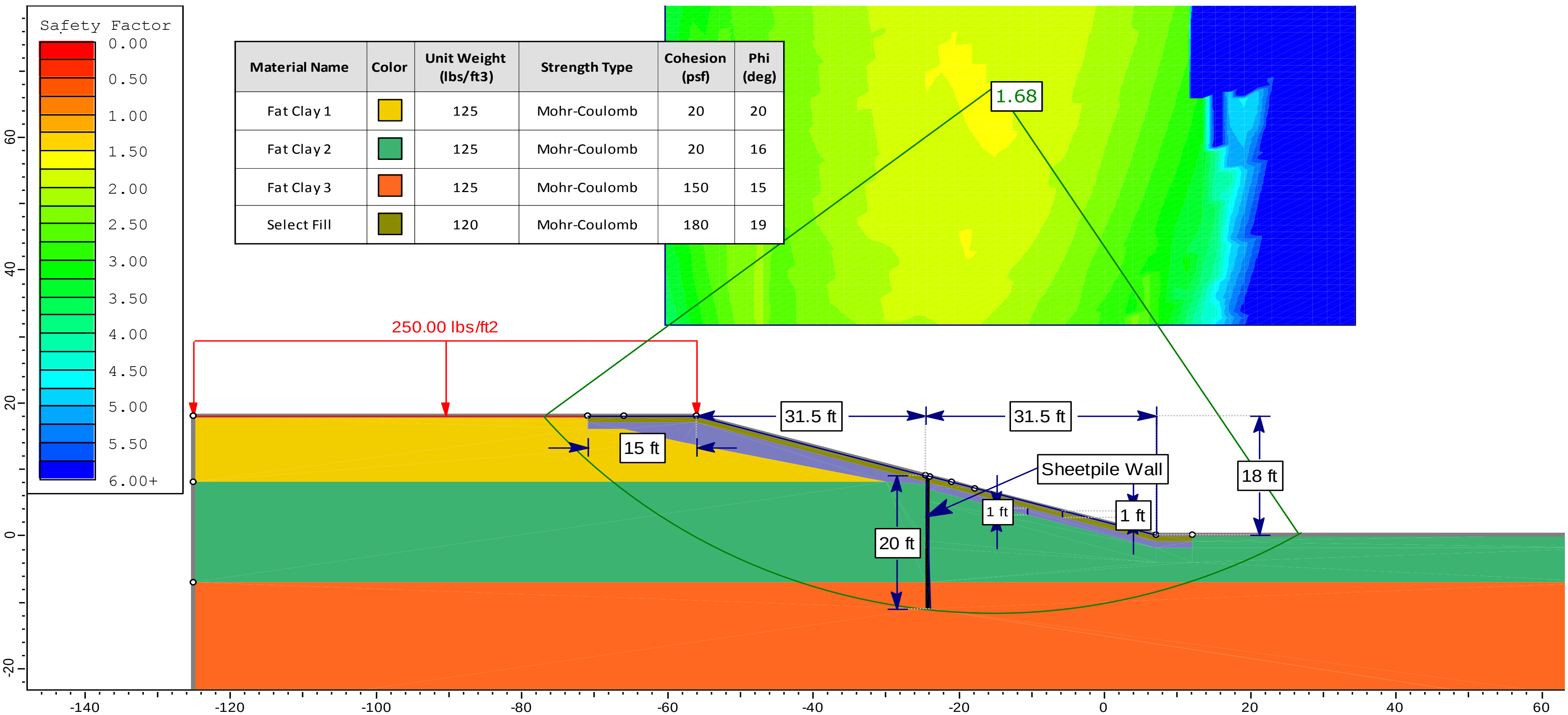
Approved by: PB

Landing Ditch Slope Evaluation

Terracon Project Number 91175006

Exhibit

C-7



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Fat Clay 1		125	Mohr-Coulomb	20	20
Fat Clay 2		125	Mohr-Coulomb	20	16
Fat Clay 3		125	Mohr-Coulomb	150	15
Select Fill		120	Mohr-Coulomb	180	19

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Houston, Texas 77043

Long Term Slope Stability Analysis using CSS/Embankment Fill and a Sheetpile Wall at Mid-Slope

Simplified Bishop's Method

Drawn by: AW
Reviewed by: BP
Approved by: PB

Landing Ditch Slope Evaluation

Terracon Project Number 91175006

Exhibit
C-8

APPENDIX D

SUPPORTING DOCUMENTS

GENERAL NOTES

DESCRIPTION OF SYMBOLS AND ABBREVIATIONS

SAMPLING	Auger Cuttings Shelby Tube	WATER LEVEL	Water Initially Encountered Water Level After a Specified Period of Time Water Level After a Specified Period of Time Water levels indicated on the soil boring logs are the levels measured in the borehole at the times indicated. Groundwater level variations will occur over time. In low permeability soils, accurate determination of groundwater levels is not possible with short term water level observations.	FIELD TESTS	**N** Standard Penetration Test Resistance (Blows/Ft.) **(HP)** Hand Penetrometer **(T)** Torvane **(DCP)** Dynamic Cone Penetrometer **(PID)** Photo-Ionization Detector **(OVA)** Organic Vapor Analyzer

DESCRIPTIVE SOIL CLASSIFICATION

Soil classification is based on the Unified Soil Classification System. Coarse Grained Soils have more than 50% of their dry weight retained on a #200 sieve; their principal descriptors are: boulders, cobbles, gravel or sand. Fine Grained Soils have less than 50% of their dry weight retained on a #200 sieve; they are principally described as clays if they are plastic, and silts if they are slightly plastic or non-plastic. Major constituents may be added as modifiers and minor constituents may be added according to the relative proportions based on grain size. In addition to gradation, coarse-grained soils are defined on the basis of their in-place relative density and fine-grained soils on the basis of their consistency.

LOCATION AND ELEVATION NOTES

Unless otherwise noted, Latitude and Longitude are approximately determined using a hand-held GPS device. The accuracy of such devices is variable. Surface elevation data annotated with +/- indicates that no actual topographical survey was conducted to confirm the surface elevation. Instead, the surface elevation was approximately determined from topographic maps of the area.

STRENGTH TERMS

RELATIVE DENSITY OF COARSE-GRAINED SOILS (More than 50% retained on No. 200 sieve.) Density determined by Standard Penetration Resistance		**CONSISTENCY OF FINE-GRAINED SOILS** (50% or more passing the No. 200 sieve.) Consistency determined by laboratory shear strength testing, field visual-manual procedures or standard penetration resistance		
Descriptive Term (Density)	**Standard Penetration or N-Value Blows/Ft.**	**Descriptive Term (Consistency)**	**Unconfined Compressive Strength Qu, (tsf)**	**Standard Penetration or N-Value Blows/Ft.**
Very Loose	0 - 3	Very Soft	less than 0.25	0 - 1
Loose	4 - 9	Soft	0.25 to 0.50	2 - 4
Medium Dense	10 - 29	Medium Stiff	0.50 to 1.00	4 - 8
Dense	30 - 50	Stiff	1.00 to 2.00	8 - 15
Very Dense	> 50	Very Stiff	2.00 to 4.00	15 - 30
		Hard	> 4.00	> 30

RELATIVE PROPORTIONS OF SAND AND GRAVEL

Descriptive Term(s) of other constituents	Percent of Dry Weight
Trace	< 15
With	15 - 29
Modifier	> 30

GRAIN SIZE TERMINOLOGY

Major Component of Sample	Particle Size
Boulders	Over 12 in. (300 mm)
Cobbles	12 in. to 3 in. (300mm to 75mm)
Gravel	3 in. to #4 sieve (75mm to 4.75 mm)
Sand	#4 to #200 sieve (4.75mm to 0.075mm
Silt or Clay	Passing #200 sieve (0.075mm)

RELATIVE PROPORTIONS OF FINES

Descriptive Term(s) of other constituents	Percent of Dry Weight
Trace	< 5
With	5 - 12
Modifier	> 12

PLASTICITY DESCRIPTION

Term	Plasticity Index
Non-plastic	0
Low	1 - 10
Medium	11 - 30
High	> 30

UNIFIED SOIL CLASSIFICATION SYSTEM

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests [A]				Soil Classification: Group Symbol	Soil Classification: Group Name [B]
Coarse Grained Soils: More than 50% retained on No. 200 sieve	**Gravels:** More than 50% of coarse fraction retained on No. 4 sieve	**Clean Gravels:** Less than 5% fines [C]	$Cu \geq 4$ and $1 \leq Cc \leq 3$ [E]	GW	Well-graded gravel [F]
			$Cu < 4$ and/or $1 > Cc > 3$ [E]	GP	Poorly graded gravel [F]
		Gravels with Fines: More than 12% fines [C]	Fines classify as ML or MH	GM	Silty gravel [F,G, H]
			Fines classify as CL or CH	GC	Clayey gravel [F,G,H]
	Sands: 50% or more of coarse fraction passes No. 4 sieve	**Clean Sands:** Less than 5% fines [D]	$Cu \geq 6$ and $1 \leq Cc \leq 3$ [E]	SW	Well-graded sand [I]
			$Cu < 6$ and/or $1 > Cc > 3$ [E]	SP	Poorly graded sand [I]
		Sands with Fines: More than 12% fines [D]	Fines classify as ML or MH	SM	Silty sand [G,H,I]
			Fines Classify as CL or CH	SC	Clayey sand [G,H,I]
Fine-Grained Soils: 50% or more passes the No. 200 sieve	**Silts and Clays:** Liquid limit less than 50	**Inorganic:**	$PI > 7$ and plots on or above "A" line [J]	CL	Lean clay [K,L,M]
			$PI < 4$ or plots below "A" line [J]	ML	Silt [K,L,M]
		Organic:	Liquid limit - oven dried / Liquid limit - not dried < 0.75	OL	Organic clay [K,L,M,N]
					Organic silt [K,L,M,O]
	Silts and Clays: Liquid limit 50 or more	**Inorganic:**	PI plots on or above "A" line	CH	Fat clay [K,L,M]
			PI plots below "A" line	MH	Elastic Silt [K,L,M]
		Organic:	Liquid limit - oven dried / Liquid limit - not dried < 0.75	OH	Organic clay [K,L,M,P]
					Organic silt [K,L,M,Q]
Highly organic soils:	Primarily organic matter, dark in color, and organic odor			PT	Peat

[A] Based on the material passing the 3-in. (75-mm) sieve

[B] If field sample contained cobbles or boulders, or both, add "with cobbles or boulders, or both" to group name.

[C] Gravels with 5 to 12% fines require dual symbols: GW-GM well-graded gravel with silt, GW-GC well-graded gravel with clay, GP-GM poorly graded gravel with silt, GP-GC poorly graded gravel with clay.

[D] Sands with 5 to 12% fines require dual symbols: SW-SM well-graded sand with silt, SW-SC well-graded sand with clay, SP-SM poorly graded sand with silt, SP-SC poorly graded sand with clay

[E] $Cu = D_{60}/D_{10}$ $\quad Cc = \dfrac{(D_{30})^2}{D_{10} \times D_{60}}$

[F] If soil contains $\geq 15\%$ sand, add "with sand" to group name.

[G] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM.

[H] If fines are organic, add "with organic fines" to group name.

[I] If soil contains $\geq 15\%$ gravel, add "with gravel" to group name.

[J] If Atterberg limits plot in shaded area, soil is a CL-ML, silty clay.

[K] If soil contains 15 to 29% plus No. 200, add "with sand" or "with gravel," whichever is predominant.

[L] If soil contains $\geq 30\%$ plus No. 200 predominantly sand, add "sandy" to group name.

[M] If soil contains $\geq 30\%$ plus No. 200, predominantly gravel, add "gravelly" to group name.

[N] $PI \geq 4$ and plots on or above "A" line.

[O] $PI < 4$ or plots below "A" line.

[P] PI plots on or above "A" line.

[Q] PI plots below "A" line.